CIGR – INTERNATIONAL COMMISSION OF AGRICULTURAL AND BIO SYSTEMS ENGINEERING

12th CIGR Section VI International Symposium

(Postharvest Technology & Bio-process Engineering)

Theme:

INNOVATIONS AND TECHNOLOGIES FOR SUSTAINABLE AGRICULTURAL PRODUCTION AND FOOD SUFFICIENCY

Conference Center, IITA, Ibadan, Nigeria

Monday 22nd – Thursday 25th 2018

8:30am – 6pm

The Proceedings

of

International Commission of Agricultural and Biosystems Engineering

Commission International du Genie Rural

12TH CIGR SECTION VI INTERNATIONAL SYMPOSIUM

(Postharvest Technology & Bioprocess Engineering)

THEME: Innovations and Technologies for Sustainable Agricultural Production and Food Sufficiency

Held at

International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria

Monday 22 – Thursday 25 October, 2018

Edited by

Rahman Akinoso
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Mobolaji Omobowale

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Draft and Power Requirements for Some Tillage Implements Operating in Loamy Soil

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ABSTRACT

The availability of draft and power requirements data of tillage implements is an important factor in tractor selection and matching of tillage implement. Previous studies had attributed the lack of relevant data to frequent breakdown of tractors and implements on Nigerian farms. The effects of tillage depths (10, 20 and 30 cm) and tractor forward speeds (3.6, 5.4, 7.2, 9.0 and 10.8 km/hr) on draft and power requirements for three selected tillage implements namely 3-bottom disc plough, spring tine cultivator and offset disc harrow operating in loamy soil were investigated. At a tillage depth of 10 cm, draft and power requirements for 3- bottom disc plough at 0.82 m/s; spring tine cultivator at 0.74 m/s and offset disc harrow at 0.79 m/s implements' speeds were 1.06 kN and 0.87 kW; 0.12 kN and 0.09 kW and 0.92 kN and 0.72 kW. The results showed that draft and power requirements increased with increases in tractor speed at increasing levels of tillage depth. There were no optimum values of speed and depth for which minimum draft and power occurred. The 3- bottom disc plough and spring tine cultivator had the highest and lowest draft and power requirements, respectively in loamy soil. Statistical analysis indicated that tractor speed and tillage depth and their interactions had significant effect on draft and power requirement at probability of 5 % ($P \leq 0.05$).

Keywords: Tillage, Power requirement, Soil parameters, Bulk density, Loamy soil, Nigeria.

1. INTRODUCTION

Mechanized tillage is a component of agricultural mechanization and agricultural mechanization is the use of mechanical devices or systems to replace human muscle in all forms and at any level of sophistication in agricultural production, processing and storage etc., in order to reduce human drudgery, improve timeliness and efficiency of various farm operations, bring more land under cultivation, preserve the quality of agricultural produce, provide better rural living condition and markedly advance the economic growth of the rural sector (Anazodo, 1982; Onwualu *et al.*, 2006).

Studies continue to be conducted to measure draft and power requirements of tillage implements under various soil conditions in the developed nations of the world in Asia, America and Europe. Mathematical models have been developed to predict draft of some tillage tools. American Society of Agricultural Engineers (ASAE), (1990) provided mathematical expressions of draft and power requirements for tillage tools in several soil types. Kydd *et al.* (1984) developed draft equations for tillage implements and found out that variations in climatic conditions, soil moisture, soil hardness and soil types made it difficult to obtain repeatable draft data. Bowers (1985) developed a computer programme using tillage data to calculate implement power requirements. He concluded that thorough reporting of soil conditions, implement description and draft requirement was necessary to obtain useful results. Boston and Rackham (1981) found no mathematical model that predicts draft of tillage tools accurately.

Upadhyaya *et al.,* (1984) reported that draft requirements of a tillage implement depend on soil type and conditions, manner of tool's movement and tool shape. It is a function of implement width, operating depth and the operating speed at which it is pulled (Upadhyaya *et al.,* (2009). Harrigan and Rotz (1994) proposed a simple function for a range of soil conditions to model tillage draft under general conditions, where draft per unit width or cross-sectional area of the tilled zone is a function of soil type and the operating speed at which the implement is pilled. It has been reported that the draft force of a tillage implement increases with increasing bulk density (Mouazen and Ramon, 2002). This holds true because the soil strength usually increase with increasing bulk density (Horn, 1993).

2. MATERIALS AND METHODS

2.1 Site for Field Experiment

Experiments were conducted at Use Offot, Uyo Local Government area of Akwa-Ibom state, Nigeria. The soil at the experiment site was loamy. Soil samples were collected during the tillage experiments to determine the soil conditions under which the experiment was conducted. The samples were weighed using a weighing balance and the weight of each sample was recorded. Then the samples were placed in an Oven maintained at 110^0C for 48 hrs. The dried soil samples were re-weighed and the weight was again recorded. The moisture contents were calculated on a dry weight basis. (Okoko, 2017).

2.1.1 Tractor and Tillage Implements

A set of primary and secondary tillage implements comprising a 3 – bottom disc plough, and Offset Disc Harrow and a spring tine cultivator were used in this study for evaluating draft and power requirements over a wide range of implement travel speed and tillage depths. These implements were representative of the standard primary and secondary tillage implements most commonly used for seedbed preparation in Akwa – Ibom State and the study location. They were owned by the Department of Agricultural Engineering, University of Uyo. Tractor and implement specifications are given in Tables 2 and 3, respectively

2.1.2 Experimental Layout

The parameters investigated for draft and power requirements determination was speed and tillage depth. An experimental plot of 100 m long by 20 m wide was used for each implement, making 100 m by 40 m for a location. A plot of 30 m long by 10 m wide was used as a practice area prior to the beginning of the experimental runs to enable the tractor and the implement to reach the required depth. The implement travel speeds were changed using the hand throttle after ploughing for 50 m and the tillage depths were fixed using the tractor depth controller. Ploughing time, ploughing depth, implement type and width of implement cut of each implement were measure and recorded in three replications. There were fifteen (15) i.e 3 x 5 runs for each of the three implements given a total of 45 runs i.e in the factorial of 3 x 3 x 5 and replicated three times for each implement resulting in one hundred and thirty five (135) runs. The ploughing depths were measured using a steel measuring tape with the undisturbed surface as a reference (Okoko, 2017).

2.2 Determination of angle of internal friction (soil – soil) and Soil Cohesion

Soil cohesion and soil angles of internal friction (soil – soil) were determine using the direct sheer test method as described by Mamman and Oni (2005) while coefficient of friction (soil on soil) was determined using equation (1) as adopted by Grissor *et al.*, (1994):

$$\mu = \tan\varphi = \frac{F}{N} \tag{1}$$

Where:

μ = coefficient of friction (soil on soil)
F = frictional force tangent to the surface, N
N = normal force (perpendicular to the surface), N
φ = angle of internal friction, deg.

2.3 Determination of shear strength of soil

The strength of the soil in the studied location were determined using an equation given by Gill and Vanden-Berg (1967):

$$S = c + \delta \tan\Phi \tag{2}$$

Where:

S = shear strength of the soil, kPa
c = soil cohesion, kPa
δ = normal stress, kPa
Φ = angle of internal soil friction, deg.

2.4 Weight of soil determination

The weight of soil was calculated from the equation according to Srivastava *et al.*, (2006):

$$W = pbd^{*}\left(L_0 + \frac{L_1 + L_2}{2}\right) \tag{3}$$

Where:
W = weight of soil, N
ρ = bulk density of soil, kg/m^3
b = width of implement, m
d = tillage depth, m
$d^{*} = d\{[\sin(\delta + \beta)]/\sin\beta\}$, m (4)
L_o = length of implement, m
$L_1 = d\{[\cos(\delta + \beta)]/\sin\beta\}$, m (5)
L_2 = d* tan δ, m
δ = rake angle, deg.
$\beta = \frac{(90 - \Phi)}{2}$ deg (6)
Φ = angle of internal friction, degree

2.5 Determination of draft requirements

Draft refers to the force required to pull an implement in the horizontal direction of travel (Tajudeen *et al.,* 2010). Machine selection and sizing require an estimate of draft requirements of the implement. The lack of information about implement performance forces the farmer to rely on past experience for selection of tractors and implements. With the escalation in the size of equipment and speed of many new agricultural implements, the farmer's previous experience may be of little value in selecting new machines. Draft force of all the tillage implements was determined using the equation as given by Srivastava *et al.,* (2006):

$$D = \frac{W}{Z} + \frac{c\left(\frac{bd}{sin\beta}\right) + \rho bdv_0^2 sin\delta/\sin(\delta+\beta)}{Z(sin\beta + \mu cos\beta)} \qquad (7)$$

Where:

D = Draft of tillage implement, N
W = Weight of soil, N
C = Soil cohesion, kPa
μ = coefficient of internal soil friction
β = angle of the forward failure surface, deg
V_o = speed of operation, m/s.

$$Z = \frac{cos\delta - \mu' sin\delta}{sin\delta + \mu' cos\delta} + \frac{cos\beta - \mu sin\beta}{sin\beta + \mu cos\beta} \qquad (8)$$

μ' = coefficient of internal soil – metal friction

2.6 Determination of power requirement

Most farm tractors are rated power- wise according to the maximum observed power take off (PTO) horse power. Draw bar horse power is the horse power actually available to be transmitted by traction through the tractor draw bar to the implement and this is always less than the PTO due to a combination of power losses through the transmission train, rolling resistance and slippage losses of the tires when operating on a traction surface (John *et al.,* 2016). Power requirement for tractor - powered implements is computed according to equation (9) as given by ASABE (2003).

$$P = \frac{D \times S}{3.6} \qquad (9)$$

Where:

P = power requirement, W
D = implement draft, N
S = implement travel speed, m/s

2.7 Data Analysis

Statistical analysis based on randomized complete block design (RCBD) with a factorial treatment design of 3 x 3 x 5 to investigate the interactions between implement forward speed and tillage depth was carried out in Excel Programme. Analysis of Variance (ANOVA) tests were carried out to investigate the interactions between implement forward speed and tillage depth to study their significant effect.

3. RESULTS AND DISCUSSION

The result of the soil analysis test carried out at Use Offot (loamy soil) is presented in Table 1, while the specifications of the tractor and implements used are presented in Tables 2 and 3 respectively.

Table 1: Soil Analysis Test on Use Offot for the Tillage Implements

Soil Parameter	Values		
	3-Bottom Disc Plough	Spring Tine Cultivator	Off-set Disc Harrow
Soil Composition	**%**	**(%)**	**(%)**
Sand	41	41	41
Silt	35	35	35
Clay	24	24	24
Classification	Loamy	Loamy	Loamy
Average Bulk density at depth of:	**(g/cm^3)**	**(g/cm^3)**	**(g/cm^3)**
0 – 30 cm	1.32	1.32	1.32
Average Moisture content at depth of:	**(%)**	**(%)**	**(%)**
0 – 30 cm	13.9	16.2	15.0
Penetration resistance at depth of:	**(MPa)**	**(MPa)**	**(MPa)**
10 cm	0.63	0.21	0.15
20 cm	0.94	0.28	0.22
30 cm	1.98	1.33	0.23
Soil cohesion at depth of:	**(kPa)**	**(kPa)**	**(kPa)**
0 – 30 cm	12.67	12.67	12.67
Shear stress at depth of:	**(kPa)**	**(kPa)**	**(kPa)**
0 – 30 cm	18.4	18.4	18.4
Soil strength at depth of:	**(kPa)**	**(kPa)**	**(kPa)**
0 – 30 cm	14.9	14.9	14.9
Soil adhesion at depth of:	**(kPa)**	**(kPa)**	**(kPa)**
0 – 30 cm	0.23	0.34	0.30
Weight of soil at depth of:	**(N)**	**(N)**	**(N)**
10 cm	1226.5	124.9	1123.3
20 cm	2821.4	297.5	2594.9
30 cm	4789.3	517.5	4417.0
Angle of internal soil-soil friction at depth of:	**(^{o})**	**(^{o})**	**(^{o})**
0 – 30 cm	34.4	34.4	34.4
Coefficient of internal soil-soil friction at depth of :			
0 – 30 cm	0.68	0.68	0.68
Angle of soil/implement friction at depth of:	**(^{o})**	**(^{o})**	**(^{o})**
10 cm	21.7	11.5	19.8

20 cm	23.6	13.7	21.3
30 cm	25.3	15.8	23.2
Coefficient of soil/implement friction at depth of:			
10 cm	0.40	0.20	0.36
20 cm	0.44	0.24	0.39
30 cm	0.47	0.28	0.43

Table 2: Specifications of tested Tractor

Specification	Swaraj Tractor (Model 978 FE)
Effective output (hp)	72
Type of Engine	4 – cylinder
Type of Fuel	Diesel
Type of steering system	Power assisted
Type of injector pump	In – line injector
Fuel tank capacity (L)	98
Lifting capacity (kg)	1250
Rated engine speed (rpm)	2200
Type of cooling system	Water – cooled
Country of manufacture	China
Front tyres (size)	6.0 – 16
Inflation pressure (kPa)	360
Rear tyres (size)	14.9 – 28
Inflation pressure (kPa)	180

Table 3: Specifications of Implements used during Field Test

S/No	Item	Disc Plough	Tine Cultivator	Offset Disc Harrow
1	Type	Mounted	Mounted	Mounted
2	Number of bottoms / discs/Share blade	3	14	18
3	Type of disc blade	Plane concave	-	Plane concave

4	Diameter of bottom/ disc (cm)	65.3	7	62
5	Spacing of discs/share Blade (cm)	68	10	22.5
6	Rake angle (deg.)	35	49	36

3.1 Influence of Speed on Draft at different levels of Depth

Figures 1-3 illustrates the effect of tractor forward speed on draft at different levels of tillage depth for 3- bottom disc plough, spring tine cultivator and offset disc harrow operating on loamy soil. From these figures, it was observed that draft increased with increase in forward speed. For all levels of speed, draft increased with increase in tillage depth. For a 3 – bottom disc plough, at a tillage depth of 10 cm, draft increased from 1061.4 to 1322.8 N at implement speeds of 0.82 and 2.58 m/s, respectively. The draft obtained at an implement speed of 0.82 m/s increased from1061.4 to 4454.1 N while at speed of 2.58 m/s, draft increased from 1322.8 to 5305.1 N. For a tillage depth of 30 cm, draft increased from 4454.1 to 5305.1 N at implement speeds of 0.82 and 2.58 m/s respectively. For a spring tine cultivator, at a tillage depth 10 cm, draft increased from 116.5to 149.2 N at implement speeds of 0.74 and 2.60 m/s, respectively. The draft obtained at implement speed of 0.74 m/s increased from 116.5 to 527.4 N while at speed of 2.60 m/s, draft increased from149.2 to 634.6 N. For a tillage depth of 30 cm, draft increased from 527.4 to 634.6 N at implement speeds of 0.74 and 2.60 m/s, respectively. For an offset disc harrow, at a tillage depth of 10 cm, draft increased from 917.0 to 1141.5 N at implement speeds of 0.79 and 2.54 m/s respectively. The draft obtained at implement speed of 0.79 m/s increased from 917.0 to 3857.3 N while at speed of 2.54 m/s, draft increased from 1141.5 to 4585.2 N. For a tillage depth of 30 cm, draft increased from 3857.3 to 4585.2 N at implement speeds of 0.79 and 2.54 m/s, respectively.

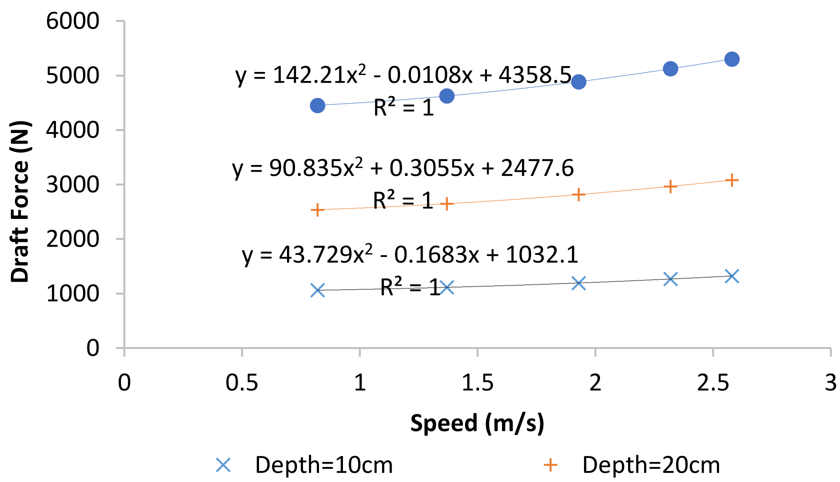

Figure 1: Effect of Speed and Depth on Draft Force for 3-Bottom Disc Plough at Use Offot (loamy soil).

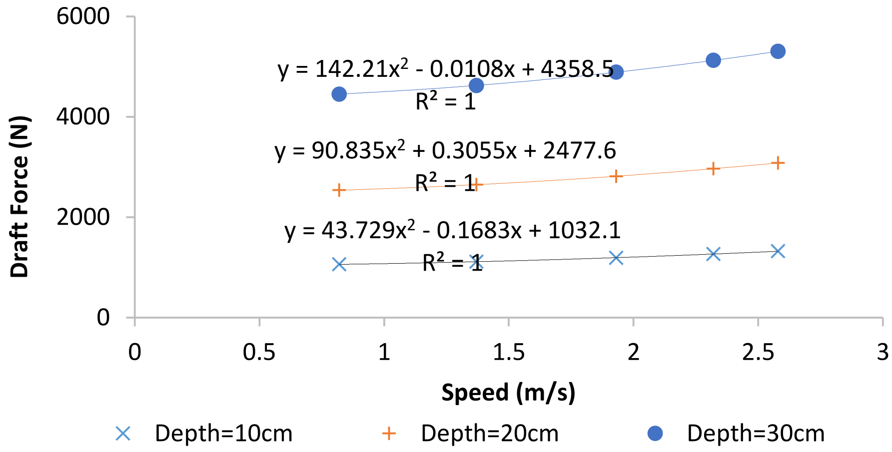

Figure 2: Effect of Speed and Depth on Draft Force for Spring Tine Cultivator at Use Offot (loamy soil).

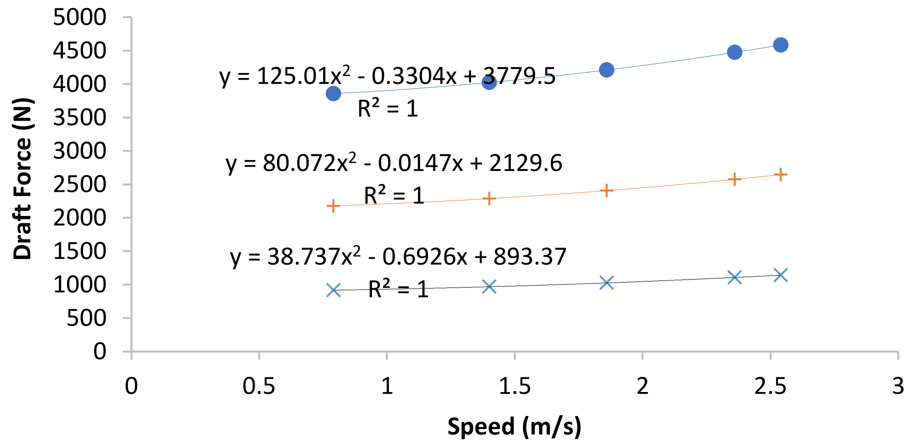

Figure 3: Effect of Speed and Depth on Draft Force for Offset Disc Harrow at Use Offot (Loamy soil).

3.2 Influence of Speed on Power requirements at different levels of Depth

Figures 4 – 6 illustrates the effect of tractor forward speed on power requirement at different levels of tillage depth for 3 – bottom disc plough, spring tine cultivator and offset disc harrow on loamy soil. For a 3 – bottom disc plough, at a tillage depth of 10 cm, power requirement increased from 870.3 to 3412.8 W at implement speeds of 0.82 and 2.58 m/s, respectively. The power requirement obtained at an implement speed of 0.82 m/s increased from 870.3 to 3652.4 W while at speed of 2.58 m/s, power requirement increased from 3412.8 to 13687.2 W. For a tillage depth of 30 cm, power requirement increased from 3652.4 to 13687.2 W at implement speeds of 0.82 and 2.58 m/s, respectively. For a spring tine cultivator, at a tillage depth 10 cm, power requirement increased from 86.2 to 387.9 W at implement speeds of 0.74 and 2.60 m/s, respectively. The power requirement obtained at implement speed of 0.74 m/s increased from 86.2 to 390.3 W while at speed of 2.60 m/s, power requirement increased from 387.9 to 1749.9 W. For a tillage depth of 30 cm, power requirement increased from 390.3 to 1649.9 W at implement speeds of 0.74 and 2.60 m/s, respectively. For an offset disc harrow, at a tillage depth of 10 cm, power requirement increased from 724.4 to 2899.4 W at implement speeds of 0.79 and 2.54 m/s respectively. The power requirement obtained at implement speed of 0.79 m/s increased from 724.4 to 3047.3 W while at speed of 2.54 m/s, power requirement increased from 2899.4 to 11646.4 W. For a tillage depth of 30 cm, power requirement increased from 3047.3 to 11646.4 W at implement speeds of 0.79 and 2.54 m/s, respectively.

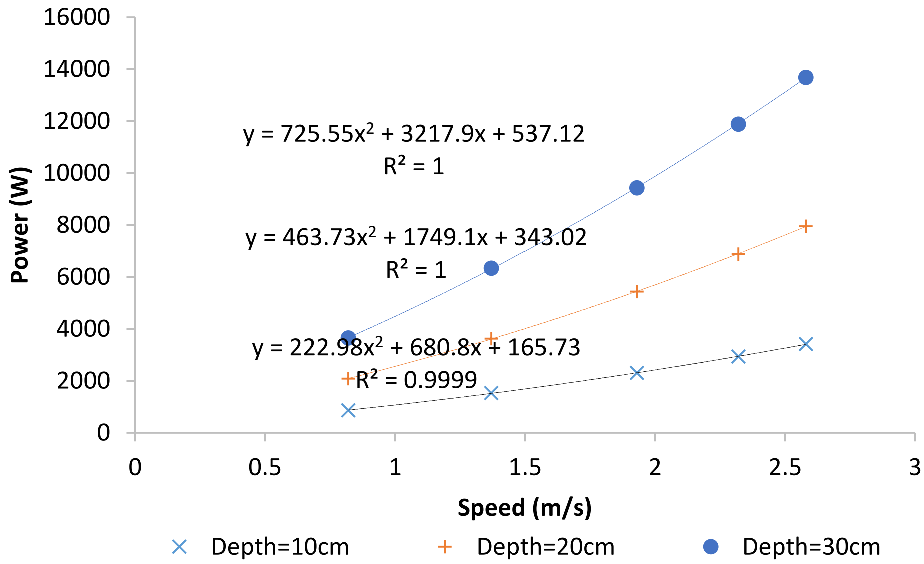

Figure 4: Effect of Speed and Depth on Power Requirement on a Disc Plough at Use Offot (loamy soil)

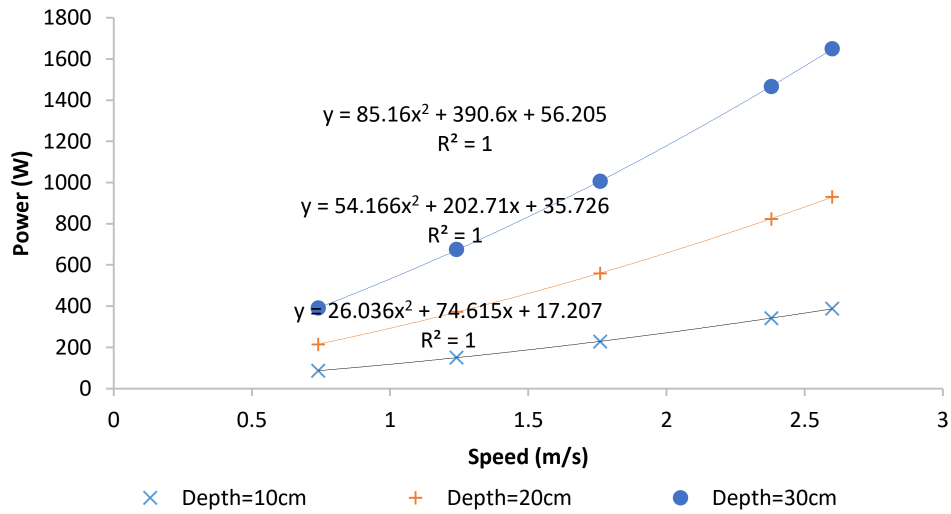

Figure 5: Effect of Speed and Depth on Power Requirement on a Spring Tine Cultivator at Use Offot (loamy soil)

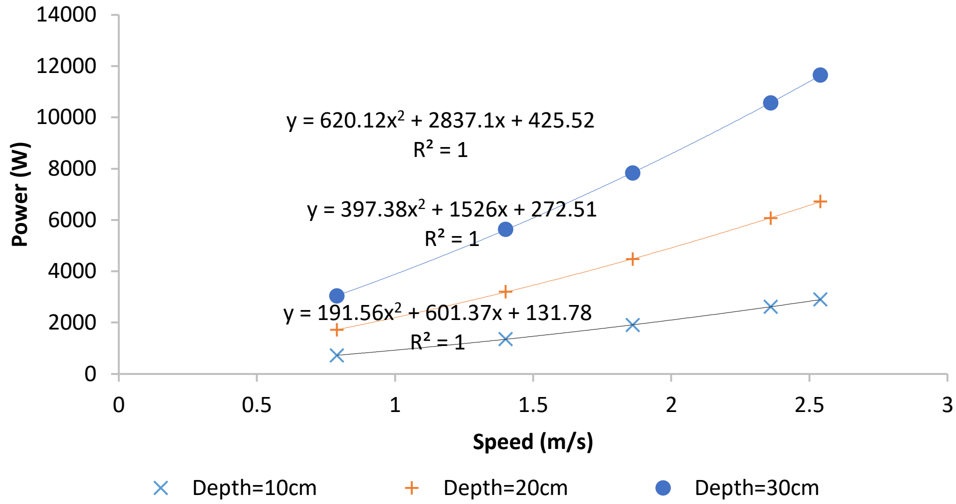

Figure 6: Effect of Speed and Depth on Power Requirement on an Offset Disc Harrow at Use Offot (loamy soil)

3.3 Analysis of Variance for Speed and depth on Draft requirements

The result of the analysis of variance (ANOVA) for the test of speed and tillage depth effect on draft for 3- bottom disc plough, spring tine cultivator and offset disc harrow on loamy soil. The result showed that forward speed and tillage depth affected the draft of the tillage implements significantly at 5% level of probability ($p<0.05$). The interaction between the two factors was also statistically significant at 5% level of probability ($p<0.05$).

3.4 Analysis of Variance for Speed and Depth on Power requirements

The result of the analysis of variance (ANOVA) for the test of speed and tillage depth on power requirement for 3 – bottom disc plough, spring tine cultivator and offset disc harrow on loamy soil. The result indicated that forward speed and tillage depth affected the power requirement of the tillage implements significantly at 5% level of probability ($P<0.05$). The interaction between the two factors was also statistically significant at 5% level of probability ($P<0.05$).

4. CONCLUSION

Field experiments were conducted to examine the effects of implements travel speed depth on the three tillage implements mostly used for seed bed preparation in Use Offot (loamy soil), Uyo Local Government Area of Akwa-Ibom state, Nigeria. A significant increase in draft and power requirements were noticed for all the three tillage implements with an increase in implement travel speed and tillage depth. Analysis of variance (ANOVA) showed that the implement travel speed and tillage depth have significant effect ($P\leq0.05$) on draft and power requirement. In the same way, the interaction between implement travel speed and tillage depth was significant at ($P\leq0.05$).

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Mechanical Properties of Tigernut (*Cyperus esculentus*) as Influenced by Moisture Content

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ABSTRACT

Tigernut **(***Cyperus esculentus*) is one among the underutilized crops in Nigeria despite its high economic value. The compressive strength as influenced by moisture content at 8%, 16%, 24%, 32% and 40% (db) respectively was investigated. The tigernut samples were collected directly from a farm in Minna, Niger State and cleaned to remove all foreign materials, initial moisture content was determined using ASAE 1990 standard after which samples were conditioned to the desired moisture levels following standard method. A Universal testing machine was used for the compressive test. The Maximum compressive stress ranged from 1.76 to 2.87 MPa, Compressive strain at maximum compressive stress ranged from 0.231 to 0.344 mm/mm, Energy at maximum compressive stress ranged from 0.157 J to 0.222 J, Compressive load at maximum compression stress ranged from 144 N to 234 N, Compressive extension at maximum compression stress ranged from 2.18 mm to 2.87 mm. Compressive stress at break ranged from 1.64 MPa to 2.22 MPa, Compressive load at break ranged from 134 N to 181 N. Compressive strain at break ranged from 0.27 to 0.387 mm/mm, Load at maximum compressive stress ranged from 144 N to 234 N, Extension at maximum compressive stress ranged from 2.18 mm to 2.87 mm, Compressive extension at break ranged from 2.12 mm to 3.03 mm. Load at break ranged from 134 N to 181 N, extension at break ranged from 2.27 mm to 2.81 mm, Energy at break ranged from 0.178 J to 0.245 J, Compressive stress at yield ranged from 1.79 MPa to 3.33 MPa and compressive load at yield ranged from 156 N to 271 N. ANOVA (at $p<0.05$) revealed a significant effect of moisture content on the maximum compressive stress, compressive load at maximum compressive stress, load at maximum compressive stress, extension at break, compressive stress at yield and compressive load at yield. Correlation and regression analysis revealed a positive linear relationship between all the measured parameters and moisture content with a stronger correlation coefficient for compressive stress at yield and compressive load at yield. These information is needed in the design and adjustment of machines used for harvesting, handling, processing and storage of tigernut.

Keywords: Compressive Strength Test, Mechanical Properties, Moisture Content, Tigernut

1. INTRODUCTION

Tigernut *(Cyperus esculentus)* is a perennial grass-like plant that is cultivated between March and December in Nigeria with spherical tubers of dimension 8 mm-16 mm as reported by Osagie *et al.* (1986). It is a pale yellow cream kernel surrounded by a fibrous sheath that have been cultivated for over 400 years ago in both commercial and substantial quantity depending on its demand. According to Obadina *et al.* (2008), tigernut was cultivated in the ancient Mesopotamia between the rivers Tigris and Euphrates. Tigernut generally is called earth almonds but different people from different countries have different names for tigernut.

In Nigeria, Tigernut is call (*aya)* by the Hausas, (*akiawusa)* by the Igbos and (*ofio)* by the Yorubas. It is cultivated more in the middle belt and northern regions of Nigeria. Tigernut has three varieties classified based on colour, which are Black, Brown and Yellow varieties (Osagie and Eka, 1998). According to Okafor *et al.* (2003) and Ebringa (2007), the yellow variety is considered the best among the three varieties because of its large size; the fact that more milk can be extracted from it when processed, contains higher protein, has lower fat content and less anti nutritional factors such as polyphenol.

Tigernuts are edible, sweet, nutty, flavoured tubers that contain protein, carbohydrate, sugars, and lots of oil and fiber, and can be processed into many other edible products (Gambo and Da'u 2014). According to Gambo and Da'u (2014), it is one among the best nutritional crops used to augment the diet of humans and it produces high quality oil of about 25.5 % and protein content of about 8 %. Tigernut can be roasted, dried, baked and made into milk recommended for those who have heavy digestion, diarrhea and dysentery because of its high content of digestive enzymes and no lactose or gluten content (Abaejoh *et al*. 2006). The Egyptians and the Mediterranean uses tigernut as sources of food, medicine and perfumes (Ndubuisi, 2009).

Tigernut has very high fiber content that makes it very healthy and does not lose its nutritional contents during milling process as reported by Salau *et al*. (2012). Bamishaiye and Bamishaiye (2011) reported that tigernut is an excellent source of minerals such as iron and calcium that are essential for body growth and development. Tigernut can help to prevent heart attacks, thrombosis and activate blood circulation and due to the high contents of soluble glucose, it can help prevent cancer and reduce the risk of suffering colon cancer.

Mechanical properties are those properties that indicate the behavior of biomaterials under applied forces or load. Mechanical damage to seeds and grains which occur during harvesting, threshing and handling can seriously affect viability and germination power, growth vigor, insect fungi attach and quality of final product (Mohsenin, 1990). Mechanical properties such as compressive strength, impact and shear resistance are important and necessary engineering data in studying size reduction of cereal grains as well as seed resistance to cracking under harvesting and handling conditions. Jha *et al.* (2006) reported that in the design of a dehulling machine, milling machines, mechanical properties such as rupture force, hardness and energy used for rupturing fruits are useful information. As seen by the food engineer, one of the problem of agricultural mechanization has been mechanical damage to the crop during harvesting and handling; when it is dropped (impact), when it is piled up (quasi-static loading), and when it is shaken or struck in transit (vibrational bruising). During tigernut harvesting, for instance, the possibilities for injury to the tuber are numerous. Mechanical action can cause skinning, external cracking, and puncturing. In handling and processing of agricultural produce or biomaterials, mechanical damages are majorly due to external forces under static and dynamic conditions. However, internal forces that cause mechanical damage include variation in temperature and moisture content. Mechanical damage to agricultural produce becomes more susceptible to infection and diseases Bamgboye and Adebayo (2012).

Information on the mechanical properties of agricultural products as a function of moisture content is needed in the design and adjustment of machines, used during harvest, separation, cleaning, handling and storage. It is also use in processing these agricultural materials into food. The properties useful for design must be determined at laboratory conditions (Gürsoy and Güzel, 2010). The physical and mechanical properties of nuts, kernels, seeds and fruits such as soya, sunflower, pigeon pea, apricot kernels have been studied (Deshpande, 1993). Oladele *et al*. (2007) studied some engineering properties of cassava tuber under five moisture content levels of 70 %, 65 %, 60%, 55 %, and 50 % wet basis. The properties measured were tensile strength, compressive strength and elasticity. The studies showed that tensile, compressive and shear strength of cassava reduces as the moisture content of the tuber decreases. The effect of different moisture content of 10, 15, 20 and 25% (wb) on some mechanical properties of pigeon pea (*Cajanus cajan*) was investigated by Okey *et al*. (2014). The properties; rupture force, compressive strength, maximum displacement, strain at maximum load and the Young's modulus, were significantly dependent ($p<0.05$) on the moisture content.

Despite these numerous importance of tigernut as a multipurpose tuber, it has been one among the neglected and underutilized crops in Nigeria as reported by Bamishaiye and Bamishaiye (2011) because of inadequate knowledge on its production, utilization, nutritional and health value, and non-availability of processing machines in Nigeria. Tigernut is locally processed without minding its effect on its nutritional quality or value. Developing mechanized processes for harvesting, size reduction, oil or milk extraction, handling and storage facilities for tigernut cannot be successful without an accurate knowledge and availability of its engineering properties such as physical, mechanical, thermal, optical, electrical properties among others. Tigernut can be a raw material for industries in Nigeria if well utilized for the production of milk, flour, oil, bread among many other products. Studies carried out are majorly on physical properties of tigernut and little has been reported on its mechanical properties. These properties are needed in the designing of machines for unit process operations such as size reduction, sorting, cleaning, drying, storage and extraction of oil and juice for modern processing of tigernut.

Therefore, this work is aimed at determining the mechanical properties of tigernut as influenced by moisture content which is relevant in the design and handling of tigernut processing machines.

2. MATERIALS AND METHODS

2.1 Sample Preparation

The tigernut was purchased from a farm located in Minna Local Government Area of Niger State, Nigeria after harvest and were cleaned and sorted manually of all foreign matter (such as dirt, stones, premature and broken seeds) and stored in a plastic container. The initial moisture contents of the sample was determined to be 7.8%db using the ASAE standard (ASAE, 1990) by oven drying the sample at 103°C for 48 hours at the multipurpose central laboratory, University of Ibadan

2.2 Seed conditioning

The sample was divided into five equal weight and conditioned to the desired moisture contents range of 8, 16, 24, 32 and 40 (% db) which captures the moisture content at harvest and storage by weighing and adding a calculated amount of distilled water using the equation 1.

$$Q = W_i\left[\frac{M_f - M_i}{100 - M_f}\right] \qquad (1)$$

Where; Q is the mass of water to be added in kg,

$\boldsymbol{W_i}$ *is the initial mass of the sample in kg,* $\boldsymbol{M_i}$ *is the initial moisture content of the sample in % d.b and* $\boldsymbol{M_f}$ *is the final moisture content in % d.b*

The conditioned samples were stored in airtight bag and kept in a refrigerator at 5°C for 168 hours to ensure uniformity of distributed moisture throughout the samples. The moisture content of the conditioned samples were verified after the seventh day before being used for the tests.

2.3 Determination of Mechanical Properties

Quasi-static compression strength test was performed on the tigernut samples using an Instron Universal Testing Machine (Model 3369) at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife. The Instron Universal Testing Machine was fitted with a compression cage, comprising two parallel plates made of hardened stainless steel. A deformation rate of 1.0 mm/min was used as specified by ASAE (1990). The seeds were loaded along the major axis on the static plate and the moveable plate was allowed to touch the top of the sample without any pressure on it. The start button was pressed and the resulting compression strength test of the sample was analyzed automatically by the UTM software in both tabular and graphical form on the computer for usage. The experiment was repeated five (5) times on each sample and analysis of variance (ANOVA) was performed using SPSS (Version 20) where the level of significant difference was found among the experimental data at 95% confident level, means separation was performed using Duncan New Multiple's range test (DNMRT) as well as correlation and regression analysis to check the relationship of moisture content and the tested parameters.

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties

Results for compressive test at the different moisture contents are presented on figure 1-16 below

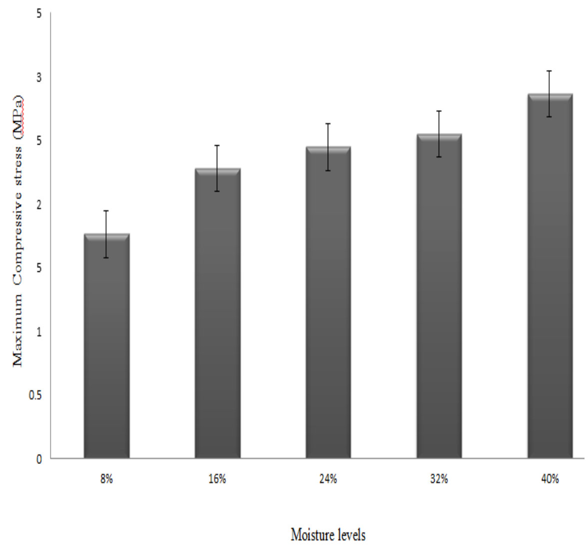

Fig. 1: Maximum compressive stress trend

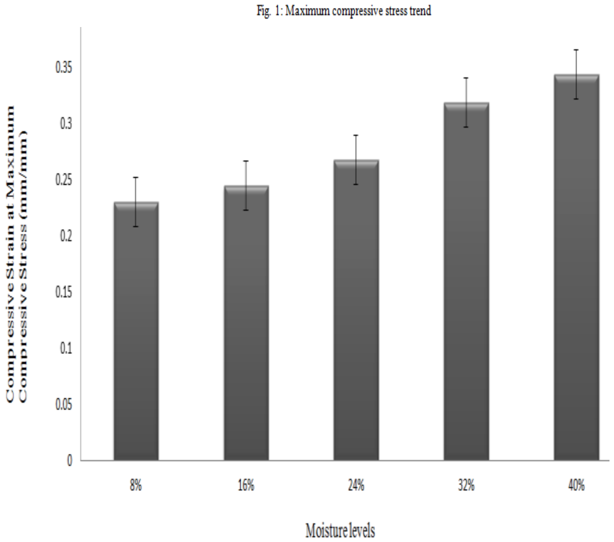

Fig. 2: Compressive strain at Maximum compressive stress trend

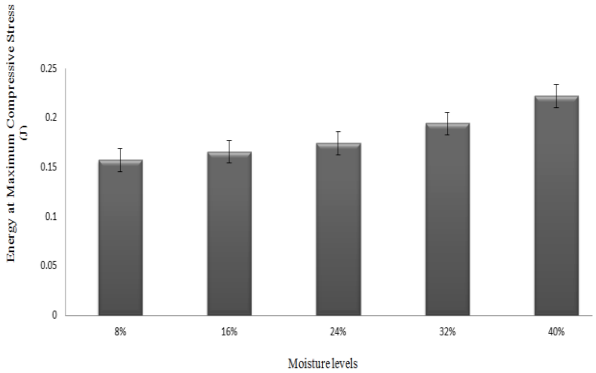

Fig. 3: Energy at maximum compressive stress trend

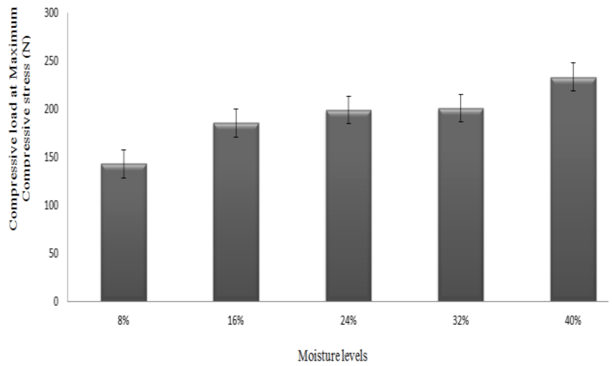

Fig. 4: Compressive load at Maximum compressive stress trend

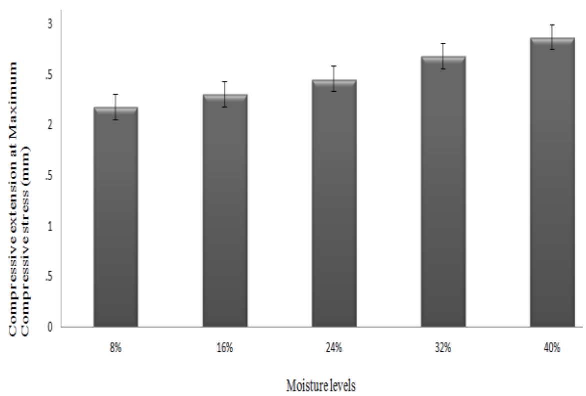

Fig. 5: Compressive extension at maximum compressive stress trend

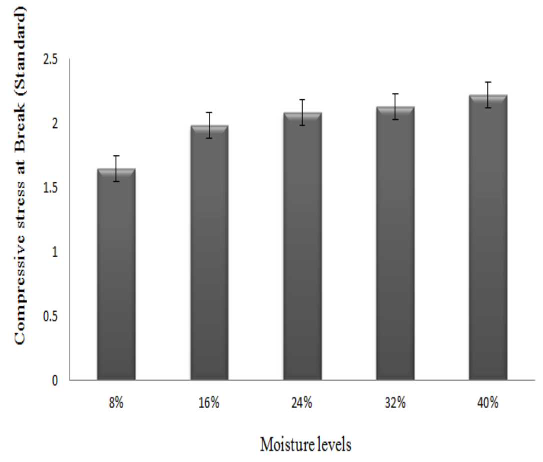

Fig. 6: Compressive stress at break

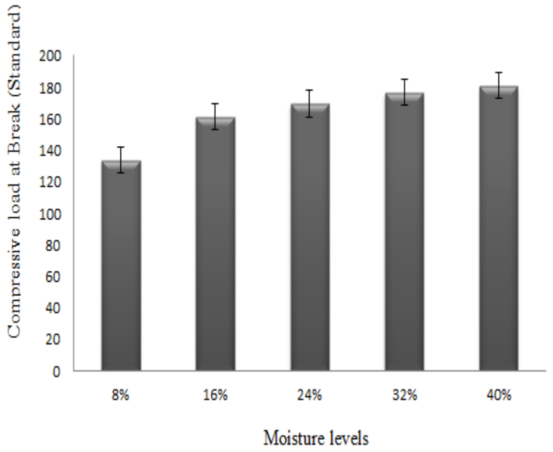

Fig. 7: Compressive load at break

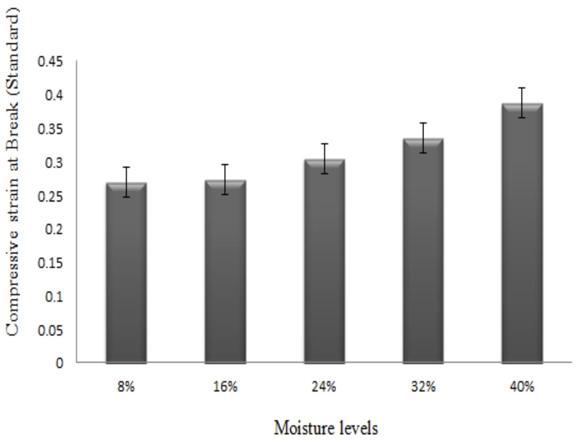

Fig. 8: Compressive strain at break trend

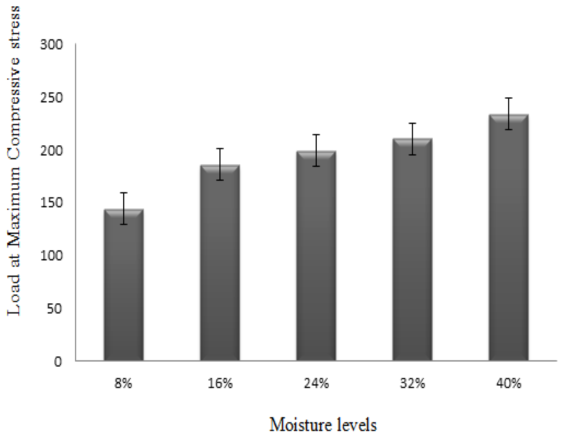

Fig. 9: Load at maximum compressive stress trend

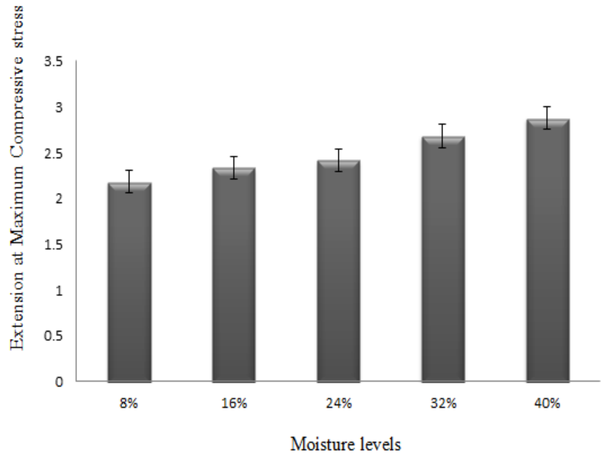

Fig. 10: Extension at maximum compressive stress trend

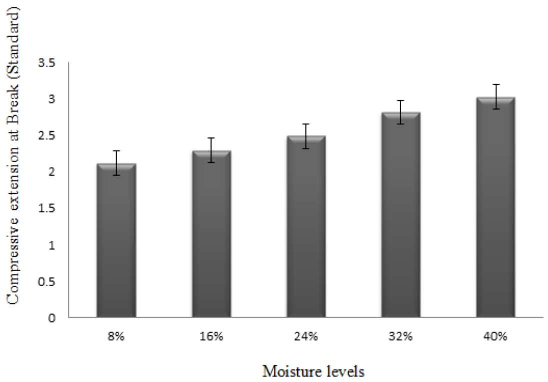

Fig. 11: Compressive extension at break trend

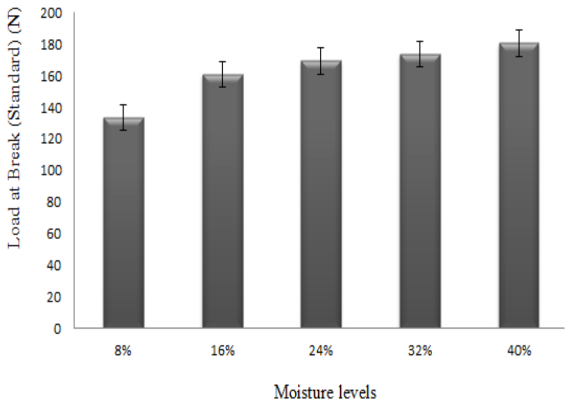

Fig. 12: Load at break trend

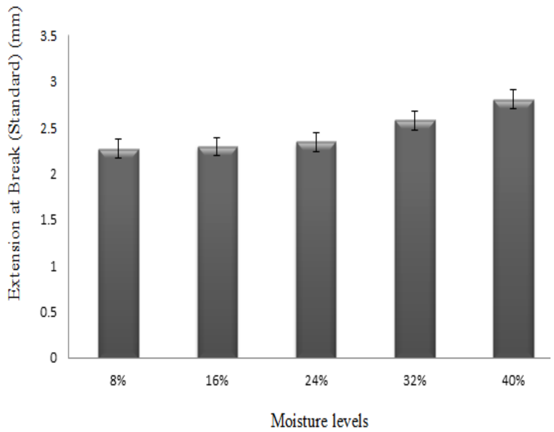

Fig. 13: Extension at break trend

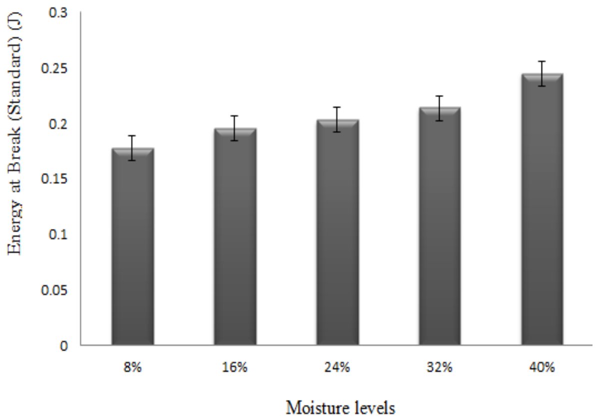

Fig. 14: Energy at break trend

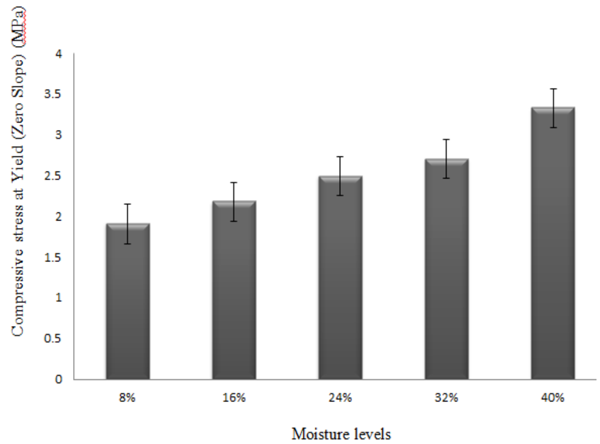

Fig. 15: Compressive stress at yield trend

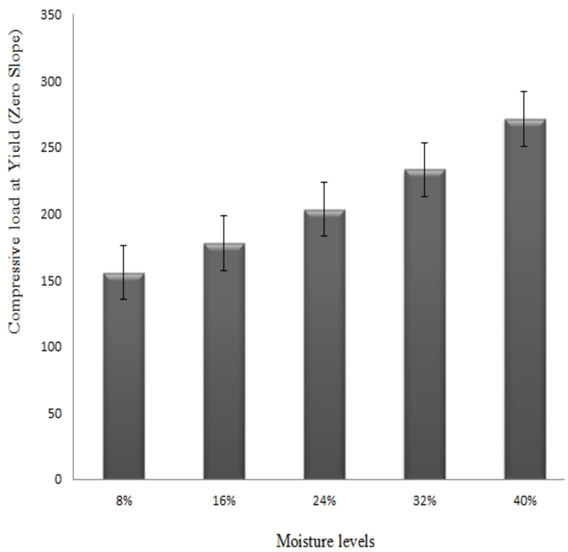

Fig. 16: Compressive load at yield trend

The compressive test of tigernut as influenced by moisture content using the Universal testing machine revealed that the maximum compressive stress ranged from 1.76 MPa to 2.87 MPa. The compressive strain at maximum compressive stress ranged from 0.231 mm/mm to 0.344 mm/mm. The energy at maximum compressive stress ranged from 0.157 J to 0.222 J. The compressive load at maximum compression stress ranged from 144 N to 234 N. The compressive extension at maximum compression stress ranged from 2.18 mm to 2.87 mm. The compressive stress at break ranged from 1.64 MPa to 2.22 MPa. The compressive load at break ranged from 134 N to 181 N. The compressive strain at break ranged from 0.270 mm/mm to 0.387 mm/mm. The load at maximum compressive stress ranged from 144 N to 234 N. The extension at maximum compressive stress ranged from 2.18 mm to 2.87 mm. The compressive extension at break ranged from 2.12 mm to 3.03 mm. The load at break ranged from 134 N to 181 N. The extension at break ranged from 2.27 mm to 2.81 mm. The energy at break ranged from 0.178 J to 0.245 J. The compressive stress at yield ranged from 1.79 MPa to 3.33 MPa while the compressive load at yield ranged from 156 N to 271 N. It was observed that the compressive test parameters were all increasing as the moisture content increases which was in line with the report by Oladele *et al.* (2007) and Tavakoli *et al*. (2009)

in their study of cassava tuber and soybean grains respectively. Riswanti (2014) also reported a similar observation in his study of Jatropha curcas seeds.
Analysis of variance performed on the compressive test results (table 1), revealed a significant difference among the maximum compressive stress, compressive load at maximum compressive stress, load at maximum compressive stress, extension at break, compressive stress at yield and compressive load at yield at $P<0.05$. Regression and correlation Analyses carried out on the compressive strength test revealed poor positive linear relationship between moisture content with all the measured compressive parameters except for the compressive stress at yield and compressive load at yield having a stronger positive relationship of R and R^2 of 0.855 and 0.732 respectively. The compressive stress at yield (CSY) and compressive load at yield (CLY) as a function of moisture content (M) can be expressed using the regression equations 2 and 3 below.

$$CSY = 1.422+0.356M \quad (2)$$

$$CLY = 122.166+28.545M \quad (3)$$

Table 1: ANOVA Result on Mechanical Properties of Yellow Tigernut at 95% Significant Level

Mechanical Properties		Sum of Squares	Df	Mean Square	F	Sig.
Maximum compressive stress (MPa)	Between Groups	3.356	4	0.839	3.003	**0.041***
	Within Groups	6.147	22	0.279		
	Total	9.503	26			
Compressive strain at maximum compressive stress (mm/mm)	Between Groups	0.050	4	0.013	2.167	0.106
	Within Groups	0.127	22	0.006		
	Total	0.178	26			
Energy at maximum compressive stress (J)	Between Groups	0.014	4	0.003	1.373	0.275
	Within Groups	0.055	22	0.002		
	Total	0.069	26			
Compressive load at maximum compressive stress (N)	Between Groups	21346.717	4	5336.679	3.067	**0.038***
	Within Groups	38281.386	22	1740.063		
	Total	59628.102	26			
Compressive extension at maximum compressive stress (mm)	Between Groups	1.624	4	0.406	1.017	0.420
	Within Groups	8.785	22	0.399		
	Total	10.409	26			
Compressive stress at break (MPa)	Between Groups	1.014	4	0.253	1.419	0.261
	Within Groups	3.930	22	0.179		
	Total	4.944	26			

Compressive load at break (N)	Between Groups	6810.808	4	1702.702	1.420	0.260
	Within Groups	26376.982	22	1198.954		
	Total	33187.790	26			
Compressive strain break (mm/mm)	Between Groups	0.049	4	0.012	2.045	0.123
	Within Groups	0.131	22	0.006		
	Total	0.179	26			
Load at maximum compressive stress (N)	Between Groups	22765.187	4	5691.297	3.378	**0.027***
	Within Groups	37067.827	22	1684.901		
	Total	59833.014	26			

Mechanical Properties		**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Extension at maximum compressive stress (mm)	Between Groups	1.616	4	0.404	1.016	0.421
	Within Groups	8.743	22	0.397		
	Total	10.358	26			
Compressive extension at break (mm)	Between Groups	2.911	4	0.728	1.753	0.175
	Within Groups	9.134	22	0.415		
	Total	12.045	26			
Load at break (N)	Between Groups	6847.944	4	1711.986	1.441	0.254
	Within Groups	26131.490	22	1187.795		
	Total	32979.434	26			
Extension at break (mm)	Between Groups	1.076	4	0.269	4.617	**0.007***
	Within Groups	1.282	22	0.058		
	Total	2.357	26			
Energy at break (J)	Between Groups	0.013	4	0.003	0.927	0.466
	Within Groups	0.074	22	0.003		
	Total	0.087	26			
Compressive stress at yield (MPa)	Between Groups	6.795	4	1.699	17.156	**0.000***
	Within Groups	2.178	22	0.099		
	Total	8.973	26			
Compressive load at yield (N)	Between Groups	42776.585	4	10694.146	15.744	**0.000***
	Within Groups	14943.274	22	679.240		
	Total	57719.858	26			

* Represents significant difference at P< 0.05

4. CONCLUSION

The effect of moisture contents on compressive strength of tigernut has been studied and moisture content has significant influence at $P<0.05$ on the maximum compressive stress, compressive load at maximum compressive stress, load at maximum compressive stress, extension at break, compressive stress at yield and compressive load at yield. The Compressive strain at maximum compressive stress, Energy at maximum compressive stress, Compressive extension at maximum compressive stress, Compressive stress at break, Compressive load at break, Compressive strain break, Extension at maximum compressive stress, Compressive extension at break, Load at break, Energy at break were not significantly influenced by moisture content at $P<0.05$ though there is a poor positive linear relationship between them and moisture content with compressive stress at yield and compressive load at yield having the strongest correlation coefficient.

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Evaluation of the physicochemical and thermal properties of honey samples from different floral locations in Enugu North senatorial zone, Nigeria.

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ABSTRACT

This study was carried out to investigate the physicochemical and thermal properties of natural honey collected from different floral locations in Enugu North senatorial zone. The physicochemical and thermal parameters like moisture content, pH, sucrose, glucose, fructose, acidity, density, thermal conductivity, thermal heat diffusivity, specific heat capacity, viscosity, ash content, colour and electrical conductivity were analyzed. The results obtained show that the pH values of the samples ranged from 4.7 – 5.7. The maximum and minimum moisture content were 22.5 and 16.59% (wb) respectively, with sample from Igbo-Etiti having the lowest moisture content. The density value ranged from 820-1250 kg m^{-3}, with honey samples from Igboeze- South recording the highest density. It was also observed that the sucrose content of the samples ranged from 1.037- 1.78g/100g which is considered good and within international acceptable value for honey. Electrical conductivity values for Igboeze-North, Udenu, Igboeze-South, Igbo-Etiti and Nsukka were 16.5, 6.0, 25.4, 3.5 and 11.4µS/cm respectively, Fructose values were 34.339, 33.484, 34.515, 39.434 and 33.136 g/100g respectively and glucose contents were 31.361, 30.856, 31.639, 35.224 and 30.621 g/100g respectively It was also observed that honey from Igbo-Etiti is more viscous than all the samples. The honey samples from the different floral locations in Enugu North Senatorial zone were acidic. The colour of the sample is classified as Amber for sample from Igboeze-North, Igboeze-South and Igbo-Etiti, while that of Udenu is Light Amber and that of Nsukka is Extra White. The thermal properties fell within international acceptable range of values. Thermal heat conductivity ranged from 0.4358-0.4490 $Wm^{-1}K^{-1}$, specific heat capacity was from 1.3024-1.6355 $kJkg^{-1}K^{-1}$,and thermal heat diffusivity ranged from 2.4252×10^{-4} - $3.8313\times 10^{-4} m^2s^{-1}$. Honey is a promising source of food, raw material and essential minerals. Knowledge of its physicochemical and thermal properties is inevitable in other to facilitate its postharvest processing.

Keywords: moisture content, sucrose, acidity, density, thermal heat diffusivity, viscosity, ash content, electrical conductivity

1. INTRODUCTION

Honey is the natural sweet substance produced by honeybees from the nectar of plants or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honeycomb to ripen and mature (Codex Alimentarius, 2001). Honey is considered as oldest sweetening substance consisting mainly of 70% of sugars such as glucose and fructose (Nayik et al., 2014; Smanalieva and Senge, 2009; Nayik et al., 2016a). It possesses valuable nourishing, healing and prophylactic properties. Honey is perhaps one of the most complex foodstuffs produced by nature and certainly the only sweetening agent that can be used by humans without any processing (Khaled, 2007, Hernandez et al., 2004).

Bee honey can be a good source of major and trace elements needed by humans. The general features and elemental composition of honey depend on its botanical and geographical origin. The concentration of mineral compounds ranges from 0.1% to 1.0% that varies widely depending on the particular floral location, pedoclimatic conditions and extraction technique (Kebede et al., 2012). The dominant element in honey is potassium, followed by chlorine, sulphur, sodium, phosphorus, magnesium, silicon, iron and copper (La Serna et al., 1999). Bee honey can contain metals up to 0.17%. Metals such as Cr, Co, Cu, Fe, Mn and Zn are essential for humans, and they may play an important role in a number of biochemical processes. Some of them are present at the trace level, being toxic if they exceed safety levels. As a foodstuff used for healing purposes, honey must be free of any objectionable content and should contain only small amounts of pollutants, such as heavy metals (Khaled et al., 2007).

Honey has a variety of uses. Honey provides a good source of energy, used in cooking, baking, as a spread on bread, and as an addition to various beverages, such as tea, and as a sweetener in some commercial beverages. It is also used in the fermentation of alcoholic beverages, blood sugar control, wound healing, cough suppressant, and can be used to boost immunity (Karen, 2014*)*. It also has antioxidant and antimicrobial properties.

The physicochemical parameters are of vital importance to industries using honey. These constituents such as minerals, moisture content, reducing sugars, electrical conductivity, free acidity, sucrose content and Hydroxymethylfurfural (HMF) have influence on nutritional quality, granulation, the storage quality, flavour and texture of the honey. The medicinal value of honeys is also due to these constituents. Therefore, the International Honey Commission (IHC) has proposed certain constituents as quality criteria for honey. In order to have a beneficial effect, honey must be free of any contaminating agents. High concentration of metals in honey can be a source of illness to human beings, especially heavy metals (Aghamirlou et al., 2015). Artificial honeys can be produced from carbohydrate sources that have glucose-fructose composition that are within a close range with that of natural honey. These artificial honeys often have similar taste and physical appearance as natural honeys, but they lack the medicinal and nutritional properties of natural honeys because of the absence of the minor constituents that are present in natural honeys (James et al., 2009). Natural honey was found to be a suitable alternative for healing wounds, burns and various skin conditions and also to have a potential role in cancer care. The intrinsic properties of honey have been reported to affect the growth and survival of microorganisms by bacteriostatic or bactericidal actions (Mudasar et al., 2013). It is high in carbohydrates and adds useful varieties to diets. Most honey have fructose and glucose, it is more readily digestible than cane sugar. Honey varies in taste, aroma and colour according to its source.

Thermal properties of foods and beverages must be known to perform the various heat transfer calculations involved in designing storage and refrigeration equipment and estimating process times for refrigerating, freezing, heating, or drying of foods and beverages (ASHRAE, 2006).

Because the thermal properties of foods and beverages strongly depend on chemical composition and temperature, and because many types of food are available, it is nearly impossible to experimentally determine and tabulate the thermal properties of foods and beverages for all possible conditions and compositions. Thermo-physical properties often required for heat transfer calculations include density, specific heat, enthalpy, thermal conductivity, and thermal diffusivity.

Many researchers have worked on various properties of natural honey in different parts of the world, which have been compared with international standard. Sohaimy et al. (2015) conducted a study on the physicochemical characteristics of honey from different origins. Vázquez-Qui˜nones et al. (2017) did a work on the microbiological assessment of honey in México. James et al. (2009) had earlier conducted a study on the physical characterisation of some honey samples from North-Central Nigeria. Some physicochemical and rheological properties of Iranian honeys and the effect of temperature on its viscosity was evaluated by Mehryar et al. (2013). However, very little information is available in literature on the physicochemical and thermal properties of Nigerian indigenous honey from Enugu North senatorial zone. Therefore understanding the physiochemical and thermal properties of honey is very important in determining the nutritional quality, economic value and in the design of processing equipment, packaging material and evaluation of the storage conditions of honey.

The aim of this study is to characterize honey samples from from different floral locations within Enugu North senatorial zone based on their physicochemical and thermal properties, and compare the values obtained in each local government area with others, as well as the international standards.

2. MATERIALS AND METHODS

2.1 Raw materials: About 75 cm^3 honey samples were sourced from floral location in each Local Government Area of Enugu North senatorial zone. Honey sample from Udenu was collected at Obollo-Afor main market, that of Igboeze-North Local Government, was collected from Eke market at Ogurute Enugu-Ezike. Sample from Nsukka Local Government Area was collected at Afor-Opi market, that of Igbo-Etiti was sourced at Nkwo Ogbede market and that of Igboeze-South was sourced at Eke Ovoko market (Figure 1).

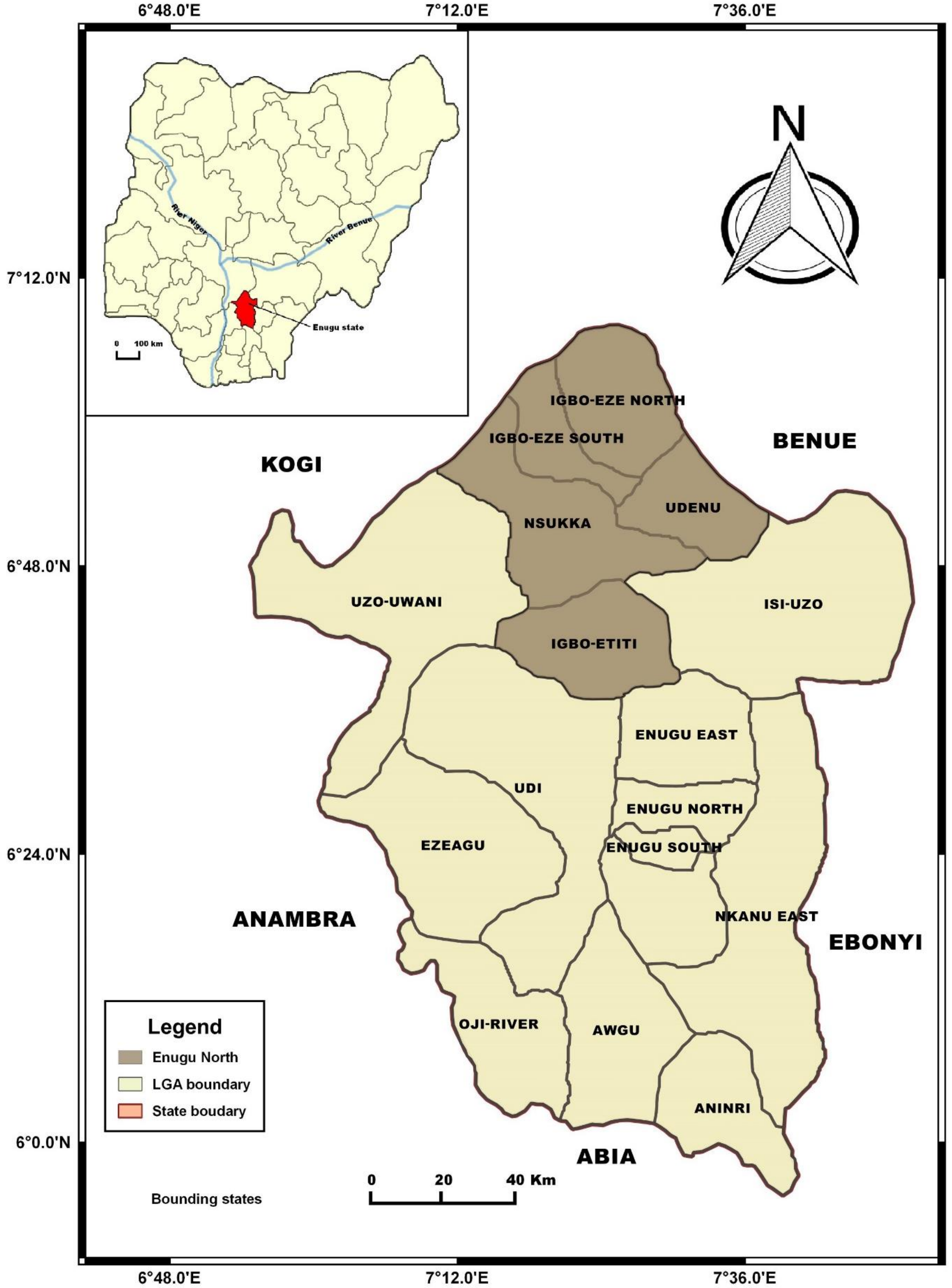

Figure 1. Map of Enugu State showing Enugu North senatorial zone

2.2 Determination of Physico-chemical properties

Determination of colour: The undiluted honey samples was filtered with Whatman filter paper and 2 cm^3 of each filtrate was measured directly with a UV spectrophotometer (Genesys UV Spectrophotometer) at 560nm. The colour of the samples was also visually observed in a 1cm^3 cuvette before each reading and compared with a colour chat. This method was based on International Honey Commission (2002).

Determination of pH: About 10 cm^3 honey solution was used for the measurement of pH. The pH was measured using a digital pH meter (Eutech Instruments Pvt Ltd., Singapore) according to the method described by the Association of Official Analytical Chemist (AOAC, 2000). The color of the honey samples was determined by using a spectrophotometer measurement of the absorbance of 50% (w/v) honey solution at 560 nm according to the method of White (1984). The color of honey samples were classified according to the Pfund scale after conversion of the absorbance values.

Determination of ash value: The ash content was determined by incinerating 5 g of the honey samples in a muffle furnace at a temperature of 550 °C for 5 hours according to the method described by AOAC (2000) Finally ash content was calculated, using Equation (1).

$$Ash\,content\,(\%) = \frac{M_A - M_T}{M_T} \times 100 \qquad (1)$$

Where M_A is mass of honey sample before testing and M_T is mass of honey sample after testing

Determination of moisture content: Moisture content of the honey samples were measured using an Abbe refractometer (Atago Co., Ltd., Tokyo, Japan) at 20 ^oC. The corresponding moisture content values were obtained from the Chatway table (AOAC (2012).

Determination of electrical conductivity: The electrical conductivity (μS/cm) was evaluated by using the expression reported by Piazza et al. (1991) in Equation 2

$$EC = 0.14 + 1.74 \times A \qquad (2)$$

Where, EC is electrical conductivity (mS/cm) and A is ash content of honey (g/100 g honey).

Determination of density: The density of the honey samples were measured using standardized instrumental methods (AOAC, 1990). In this process, the weight of specific gravity bottle (50 cm^3) filled with the honey samples was divided by the weight of the bottle filled with distilled water.

Determination of viscosity: Viscosity of the honey was measured using an Ostwald viscometer at a shear rate of 5 rpm. The viscosity of honey samples was measured at temperatures of 25^{o}C and 60^{o}C.

Determination of sugar content: The glucose, fructose and sucrose content of the honey samples were determined spectrophotometrically according to AOAC (2000) method and slightly modified method previously reported by Miller (1959), Dubois et al. (1956) and Khalil et al. (2012)

Acidity: The acidity was measured titrimetrically following the AOAC method (AOAC, 2000). In this process, the electrode of the pH meter was immersed in the solution, stirred with a magnetic stirrer and titrated to pH 8.5 by adding a 0.05 N of NaOH solution.

2.3 Determination of thermal properties

Specific heat capacity: Determination of specific heat capacity was by electrical heating method. A copper calorimeter was first weighed empty and reweighed when about two-third full of sample. The ammeter, voltmeter and heating coil (constant wire) were connected. A plastic stirrer and a thermometer were also fitted into the container through the holes in the wooden lid. The current was switched on after the initial temperature of the sample had been recorded. The rheostat was adjusted to give a suitable steady current. The liquid was stirred gently while being heated. The final temperature was read after the current was switched off. The specific heat of the sample was calculated using Equation 3

$$C_1 = \frac{VIt}{M_1(T_2 - T_1)} - M_C C_C \qquad (3)$$

Where C_1 is specific heat capacity of the sample (kJ kg^{-1} K^{-1}), C_C is specific heat capacity of the calorimeter = 400 Jkg^{-1}K^{-1}, M_C is mass of calorimeter =0.077kg, M_1 is mass of sample = 0.056kg, I is current (Amp), V is voltage (v), t is time taken (sec), T_2 and T_1 are final and initial temperatures respectively.

Thermal conductivity: The method applied was the non-steady state technique. Hot wires were used. The sample was measured using a measuring cylinder and gently poured into the pipe of which the two openings were closed with a cork. A constantan wire was inserted into the material and the terminals were connected. When the key in the circuit was closed, there was a conversion of energy from electrical energy to heat energy which flow out radially from the wire into the sample and the quantity of heat passing through the wire were recorded by the use of Ammeter and voltmeter connected in the circuit. There was a change in temperature of the wire and the logarithm time was used to calculate the thermal conductivity of the sample (Equation 4)

$$K = \frac{VI}{4\pi(T_2 - T_1)}\left(In\frac{t_2}{t_1}\right) \qquad (4)$$

Where, K is thermal conductivity (w/m/k), $T_1$is initial temperature (k), T_2 is final temperature (k), t is time (sec), V is voltage (v) and I is current (Amp).

Thermal diffusivity: This was measured with derivation method. The specific heat capacity, thermal conductivity and density were used for the calculation (Equation 5).

$$\alpha = \frac{K}{\rho \times C_P} \qquad (5)$$

Where, α is thermal diffusivity (m^{2}s^{-1}), K is thermal conductivity (W m^{-1}K^{-1}), ρ is density (kg m^{-3}), C_P is specific heat capacity (kJ kg^{-1}K^{-1}).

3. RESULTS AND DISCUSSION

The results of the physico-chemical properties of honey from floral locations in Enugu North senatorial zone are presented in Table 1 while the thermal properties of the honey samples are shown in Table 2.

Table 1 Physico-chemical properties of honey samples from floral locations in Enugu-North senatorial zone.

Parameters	Replicate	Igboeze-North	Udenu	Igboeze-South	Igbo-Etiti	Nsukka	Sd
Viscosity @ 25°C(cSt)	10	38.97	105.62	56.00	140.09	28.45	47.42
Viscosity @ 60°C (cSt)	10	7.18	21.89	8.16	62.19	4.04	24.19
Electrical conductivity (μS/cm)	10	16.5	6.0	25.4	3.5	11.4	8.76
Fructose (g/100g)	10	34.339	33.484	34.515	39.434	33.136	2.555
Sucrose (g/100g)	10	1.572	1.037	1.555	1.375	1.785	0.279
Acidity (%)	10	0.387	0.385	0.700	0.383	0.353	0.145
Ash (%)	10	2.11	0.57	1.65	0.059	0.33	0.89
Moisture content (%)	10	21.54	19.69	22.56	16.59	22.12	2.44
Density (kg/m^3)	10	1000	1000	1250	820	1240	182.5
Glucose (g/100g)	10	31.361	30.856	31.639	35.224	30.621	1.879
Ph	10	5.10	5.70	4.70	4.80	4.90	0.39
Colour (absorbance's at 560nm)	-	1.826	1.272	1.999	1.612	0.859	-

Table 2. Thermal properties of honey samples from Enugu-North senatorial zone

Parameters	Replicate	Igboeze-North	Udenu	Igboeze-South	Igbo-Etiti	Nsukka	Sd
Thermal conductivity (k) ($Wm^{-1} K^{-1}$)	10	0.4370	0.4358	0.4396	0.4468	0.4490	0.0059
Specific heat capacities (kJ $kg^{-1} K^{-1}$)	10	1.3024	1.4594	1.5252	1.6355	1.4043	0.1253
Thermal diffusivity (m^2s^{-1})	10	3.4993×10^{-4}	3.8313×10^{-4}	2.4252×10^{-4}	2.8460×10^{-4}	2.6913×10^{-4}	5.8579×10^{-5}

3.1 Physicochemical properties

Viscosity: The viscosity of natural honey samples has been reported to be affected by temperature, moisture content and floral source. It was observed that at room temperature, the honey sample from Igbo-Etiti Local Government Area was more viscose than the rest of all the honey samples from other floral locations. This did not change even when the temperature was increased to 60 ℃. Therefore, Igbo-Etiti honey samples are good for long term storage.

Electrical conductivity: Electrical conductivity is directly related to the concentration of mineral salts, organic acids and proteins, and very useful in the determination of the floral origin (Acquarone et al., 2007). Igboeze North had the highest electrical conductivity values (16.5 µS/cm), while honey samples from Igboe-Etiti recorded the least electrical conductivity values (3.5 µS/cm). None of the analyzed honey types showed electrical conductivity values greater than 800 µS/cm. The electrical conductivity values ranged between 3.5 µS/cm – 25.5 µS/cm and that of Tygray in Table 4 ranged 8.25-33.50 µS/cm. The values suggesed that samples from Udenu, Igboeze-North and Igbo-Etiti were nectar honey, while that of Igboeze-North and Igboeze-South were honeydew. This measurement depends on the ash and acid content of honey; the higher their content, the higher the resulting electrical conductivity.

Sugar content: The international standard established by the Codex Alimentarius Commission (2001) required that a good quality honey should not contain more than 5 g/100 g sucrose. The mean sucrose contents of the honey samples studied were in the range of 1.037 to 1.785g/100g. The values obtained for sucrose content of all the honey samples from different floral locations were all within the limits of international standards.

Generally the sugar content of honey (fructose, sucrose and glucose) depends on the sugars present in the nectar and enzymes present in the honey bee. Table 1 showed that glucose were found to occur in the range of 31.361- 35.224g/100g. These results agreed with the Codex Alimentarius commission (2001) that the sum (glucose + fructose) should have a value greater than 60g/100g. All the honey samples conformed to that. The dominance of fructose over glucose (Table 1) is one way in which honey differs from commercial invert sugars. For honeys of good quality, the fructose content should exceed the glucose content.

Acidity: The acidity of honey may be explained by taking into account the presence of organic acids in equilibrium with their corresponding lactones, or internal esters, and some inorganic ions, such as phosphate (Gomes et al., 2010). The mean acidity value of the honey samples ranged from 0.343 – 0.700%, and that of Table 3 for US honey ranged from 0.17 - 1.17%. The value of acidity of honey samples from Enugu North senatorial zone were in conformity with those of international standards and they fall within the range of acceptability.

Ash content: The mineral content in honey is generally small and depends on nectar composition of predominant plants in their formation. The soil type in which the original nectar-bearing plant was located also influences the quantity of minerals present in the ash. As such, the variability in ash contents has been associated in a qualitative way with different botanical and geographical origins of honeys (Felsner et al., 2004). The determination of this parameter gives an insight of the honeys' quality, as the blossom honeys have lower ash content than the honeydew honeys (Andrade et al., 1999). Thus, by reference to the Codex Alimentarius (2001) Standards, honey samples from Igboeze-North and Igboeze-South analysed in this study correspond to honeydew honey since their ash contents fall within the values <0.6% while that of Nsukka, Igbo-Etiti and Udenu can be classified as nectar honeys. The ash content of this honey sample is not in line with that of Table 3 and it is not also in line with that of Table 4. Only that of Igbo-Etiti fell within the range of values reported in Table 3 for US honey samples.

Moisture content: Honey sample from Igboeze-North, Nsukka and Igboeze-South LGA were slightly higher than the limit indicated in Codex Alimentarus standard (2001). The implication is that the honey samples from these floral locations have the high moisture content and thus may be said to be of the lowest quality, and with the highest probability of encouraging yeast fermentation which may lead to increased in acidity. This may be attributed to the high relative humidity of these floral areas, the packaging material used or it was not fully ripped before it was harvested. Moisture content of honey samples from Igbo-Etiti and Udenu local government areas, the values were within the range reported by Codex Alimentarius (2001) for a good quality honey.

Table 3 Some selected composition of range of values of U.S honeys with those of Enugu North senatorial zone, Nigeria (ENSZN).

Component (% except pH)	Range (USA)	Range (ENSZN)
Water	13.4 - 22.9 (1.5)	16.59-22.56 (2.44)
Fructose	27.2 - 44.3 (2.1)	33.14-39.43 (2.56)
Glucose	22.0 - 40.7 (3.0)	30.62-35.22 (1.9)
Sucrose	0.2 - 7.6 (0.9)	1.04-1.79) (0.28)
Higher sugars	0.1 - 8.5 (1.0)	-
Free acids (as gluconic acid)	0.13 – 0.92 (0.16)	0.353-0.7 (0.15)
Total acid (as gluconic acid)	0.17 - 1.17 (0.2)	-
Ash	0.020 - 1.028 (0.15)	0.059-2.11 (0.89)
pH	3.42 - 6.10	4.7-5.1 (0.39)

Source: White et al. (1980)

Table 4 Some selected properties of Tigray honey (%), RSD in parenthesis in comparison with Enugu North senatorial zone, Nigeria (ENSZN).

No	Place and type of honey samples	pH	Electrical conductivity (µS/cm)	Moisture content (%)	Total ash (g ash/100 g honey)
1	Atsbi, white	4.088 (0.1)	25.50 (20)	18.60 (0.1)	0.169 (0.1)
2	Hawzene, white	3.820 (0.7)	8.270 (1.8)	18.60 (0.2)	0.078 (0.2)
3	Abiy Adi, yellow	4.450 (0.7)	33.50 (19)	18.80 (0.1)	0.152 (0.2)
4	Adigrat, white	3.952 (0.1)	24.40 (16)	18.60 (0.3)	0.111 (0.1)
5	Hagereselam, white	3.855 (0.1)	15.50 (10)	18.80 (0.1)	0.078 (0.3)
6	ENSZ (Range)	4.7-5.1 (0.39)	3.5-25.4 (8.76)	16.59-22.56(2.44)	0.059-2.11 (0.89)

Source: Kebede et al. (2012)

Density: The density of honey samples from Udenui and Igboeze-North has the same value of 1000 kg m^{-3}, which is equal to that of water. The density sample from Igboeze-South and Nsukka were above 1000 kg m^{-3}, while that of Igb0-Etiti was below 1000 kg m^{-3}

pH: The pH of the honey samples were in the range of (4.7 – 5.7). It showed that all the honey samples were acidic. It was observed that honey sample from Igboeze-South local government has the least pH (4.7) and that of Udenu local government has the highest value of pH (5.7) compared to other samples. The result was in line with pH analysis of honey from Umuahia by Olugbemi et al. (2013) which falls between 3.8-4.13. This also agreed with the values of pH for US honey (3.42-6.1) (Table 3) and Tigray honey (3.855-4.450) (Table 4).
Colour: Igboeze-South honey sample was classified as Amber, sample from Udenu was classified as Light Amber, Igbo-Etiti was classified as Amber, Igboeze-North was also classified as Amber and that of Nsukka was Extra White. This was based on colour classification in Table 5.From the analysis of variance (ANOVA), as shown in Table 6, Local Government Area had no significant effect on the physic-chemical properties of honey ($p \leq 0.05$). This may likely be due to the closed spatial distribution, similar weather and climatic conditions of the Enugu North floral location.

Table 5. Colour classification based on honey samples absorbance at 560nm.

Colour	P-fund scale	Absorbance @ 560nm
Water white	< 8	0.0945
Extra white	9 – 17	0.189
White	18 – 34	0.378
Extra light amber	35 – 50	0.595
Light amber	51 – 85	1.389
Amber	86 – 114	3.003
Dark amber	> 114	> 3.1

P-fund scale is a scale used in honey industry to describe the color of honey
Sources: Biochrom Partners in Science, USDA (1985)

Table 6. Analysis of variance (ANOVA) on the effect of Local Government Area on the physic-chemical properties of honey

Dependent Variable: Physicochemical properties (PCP)

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	667713.302	1	667713.302	428.209	.000
	Error	6237.258	4	1559.315a		
Type of PCP	Hypothesis	5015162.965	11	455923.906	144.579	.000
	Error	138752.632	44	3153.469b		
LGA	Hypothesis	6237.258	4	1559.315	.494	.740
	Error	138752.632	44	3153.469b		
Type of PCP * LGA	Hypothesis	138752.632	44	3153.469	.	.
	Error	.000	0	.c		

a. MS(LGA)
b. MS(Type of PCP * LGA)
c. MS(Error)

3.2 Thermal properties

It was observed that the thermal conductivity of honey samples ranged between 0.4358 – 0.4490 W $m^{-1}K^{-1}$. This was in close agreement with the value of 0.493W m^{-1} K^{-1} reported by Andre et al. (2012), and slightly above the value reported for Slovakian honey (Table 7).
Specific heat capacity of the honey samples ranges from 1.3024 – 1.6355 kJ kg^{-1} K^{-1}. This is in good agreement with the range of values reported for Slovakian honey (Table 7). Specific heat capacity is needed in situation requiring heat transfer during processing in other to avoid loss of quality.

Thermal diffusivity of this honey samples have higher values than that of water $0.143 \times 10^{-6} m^2 s^{-1}$ at 25 °C according to Wikipedia, (2016). This showed that this honey samples have low thermal diffusivity compared with water. From Table 7, thermal properties of Slovak mixed flower honey and forest honey) showed comparable results with honey samples from Enugu North senatorial zone. In like manner with that of physic-chemical properties of honey, analysis of variance (ANOVA) showed that Local Government Area (LGA) does not significantly affect thermal properties of honey ($p \leq 0.05$) (Table 8). This may likely be due to the afore mentioned reasons.

Table 7. Thermal properties of Slovak mixed flower honey and forest honey

Flower honey measurement	Thermal heat conductivity (W/m.K)	Thermal heat diffusivity (mm2/s)	Specific heat capacity (J/kg.K)
1st	0.337917	0.1167	1,895.35
Next	0.341472	0.1242	2,001.91
Forest honey measurement			
1st	0.347000	0.1166	1,899.44
Next	0.347889	0.1261	2,015.64

Source: Božikova and Hlavac (2013).

Table 8. Analysis of variance (ANOVA) on the effect of Local Government Area on the thermal properties of honey

Tests of Between-Subjects Effects

Dependent Variable: Thermal Properties (TP)

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	6.063	1	6.063	2.147	.280
	Error	5.649	2	2.824[a]		
LGA	Hypothesis	.022	4	.005	1.053	.438
	Error	.041	8	.005[b]		
TP	Hypothesis	5.649	2	2.824	547.476	.000
	Error	.041	8	.005[b]		
LGA * TP	Hypothesis	.041	8	.005	.	.
	Error	.000	0	.[c]		

a. MS(TP)

b. MS(LGA * TP)

c. MS(Error)

4. CONCLUSIONS

This study showed that honey samples from Nsukka North Senatorial zone have criteria to be classified as good quality honey, except in terms of moisture, in which only two samples from Udenu and Igbo-Etiti Local Government Areas, were in accordance with the Codex Alimentarius standard, while other three samples did not meet with the standard. All other physico-chemical parameter analyzed for honey from all floral locations within Enugu senatorial zone were all in accordance with the international standard. The thermal properties also met the quality standard of most honey reported in the literature. The observed results could be used for processing, product development and storage of honey and honey-based products, as well as quality assurance.

5. ACKNOWLEDGEMENT

Authors are thankful to the Department of Food Science and Technology and the Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka for providing facilities for the study.

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Performance optimization of a solar-powered evaporative cooling system

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ABSTRACT

Fruits and vegetables are important sources of digestible carbohydrates, minerals and vitamins A and C. For maximum usefulness and optimum nutritive value, fruits and vegetables are usually consumed when they are fresh and fully matured and harvested. The research work aimed to determine the optimum cooling conditions in a solar-powered evaporative cooling system for maximum preservation of fruits and vegetables. A three-factor, five levels Central composite rotatable design (CCRD) of response surface methodology (RSM) was employed to determine the optimal cooling condition with respect to the three main cooling parameters such as water flow rate), pad thickness and air velocity. The highest cooling efficiency of 80.8% was obtained at water flow rate of 2.5 L/min, pad thickness of 60 mm and air velocity of 1.7 m/s. The optimization of the cooling parameters produced optimum cooling efficiency of 81.05% with desirability of 98.3% from optimal cooling parameters of 2.33 L/min of water flow rate, 61.24 mm of pad thickness and 1.78 m/s of air velocity. The water flow rate and pad thickness had positive significant effects on the cooling efficiency while air velocity has insignificant effect. Cooling efficiency increase with both increased in water flow rate and pad thickness. The model showed that the value of coefficient of determination, R^2 (88.86%) was high and *p*-value of 0.0010 at $\alpha = 0.05$. Hence the model can be said to be of high significance and can adequately predict the cooling efficiency of solar-powered evaporative cooling system.

Keywords: Evaporative cooler, Response surface methodology (RSM), Optimization, Cooling parameters, Solar-powered, Cooling efficiency.

1. INTRODUCTION

The market for tropical fruits and vegetables has expanded beyond Asia, Hispanic and other ethnic communities around the world as individuals and organizations have become more interested in their personal health, as well as the potentials of vegetables to provide such health building nutrients (Barre *et al.*, 1992). Nigeria is the one hundred and fifty ninth largest producer of fruits and vegetables in the world (FAO, 2018). For this reason, international commerce in fruit and vegetables has so much expanded over the past few decades. Tones of produce are now shipped daily over long distances both within and across countries, and huge investments of resources are being channeled into transportation, storage and marketing to maintain a continuous supply of these perishable commodities (Anyasi1 *et al.*, 2016). This further stress the importance of fruit and vegetables in the economic and industrial development of developing countries, among which Nigeria is one.

The most abundant constituent of fruits and vegetables is water. In their fresh form most fruits and vegetables contain more than 80 percent water with some varieties such as cucumber, lettuce, and melons containing about 95 percent water (Olosunde *et al*., 2009). Some fruits and vegetable are susceptible to low temperature. These crops are injured after a period of exposure to chilling temperatures below 10–15^{0}C but above freezing point (Gross *et al*. 2002; Olosunde *et al*., 2015). Therefore, vegetables are generally classified as perishable crops. After harvest they shrivel, wither or rot away rapidly, particularly under hot tropical conditions. The damages that occur in these crops are caused primarily by loss of moisture, change in composition and pathological attack (Ndirika and Asota, 1994). Losses of fruits and vegetables occur everywhere from the field to the ultimate consumer and depend on the degree of perishability of the produce. Fresh fruits and vegetable deteriorate easily when stored under ambient condition, mainly due to physiological and microbial activities, which are accelerated at high temperature and low relative humidity of the storage environment. Adequate storage of fruits and vegetables prolongs their usefulness, checks market gluts, provides a wider selection of fruits and vegetables throughout the year and helps in orderly marketing and may increase the financial gain to the producer by reducing subsequent losses.

Evaporating cooling is an effective means of providing low air temperature and high relative humidity for cooling produce. An active evaporative cooling system consists of a pad (moist material), fan, storage cabin and water pump (Olosunde *et al.*, 2016). Apart from the general requirements for the efficient operation of an evaporative cooling system, the efficiency of an active evaporative cooler depends on the rate and amount of evaporation of water from the pad. This is dependent upon the air velocity through the pad, pad thickness and the degree of saturation of the pad, which is a function of the water flow rate wetting the pad and the material of construction of the pad (Ndukwu 2011; (Atanda *et al*., 2011; Olosunde *et al.*, 2016). Minimizing deteriorative reactions in fruits and vegetables enhances their shelf lives, implying that the produce will be available for longer periods; this would reduce fluctuation in market supply and prices. These are favourable indices for food companies that rely on steady supply for processing. There is also every possibility that availability of fruits and vegetables in all seasons at affordable prices would encourage the consumption of fruits and vegetables at the end user's level with a concomitant improvement in the nutritive status of the populace.

Several researchers have investigated the application of evaporative cooling system in extending the shelf life of fruits and vegetables. Onwude *et al.* (2018) studied the relationship between dimensionless moisture content and shrinkage of sweet potato in terms of volume, surface area, perimeter and illuminated area, they observed that the shrinkage of sweet potato based on computer vision and backscattered optical parameters is affected by the product thickness, drying temperature and drying time. In a related study, Cíntia *et al.* (2014) evaluate an evaporative cooling system using a water driven ejector, allowing it to be installed in places with plenty of water of evaporative cooling system. It was also observed that the pulse-like disturbance generated by replacing the cooling water at different periods of times did not result in significant affect vacuum destabilization and the temperature rise in the cooling tank. On the other hand, the effects of air velocity, pad thickness and degree of saturation have been studied by different authors. However, none of these studies considered the performance of solar-assisted evaporative cooling system. Therefore, the objective of this paper was to optimize the performance of a solar-powered evaporative cooling system for banana, tomato, mango and carrot and develop mathematical model to predict the efficiency of the cooling system.

2. MATERIALS AND METHODS

2.1 The Evaporative Cooler

The solar powered evaporative cooling system in this study is intended for small-scale commercial storage of perishable crops, such as mango, tomato, banana and carrots. The solar powered evaporative cooling system consists of a pad end, storage cabin, suction fan, solar panel, control panels, lead acid battery and water distribution components. The water distribution components include a water pump, pipes, overhead and collection tanks Olosunde *et al.*, (2015).

The pad is installed on one side of the cabin, and the suction fan on the other side opposite the pad end. An overhead tank is installed on the top of the cooler from which water drips on to the pad through a lateral pipe laid on top of the pad. There is a collection tank at the bottom of the cooler to collect excess water from the pad. The pump re-circulates the excess water back to the overhead tank. The solar panel powered the fan and the pump and at the same time charges the battery. The battery is used to power the fan and pump in the night when there is no sun light. Plate 1 shows pictorial view of the existing passive evaporative cooling system and solar powered evaporative cooling system.

Plate 1: Pictorial view of the solar photovoltaic powered evaporative cooling systems.

2.2 Features of the Cooler

2.2.1 Pad-end

The pad is held in position by a wooden framework and wire mesh, which covers both sides of the wooden framework. The wire mesh has rectangular large holes to allow for free passage of air to the pad. The framework is of five different thickness of 20, 40, 60, 80 and 100 mm and of size 110 mm x 1130 mm corresponding to one side of the storage cabin.

The framework is constructed with 5 mm thick plywood and the pad is held in between the plywood by nailing them together and by covering with wire mesh. The bottom of the framework is perforated to allow excess water from the pad to flow down to the bottom tank. The inside of the wooden framework is covered with high, density plastic material. This is to protect the plywood from moisture (Olosunde *et al.*, 2015).

2.2.2 Storage cabin

The main framework of the cabin is constructed with 50 x 50 mm thick, hardwood. The walls, roof and floor are constructed with 5mm plywood and insulated internally with 25.4 mm polystyrene materials. It is also covered internally with high, density plastic material to protect the wood from moisture. The outside is painted white to reduce heat absorption. The interior of the cabin is divided into three shelves by horizontal wire mesh. The shelves are of dimensions: 1130 x 600 mm and are reinforced at the edges with 50 mm softwood. The dimensions of the storage cabin are 1130 x 600 x 580 mm (Olosunde *et al.*, 2015).

2.2.3 Water re-circulation system

The water re-circulation system consists of a small direct current water pump, (80 watts with a discharge capacity of 6 L/min) and a maximum suction head of 1m and maximum distance of discharge of 5m), a bottom tank (510 mm x 530 mm x 200 mm), pipes and an overhead (510 x 530 x 200 mm). The system is designed to re-circulate the water by the pump, the water to be re-circulated is supplied to the bottom tank either manually or from the overhead tank. The pump delivers the water through a vertical pipe of diameter 19.2 mm into the overhead tank at a height of 1650 mm, which in turn delivers the water through the lateral pipe at pre-determined flow rate onto the pad. Figure 12 shows the closed loop of the panel that regulate the pump flow rate. The horizontal pipe is perforated with a 1mm, diameter hole through which the water drips onto the pad. Excess water that passes down the pad is collected by trough at the bottom of the pad and drains off into the bottom tank to be re-circulated back to the overhead tank again (Olosunde *et al.*, 2015).

2.2.4 Pad thickness

The pad thickness is one of the parameters, whose effect on the saturation efficiency of the cooler is to be investigated. Taye and Olorunisola (2011) suggested pad thickness of 25.4 mm to 50.8 mm of wood wool pad for an evaporative cooler. Five levels of 20, 40, 60, 80 and 100 mm of pad thickness were chosen for investigation in this study. The area of the pad was chosen in such a way that it covers one side of the storage chamber. This was to ensure uniform distribution of the cool and humid air from the wetted pad into the storage chamber to move over and cool the produce inside the storage chamber.

The choice of the material for the pad was based on the following: porosity of the material; water absorption/evaporation rate of the material; availability; cost; ease of construction (Dzivama, 2000).

Olosunde *et al*. (2009) carried out a study to test three materials (cotton waste, jute and hessian) to be used as pad in an active evaporative cooler. The results showed that the cooling efficiency is highest for jute. Based on the required quality of the pad material, jute material was used for this study.

2.3 Instrumentation

Instruments and various equipment were used to measure and monitor the dependent variables in the course of the research work.

2.3.1 Temperature and relative humidity measurement

Lascar Electronics temperature and RH USB data loggers were used for temperature and relative humidity measurement. Data logger type EL-USB-2 (LASCAR, England, UK) was used for the collection and storage of the temperature and relative humidity data. The data loggers were programmed to record the minimum temperature and maximum relative humidity for every 30 minutes. Data were retrieved from the logger via USB port, on to a Laptop computer (Olosunde *et al.*, 2015).

2.3.2 Air velocity measurement

The air velocity through the pad varies and differs at a point within the pad and was difficult to measure. However, the velocity of the air exiting from the pad, referred to as pad face velocity, was measured. The air velocity was measured by a Smart Sensor Digital Anemometer AR826 (Graigar, China) measuring to an accuracy of 0.3 m/s. The air velocity was measured by placing the air flow meter vane at the back of the cooler where the fan is located and then the value was read directly from the LCD.

2.3.3 Water flow rate measurement

The pump, which was used to circulate the water to the pad, has a regulator through which the rate of water flow to the pad was regulated. The rate of water flow to the pad was measured by collecting the amount of water flowing onto the pad for 30 seconds and then the average value was determined and calculated as the water flow rate in L/min.

2.4 Design of Experiment

Design Expert software (Version 11.0. 1, Stat-Ease Inc, Minneapolis, MN 55413, USA) was used in this study to design the testing and optimizing the performance of the solar-powered evaporative cooling system. The experimental design employed in this work was a five-level-three factor full factorial design. Central Composite Response Design and 20 (i.e. 8 + 2*3 + 6) test runs were performed for fresh banana, tomato, mango and carrot samples each. Water Flow Rate (WFR), Pad Thickness (PT) and Air Velocity (AV) were selected as independent factors for the optimization study. Five levels of water flow rate (0.5, 1.5, 2.5, 3.5 and 4.5 L/min), path thickness of (20, 40, 60, 80 and 100 mm) and air velocity of (0.7, 1.2, 1.7, 2.2 and 2.7 m/s) were chosen. The response chosen was the cooling efficiency. Six replications of centre points were used to predict a good estimation of errors and testing were performed in a randomized order. The actual and coded levels of each factor are shown in Tables 1 and 2. The coded values were designated by –2 (minimum), −1, 0 (centre), +1, +2 (maximum), −α and +α. Alpha is defined as a distance from the centre point which can be either inside or outside the range, with the maximum value of 2n/4, where n is the number of factors. It is noteworthy to point out that the software uses the concept of the coded values for the investigation of the significant terms, thus equation in coded values is used to study the effect of the variables on the response. The empirical equation is represented in equation (1) as:

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X^2{}_i + \sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta_{ij} X_i X_j \qquad (1)$$

Y = Response (Cooling Efficiency)

β_0 = Constant term

$\sum_{i=1}^{2} \beta_i$ = Summation of coefficient of linear terms

$\sum_{i=1}^{2} \beta_{ii}$ = Summation of quadratic terms

$\sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta_{ij}$ = summation of coefficient of interaction terms

$X_i X_j$ = independent variables

Table 1: Levels, codes and intervals of independent variables used for the experiment

Factors	Units	Codes	Levels					Interval of Variation
			-2	**-1**	**0**	**1**	**2**	
Water flow rate	L/mm	A_1	0.5	1.5	2.5	3.5	4.5	1.0
Pad thickness	mm	A_2	20	40	60	80	100	20
Air flow rate	m/s	A_3	0.7	1.2	1.7	2.2	2.7	0.5

2.5 Sample Preparation and Storage experiment

Fresh samples of banana, tomato, mango and carrot were procured from the market and washed clean to remove dirt and any other foreign materials. The experiment was conducted for each of the product at the optimum operating condition of the SPECSS established in the first experiment. Mango (20.6 kg), tomato (16.8 kg), banana (18.2 kg) and carrot (12.0 kg) were stored in the SPECSS chamber. On the first day of the experiment, one analysis was carried out for each of the quality factors to be assessed. Three samples were used for each quality assessment, and the experiments were done in three replicates. Subsequently analysis was carried out at three days intervals. Under this experiment too, the maximum shelf life of each of the produce stored in the cooler was established.

Data loggers were programmed to record temperature and relative humidity at 30 minutes intervals within the chamber until a steady condition was reached. This indicated the temperature depression and maximum humidification achieved by the SPECSS.

2.6 Performance Criteria

The performance efficiency of the cooler for the storage of banana, tomato, mango and carrot were evaluated. These crops were selected because of their perishability after harvest. Quality assessments of the produce stored inside the cooler were determined. Some quality parameters for effective storage were used to assess the effect of the storage environment on the crops. The fruits and vegetables were analyzed for their chemical changes based on the AOAC (2012) methods. The quality assessment tests that were carried out include changes in: physiological weight, total titratable acids, redox potential, total soluble solids and firmness.

2.7 Determination of Effect of Water Flow Rate, Pad Thickness and Air Velocity on the Saturation Efficiency of the Solar Powered Evaporative Cooler.

The basic format of the experiment involved an interaction study of the effects of the three parameters on the saturation efficiency of the cooler. These parameters are combined in a split-split plot experiment. Five levels of Water Flow Rate (WFR), Pad Thickness (PT) and Air Velocity AV were used. Split-split plot design is uniquely suited for a three-factor experiment. It can therefore be applied to this experiment, where three variables were investigated. In this experiment, the three variables were divided as follows. The pad thickness was considered as the main plot and had five levels, which were tested randomly. It was therefore referred to as the main plot. Five levels of water flow rate and five levels of air velocity were assigned and tested randomly against the five levels of pad thickness. They were therefore considered as the subplot and sub-subplot, respectively. Three two-way combinations (e.g., PT vs. WFR, PT vs. AV and WFR vs. AV) and one three-way combination were considered in this study. The experimental layout is presented in Table 2 and carried out in three replicates.

Selection of the variable and their levels was influenced on ranges suggested by various researchers. Xuan *et al.*, (2012), and Umbarker *et al.* (1991) have recommended pad face velocities for various pad materials like celdek, fluted paper pads and cement coated pads as 1.25 to 1.7 m/s for pad thickness ranging from 50 mm to 100 mm.

2.8 Statistical Analysis

Analysis of variance was carried out as described by Gomez and Gomez (1983). Analysis of variance (ANOVA) is one of the principal statistical research tools in many scientific disciplines, which provides a summary of complex patterns of data in a convenient tabular form. The analysis of variance is specifically chosen in this study to examine the variation in the results of the performance efficiency of the cooler obtained under experimental variables and their interactions. Statistical software (SPSS version 17.0, IBM Corporation, USA) with split-split plot program was used for analysis on a personal computer. The Duncan multiple range test (DMRT) and Tukey HSD were used for the comparison test. They are more appropriate for the test of experimental variables with many levels.

3. RESULTS AND DISCUSSION

3.1 Interactive effect of pad thickness and water flow rate on performance efficiency

The average summary of the efficiency results at the various cooling conditions combinations is presented in Table 2.

Table 2: Tests result of cooling efficiencies at various interactions of the cooling conditions

Run	Coded and Actual factors			Response
	Water flow rate (L/min)	**Pad thickness (mm)**	**Air flow rate (m/s)**	**Efficiency (%)**
1	0(2.5)	0(60)	-2(0.7)	65.0
2	-1(1.5)	-1(40)	-1(1.2)	69.2
3	1(3.5)	-1(40)	-1(1.2)	65.0
4	-1(1.5)	1(80)	-1(1.2)	75.0
5	1(3.5)	1(80)	-1(1.2)	66.7
6	0(2.5)	-2(20)	0(1.7)	47.5
7	-2(0.5)	0(60)	0(1.7)	58.3
8	0(2.5)	0(60)	0(1.7)	80.8
9	0(2.5)	0(60)	0(1.7)	80.6
10	0(2.5)	0(60)	0(1.7)	80.7
11	0(2.5)	0(60)	0(1.7)	80.8
12	0(2.5)	0(60)	0(1.7)	80.6
13	0(2.5)	0(60)	0(1.7)	80.5
14	2(4.5)	0(60)	0(1.7)	62.5
15	0(2.5)	2(100)	0(1.7)	50.8
16	-1(1.5)	-1(40)	1(2.2)	68.3
17	1(3.5)	-1(40)	1(2.2)	56.7
18	-1(1.5)	1(80)	1(2.2)	70.8
19	1(3.5)	1(80)	1(2.2)	58.3
20	0(2.5)	0(60)	2(2.7)	74.2

From the result of the interactive effect of pad thickness and water flow rate presented in Table 2, there is a significant effect of the interaction between Pad thickness (PT) and Water flow rate (WR) on efficiency considered as an independent variable. In this case they are all significant $p = 0.00$ ($p < 0.05$), so we can conclude that pad thickness and water flow rate did have a significant effect on the independent parameter. Since p-value = 0.00< 0.05 we reject the null hypothesis. Therefore, at the 0.05 significance level, there is enough evidence to conclude that level of pad thickness and water flow rate have a significant interaction effect on mean value of the efficiency.
The effect of the interaction between pad thickness and water flow rate on the performance efficiency of the solar-powered cooling is presented in Figure 1. The result shows that saturation efficiency increases as the pad thickness is increased from 20 to 40 mm and increased more significantly when the pad thickness is increased to 60 mm for all levels of water flow rate. The saturation efficiency reduces as the pad thickness is increased to 80 mm and reduced further when the pad thickness is increased to 100 mm. The reduction in the saturation efficiency is more pronounced for the pad thickness of 20 mm follow by pad thickness of 100 mm. The result at pad thickness of 40 and 80 mm also show an initial significant increase with increase in the water flow rate from 0.5 to 1.5 l/min. There is a general reduction in saturation efficiency when the water flow rate is increased above level 2(1.5 l/min) for all levels of pad thickness.

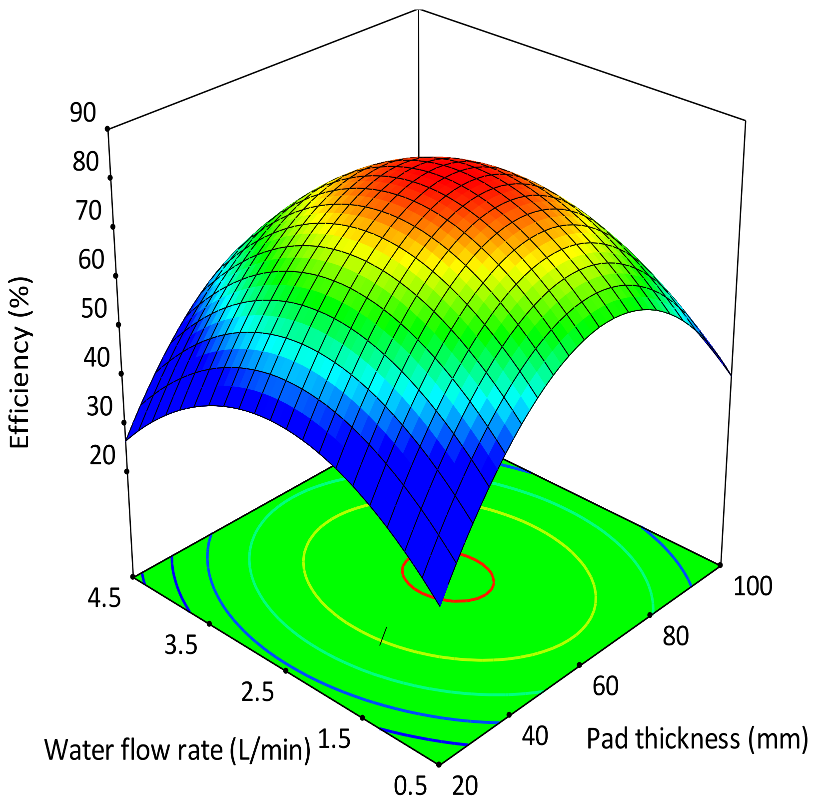

Figure 1: Effect of pad thickness and water flow rate on performance efficiency

The low performance efficiency of the cooler obtained at the low water flow rate (0.5 l/min) could be attributed to the fact that, at low level of water flow rate, the water could only partially wet the pad. This left some dry spots on the pad surface and within the pad which reduces the surface area for air-water contact and the amount of water evaporated from the pad and hence the efficiency of the cooling system. When the water flow rate is increased to 1.5 l/min, the pad becomes sufficiently wet and this increases the wet surface area for air-water contact, and more water is evaporated from the pad and result in higher efficiency of the cooling system. However, at very high-water flow rate of 4.5 l/min and especially at low pad thickness of 20 mm, the efficiency declines. This is due to the fact that, at this flow rate, the pad is excessively wet with excess water that block the pore spaces within the jute pad obstructing the free flow of air through the pad to effect enough evaporation. This could explain the high reduction in the performance efficiency at the pad thickness of 20 mm than those at 40 mm, 60 mm, 80 mm and 100 mm. Although the water flow rate is high, the pad thickness of 40 mm, 60 mm, 80 mm and 100 mm are thick enough to absorb the excess water. This result is in agreement with reports by Khater (2014) and Prajapati (2016) on optimization of cooling pads for evaporative cooling system and approach to analysis and optimization of evaporative cooling system.

3.2 Interactive effect of pad thickness and air velocity on performance efficiency

From the result of the interactive effect of pad thickness and water flow rate is presented in Table 2, there is a significant effect of the interaction between Pad thickness (PT) and Air velocity (AV) on efficiency considered as an independent variable. In this case they are all significant $p = 0.00$ ($p < 0.05$), so we can conclude that pad thickness and water flow rate did have a significant effect on the independent parameter. Since p-value = 0.00< 0.05 we reject the null hypothesis. Therefore, at the 0.05 significance level, there is enough evidence to conclude that level of pad thickness and water flow rate have a significant interaction effect on mean value of the efficiency.

The effect of the interaction between pad thickness and air velocity on the saturation efficiency of the cooler is presented in Figure 2. The result shows that at air velocity of 0.7, 1.2, and 1.7 m/s, the saturation efficiency increases positively with increase in the pad thickness from 20 mm to 60mm. It declines when pad thickness is further increased to 100 mm and the decline is more marginal at air velocity of 2.2 and 2.7 m/s.

However, at pad thickness 20 mm and 100mm there is a slight decline at air velocity 1.7 m/s. The interactive effect of pad thickness and air velocity on the mean temperature and relative humidity is presented in Figure 25 and 26 respectively. The results follow the same pattern, the combination of pad thickness level 3 and air velocity level 3 gives lowest mean temperature and highest mean relative humidity, respectively.

The low saturation of the cooling system at pad thickness 20 mm and air velocity 2.7 m/s could be due to the pad thickness is small, and this reduces the residence time within the pad to effect good evaporation couple with the high velocity that tend to pull water droplets out of the pad. As PT is to 60 mm, the distance the air has to travel through the pad and also the surface area for the evaporation of water would increase, and as a result the saturation efficiency of the system increase. Also low air velocity cannot effect good evaporation from the pad because of its low turbulence. However, the highest efficiency recorded at 60 mm and 1.7 m/s could be due to the combined effect of increase in residence time for air-water contact to effect good evaporation and the turbulence created by the high velocity. This is in tandem with earlier reports by Khater (2014) and Prajapati (2016) on optimization of cooling pads for evaporative cooling system and approach to analysis and optimization of evaporative cooling system.

3.3 Effect of water flow rate and air velocity on performance efficiency

From the result of the interactive effect of pad thickness and water flow rate is presented in Table 2, there is a significant effect of the interaction between Water flow rate (WR) and air velocity (AR) on efficiency considered as an independent variable. In this case they are all significant $p = 0.037$ ($p < 0.05$), so we can conclude that pad thickness and water flow rate did have a significant effect on the independent parameter. Since p-value = 0.037 < 0.05 we reject the null hypothesis. Therefore, at the 0.05 significance level, there is enough evidence to conclude that level of pad thickness and water flow rate have a significant interaction effect on mean value of the efficiency.

The effect of the interaction between water flow rate and air velocity on the performance efficiency of the cooler is presented in Figure 3. The result shows that at water flow rate of 0.5, 1.5, 2.5, 3.5 and 4.5 l/min and air velocity of 0.7, 1.2, 1.7, 2.2 and 2.7 m/s, the increase in performance efficiency of the evaporative cooler is high initially and then remains either constant or declines with increase in air velocity.
The result at water flow rate of 0.5 and 3.5 l/min also shows high initial increase with increase in the air velocity from 0.7 to 1.2 m/s. It then remains constant as the velocity is increased to 1.7 m/s and then declines with further increase in the air velocity to 2.7 m/s.

The initial high rate of increase in the performance efficiency of the evaporative cooler with increase in the air velocity could be due to the turbulence flow developed at high air velocity. Air moving at low velocity is not turbulent and could only evaporate the water on its path; this reduces the amount of water evaporated. The flow becomes turbulent as the air velocity is increased, this increases the area of air-water contact and hence, the amount of water that could be evaporated. The low performance efficiency of the cooler obtained at the low water flow rate (0.5 l/min) could be attributed to the fact that, at low level of water flow rate, the water could only partially wet the pad. This left some dry spots on the pad surface and within the pad which reduces the surface area for air-water contact and the amount of water evaporated from the pad and hence the efficiency of the cooling system. When the water flow rate is increased to 1.5 l/min, the pad becomes sufficiently wet and this increases the wet surface area for air-water contact, and more water is evaporated from the pad and result in higher efficiency of the cooling system. However, at very high water flow rate (4.5 l/min) and especially at low air velocity (0.7 m/s), the efficiency declines. This is due to the fact that, at this flow rate, the pad is excessively wet with excess water that block the pore spaces within the jute pad obstructing the free flow of air through the pad to effect enough evaporation. This could explain the high reduction in the performance efficiency at the air velocity of 0.7 m/s than those at 1.2 m/s, 1.7 m/s, 2.2 m/s and 2.7 m/s. At water flow rate of 0.5 and 3.5 l/min and air velocity of 1.2 and 1.7 m/s, the efficiency remain constant, this could be as a result of the combined effects of water flow rate and air velocity.

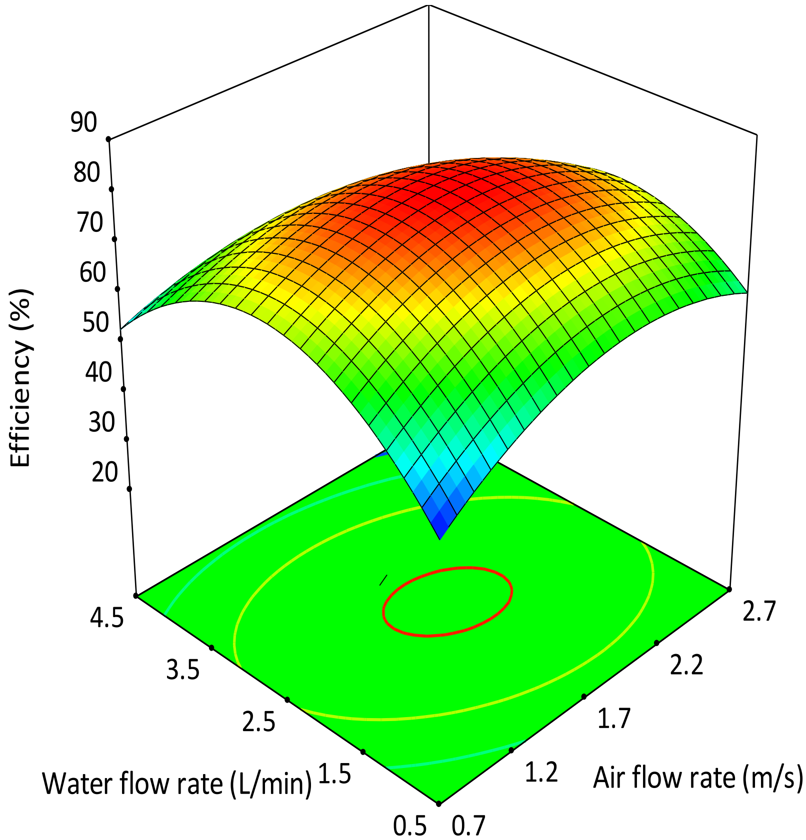

Figure 3: Effect of air flow rate and water flow rate on performance efficiency

3.4 Optimization of the Performance Efficiency and Validation of the Models

The optimization of the operating condition for the cooling performance of the solar-powered evaporative cooling system was successfully conducted in duplicate at laboratory experiments. Table 2 presents the experimental design of full factorial model of central composite rotatable design (CCRD) with the correspondent response (performance or cooling efficiency). Based on the results from the multiple regression analysis of the experimental data, a second order polynomial equation was obtained as outlined in equation (3) as follows:

$$Y = -70.13 + 29.79W_{fr} + 2.541P_t + 45.40A_{fr} - 0.031W_{fr}P_t - 2.90W_{fr}A_{fr} - 0.043P_tA_{fr} - 4.95{W_{fr}}^2 - 0.019{P_t}^2 - 10.60{A_{fr}}^2 \quad (11)$$

Where:

Y = Cooling Efficiency, %

W_{fr} = Water flow rate, L/min

P_t = Pad thickness, mm

A_{fr} = Air flow rate, m/s

The regression coefficients and corresponding *p*-values for the model are presented in Table 3, indicating that the model was highly significant because of its very low *p*-value (p = 0.0010). The confidence level of *A* (p = 0089), *B* (p = 0.0028), *AC* (p = 0.0200), *BC* (p = 0.0103), A^2 (p = 0.0005), B^2 ($p < 0.0001$) and C^2 (p = 0.0214) were above 95% ($p < 0.05$), suggesting that the model terms *A*, *B*, *C*, *AC*, *BC*, A^2, B^2, and C^2 had significant effects on the response *Y* (cooling efficiency)(Table 3). Specifically, linear terms of *A*, *B*, and *C* interactive terms *AC*, *BC*, and quadratic terms of A^2, B^2, and C^2 had a significant effect on the cooling or performance efficiency, whereas the effects of the term *AB* was not significant. The fit of the model was checked by the coefficient of determination (R^2) and the adjusted coefficient of determination (Adj-R^2).

In this study, it was found that the value of the coefficient of determination, R^2 was 88.86%, indicating that 88.86% of the cooling variation of the evaporative cooling system is attributed to the factors (water flow rate, pad thickness and air flow rate) and only 11.14% could occur due to chance. The Adj-R^2 value is a modification of R^2 based on the number of variables used in the model, which was 78.83%, indicating that the regression equation fitted the data very well. The *p*-value of 'lack-of-fit' was 0.1841 (>0.05), implying that the 'lack-of-fit' was not significantly relative to the pure error and the model was fairly stable. All these findings indicated that the models were useful in predicting the cooling performance efficiency.

Table 3: ANOVA for response surface quadratic model.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1896.08	9	210.68	8.86	0.0010
A	49.70	1	49.70	2.09	0.0089
B	20.70	1	20.70	0.8706	0.0028
C	0.7225	1	0.7225	0.0304	0.0451
AB	3.12	1	3.12	0.1314	0.7245
AC	16.82	1	16.82	0.7073	0.0200
BC	1.44	1	1.44	0.0608	0.0103
A^2	615.78	1	615.78	25.89	0.0005
B^2	1514.57	1	1514.57	63.69	< 0.0001
C^2	176.41	1	176.41	7.42	0.0214
Residual	237.81	10	23.78		
Lack of Fit	237.73	5	47.55	3241.84	0.1841
Pure Error	0.0733	5	0.0147		
Cor Total	2133.89	19			

Note: Statistically significant at 95% of confidence level ($p < 0.05$) (*); A = Water flow rate; B = Pad thickness; C = Air flow rate

The optimization of the evaporative cooling system functional parameters; water flow rate, pad thickness and air flow rate was carried out using numerical technique in RSM (response surface methodology) with the goal of maximizing the cooling performance efficiency. The ramp of the optimization process is shown in Figure 4, with optimum values of 2.33 L/min of water flow rate, pad thickness of 61.24 mm and air flow rate of 1.78 m/s. On the other hand the cooling performance efficiency and desirability of 81.05% and 0.983 respectively were also obtained.

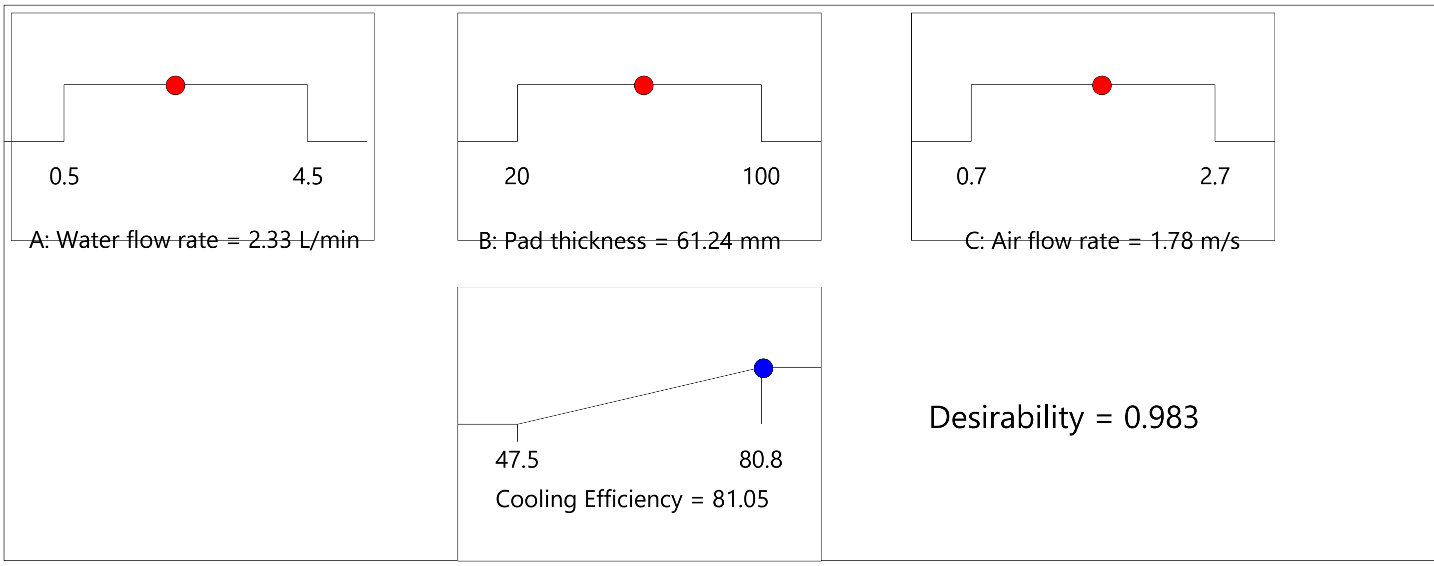

Figure 4: Ramp for optimization of cooling performance parameters

From the optimal cooling parameters of the evaporative cooler (Figure 4), giving the optimum cooling efficiency of 81.05%. This result could be explained by the fact that at pad thickness of 61.24 mm and water flow rate of 2.33 L/min, the pad was sufficiently moist, but without an excessive flow of water to block the pore spaces within the pad, for the air movement. In addition, at air velocity of 1.78 m/s, the flow is turbulent enough and mixes well as it travels in all directions through the pad. This increases the area of air water contact and hence, the amount of water that could be evaporated, thus an increase in the cooling efficiency. The 81.05% cooling performance efficiency obtained in the evaporative cooler, in Ibadan with an average ambient condition of 33^{o}C and 44% temperature and relative humidity respectively is considered efficient.

3.5 Validation of model

The cooling performance was optimized with the design expert to obtain optimal cooling conditions. The agreement between the experimental and predicted values for the cooling efficiency from the solar-powered evaporative cooler was obtained from the parity plot between the predicted and the experimental values as shown in Figure 5. For validation purposes, a test run under the obtained optimal cooling conditions was carried out in order to evaluate the precision of the quadratic model; Comparing the experimental and predicted results for cooling performance of the solar-powered evaporative cooling system, it was established that the error between the experimental and predicted is less than 0.5%, therefore it can be concluded that the generated model has sufficient accuracy to predict the cooling performance of the solar-powered evaporative cooling system.

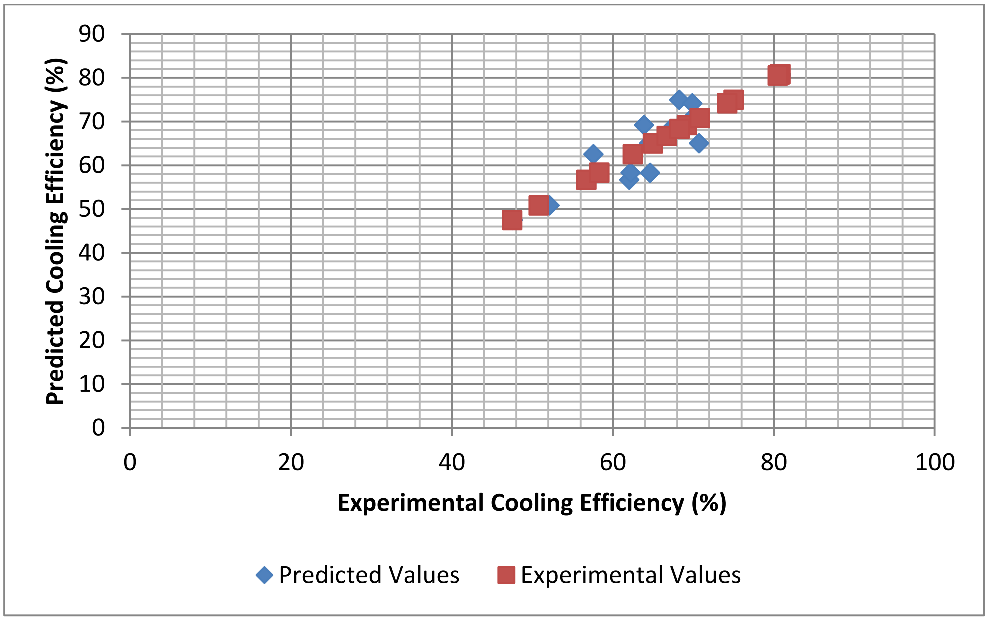

Figure 5: Predicted and actual values for cooling performance efficiency of the solar-powered evaporative cooling system

3. CONCLUSIONS

In this study, a-3 factor experiment was performed to optimize the cooling performance of the solar-powered evaporative cooling system. The individual and interactive roles of the three factors (water flow rate, pad thickness and air flow rate) were investigated by RSM. The maximal predicted value of the cooling efficiency was 81.05% and a mean value of 68.61% was achieved in the experiment under optimal cooling conditions, which was in a close agreement with the model prediction. This study provided useful information on how to improve the cooling performance efficiency by optimizing the cooling conditions by using statistical methods.

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The proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Growth Performance Characteristics of Okra (*Hibiscus esculentus*) using Improvised Drip Irrigation System

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ABSTRACT

Okra is a common and popular vegetable crop used in Nigeria. Irrigation method has very significant influence on okra (Hibiscus esculentus) production. A careful effect of marginal water quality on IDI and control system which were subjected to the same conditions was investigated. An experimental field area of 13.5 m^2 by 6.0 m^2 was properly cleared, stumped, ploughed, harrowed and levelled. High yielding and disease resistant okra variety seeds were carefully selected and planted at a regular interval of 0.6 m. The results of statistical analysis obtained using Completely Randomised Blocked Design (CRBD) ($P < 0.05$) revealed that there were significant differences on water application which reflected an increase in some agronomic parameters such as growth, weight, yield and vegetative development of the okra. These selected okra agronomic parameters showed that the okra performed in IDI. Maximum fruit yield of 71.71% and water utilization efficiency of 55.49% was obtained by using IDI system.

Keywords: Okra, irrigation, drip, and marginal water quantity, Nigeria.

1. INTRODUCTION

Okra (*Hibiscus esculentus*) is indigenous crop which grows throughout the tropics and in some part of the sub-tropic (Modupe 2015). The plant tropically grows to 180cm in height, but some indigenous varieties may grow to 360cm tall, with base stem of 6cm in diameter. The plant produces dark yellow flower that are about 5cm in diameter. The plant is cultivated in tropical, sub-tropical and warm temperate region around the world. (Okunade *et al*., 2009). In Nigeria, it is among the foremost vegetable crops in term of consumption and production (Puneet and Arun, 2015). Okra is a hot weather crop with optimum soil temperature of 75^{o}F to 90^{o}F. It is tolerant to wide variation in rainfall (Kamran *et al.*, 2012). It will grow well on all types of soil but best performance is obtained on sandy loam soil with high organic matter content and optimum soil pH ranging from 6.0 to 7.0 (Sexena *et al*., 2013).Okra is propagated by seed; 2-3 seeds are sown at 1-2cm depth per hole with 60cm – 90cm inter row spacing and 30cm along the rows.

Irrigation is the artificial application of water to the soil for the purpose of supplying the essential moisture for plant growth to eliminate moisture deficiency at various stage of plant growth (Michael, 2000). Irrigation is necessary to provide enough water to fill the deficit arising from the depletion of soil moisture from combine action exist between two separate phenomena of evaporation and transpiration (Fasina, 2008). Ahmad *et al.,* (2003) reported that the total amount of water that is used each year is utilized for the purpose of irrigation. Water management by irrigation practices are t complement the available water from natural sources such as rainfall, flood, dew and ground water. Therefore, irrigation is needed in most parts of West Africa where there may be a prolonged drought period and mostly where water from natural sources is inadequate for effective crop germination and production. The available lands in the tropical regions need irrigation to improve economic returns from production of crops by more than 100%. (Modupe *et al.,* 2015).

Drip irrigation is the method whereby water is supplied to crop root zone at regulated rate and fertilizer application can be done. It is very importance to carry out a study on the best irrigation system for the production of okra in Nigeria in order to maximize profit and reduce the cost of production. The main concern of productive agriculture is the effective and efficient supply of water and growing demand for crop production. It includes remunerative cropping which needs a systematic study of irrigation problem and method of efficient economic use of water since irrigation potential created and it utilization, and that makes the situation more serious. On the other hand, when it is limited as compound to available water, the aim would be to maximize production per unit of land without watching water. Under irrigated condition, it is usually not possible to grow more than one crop in a year and the yield from a rain-fed crop may hardly be between 1-2 tonnes of food per hectare in dry areas. But irrigation makes it possible to grow more than one crop in a year. Puneet and Arun (2015).

Metin *et al*., (2006) reported that timely irrigation leads to high yield multiple cropping under irrigation farming which assure high crop production. High yield varieties have a high water requirement than ordinary varieties; the potential of Okra varieties can be fully exploited if adequate amount of water is made available. Irrigation is necessary for vegetable (okra) production in Nigeria in order to make the crop available throughout the year.

2. MATERIALS AND METHODS

2.1 Study area and land clearing

Field experiments were located at Teaching and Research Farm of Agricultural and Bio-Environmental Engineering Department, School of Engineering Technology, The Federal Polytechnic, Ado Ekiti, Ekiti State, Nigeria. It is located between Longitude $4^0\ 5^1$ and $5^0\ 45^1$ East of the Greenwch Meridian and Latitudes $7^0\ 5^1$ and $8^0\ 5^1$ north of the Equator. It lies South of Kwara and Kogi State, East of Kwara and bounded by Ondo State in the East and in the Kogi State. The plot has a flat topography and the area was chosen for its suitable soil structure, texture, water retention capacity, loamy fertile soil, nearness to water source (well) and availability of power supply to operate the electric water pump. Land preparation involved the use of tractor for ploughing and harrowing to make it suitable for undisturbed, unobstructed free flow of water and good crop management.

2.2 Experimental design and Installation layout

The consumptive water use of okra under Improvised Drip Irrigation system were measured and recorded. These agronomic data collected were analysed using Completely Randomized

Block Design (CRBD) ANOVA method. Total experimental plot of 13.5 m^2 by 6.0 m^2 was used. In drip irrigation system, the two drums 100 litres was placed on the raised platform that serve as water reservoir, the main pipe, lateral (PVC) were measured and cut into different sizes with measuring tape and hacksaw respectively. The pipe was connected to the reservoir with a valve, the screen filter was attached, and then a quick coupling elbow was used in the coupling of the main line of the length 450 m. The lateral line of 210 m was fixed on the main line at equal interval from each other.
Typical okra farm planted in row and freshly harvested okra in Plates 1a and 1b below, respectively, and the Installation layout of Improvised Drip Irrigation System in Plate 2

Plate 1a: Typical okra farm planted in a row

Plate 1b: Typical okra freshly fruits

Plate 2: Installation Layout of the IDI system

2.3 Irrigation Design

The purpose of irrigation layout is to transmit information from engineering plans to the irrigation field. This will locate the work and provide such lines and elevations as needed for the development of Improvised Drip Irrigation system. Pictorial details of IDI layout. (Plate 3).

Plate 3: Improvised Drip Irrigation system layout

2.4 Planting of okra and data collection

2.4.1 Planting of okra

Before planting of the seeds, the irrigation system was tested by pre-irrigation in order to locate and correct any high or low spots which can lead to uneven water supply to the plants. The okra seeds were planted at 0.02 m depth with 0.6 m interval, the weeding was carried out manually on the experimental plot of land. The same treatments and analysis were carried out on the Improvised Drip Irrigation system and control at the same time on the same day to avoid predisposition of the results. The pesticide and NPK fertilizer were applied to control the diseases and increase the quality and quantity of okra yields.

2.4.2 Data collection

The moisture content and soil temperature were measured by means of moisture meter and soil thermometers, respectively from the day of planting to the maturity. The agronomic parameters, height, girth, number of leaves, okra yield, and flowers stage were measured and recorded: using digital weighing balance (± 0.01g). Kamran *et al., (*2012).

3. RESULTS AND DISCUSSION

Table 1 showed that the plant height (cm) for the readings after 5, 10, 15, 20, 25, 30, 35 and 40 days showed that there was a significant difference in IDI when compared to control system. The mean plant height after 40 days under IDI and control system were 151.68 and 63.32 cm, respectively Choudhary *et al.,* (2012) (Figure 1). the results obtained for height of okra against DAP and statistical analysis proved that there is significant difference in the methods used with respect to the height of okra for IDI and control (Okunade *et al,* 2009; Choudhary *et al.,* 2012). The mean plant diameter under IDI after 99 days 328.79 and 99.45 cm respectively.

From figure 2 results indicated that there is no significant difference in IDI used with respect to the Stem girth of okra against DAP in control system. (Babar *et al.,* 2008). The increase stem girth (cm) under IDI and control system for the eight reading after 5, 10, 15, 20, 25, 30, 35 and 40 days showed that there was a significant difference in IDI in comparison to control system.(Table 1). The mean plant stem girth after 40 days under IDI and control system were 2.696 and 2.289 cm, respectively as indicated in results by (Metin *et al*., 2006) in the studies of growth of okra fruits.

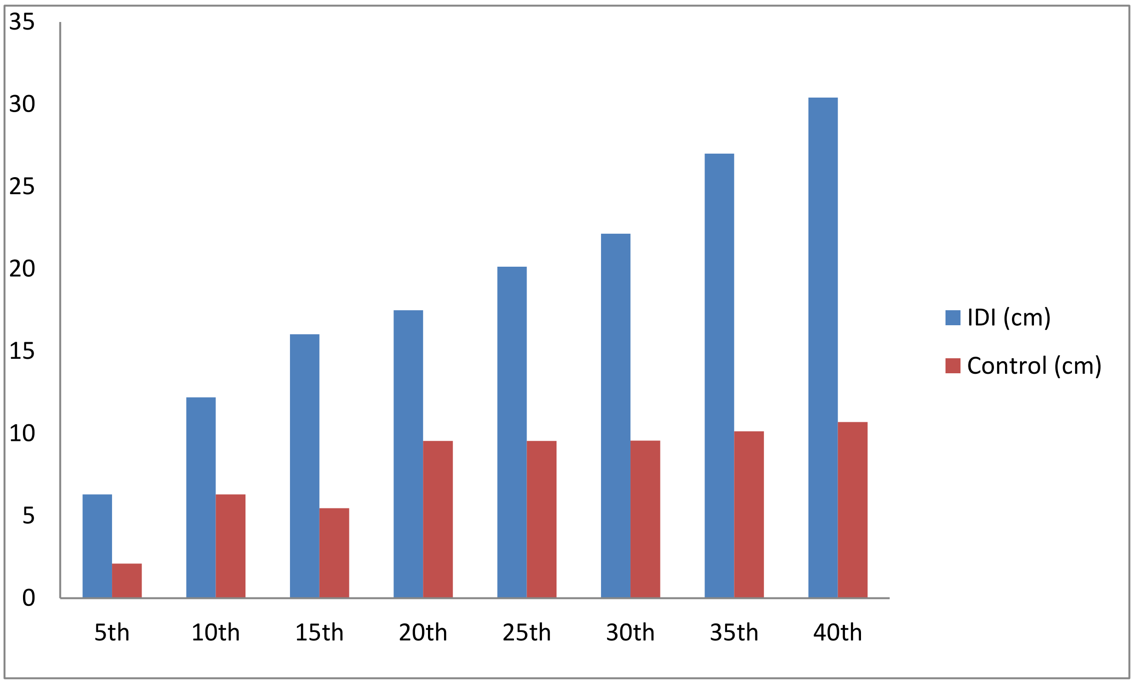
Figure 3 results showed a linear relationship in IDI when compared to control between number of leave against DAP from the results obtained there is significant differences at 0.05 percent. (Pravukalyan *et al., 2011;* Al-Harbi *et al.*, 2008). The number of leaves (cm) under IDI and control system for the eight reading after 5, 10, 15, 20, 25, 30, 35 and 40 days showed that there was a significant difference in IDI compare to control system. The mean plant height after 40 days under IDI and control system was 936 and 598 cm, respectively as indicated in results by (Alkaff, 2003) in the studies of growth of okra fruits. Therefore, this result show that as the plant growth increased inline plant height and stem diameter as contributed to the conserved soil moisture, seedling emergence, and improved plant growth. (Okunade *et al.*, 2009).

Figure 4, the results of yield for the eight days after planting showed a significant difference in DAP 5, 10, 15. 20, and 25 days among the irrigation system. However, there were no significant in 30, 35, and 40 days from plant growth under IDI as indicated by (Sexena *et al*., 2013). The mean okra yield performance after 40 days under IDI and control system was 3470 and 292 cm, respectively (Table 1). Based on the results in Figure 4, the analysis carried out proved that there is significant difference in IDI used with respect to the number of okra yield against DAP in control. Therefore, the number of Okra increase based on the amount of rainfall. (Jayapiratha, *et al.,* 2010).

From figure 5 displayed the relationship between the weights of okra against day after harvest, the relationship is linear and there is significant difference in IDI respect of control systems (Danso *et al.,* 2015). The weight of okra production against days after planting (cm) for the eight reading after 5, 10, 15, 20, 25, 30, 35 and 40 days showed that there was a significant difference in IDI compare to control system Ahmad *et al., (*2013). The summation of weight of production after 40 days of planting under IDI and control system were 45.61 and 10.60 kg, respectively (Puneet *et al.,* 2015). Thus growth is not faster under the control system because no treatment was added. This system and results is in line with findings of Ahmad *et al*., (2013).

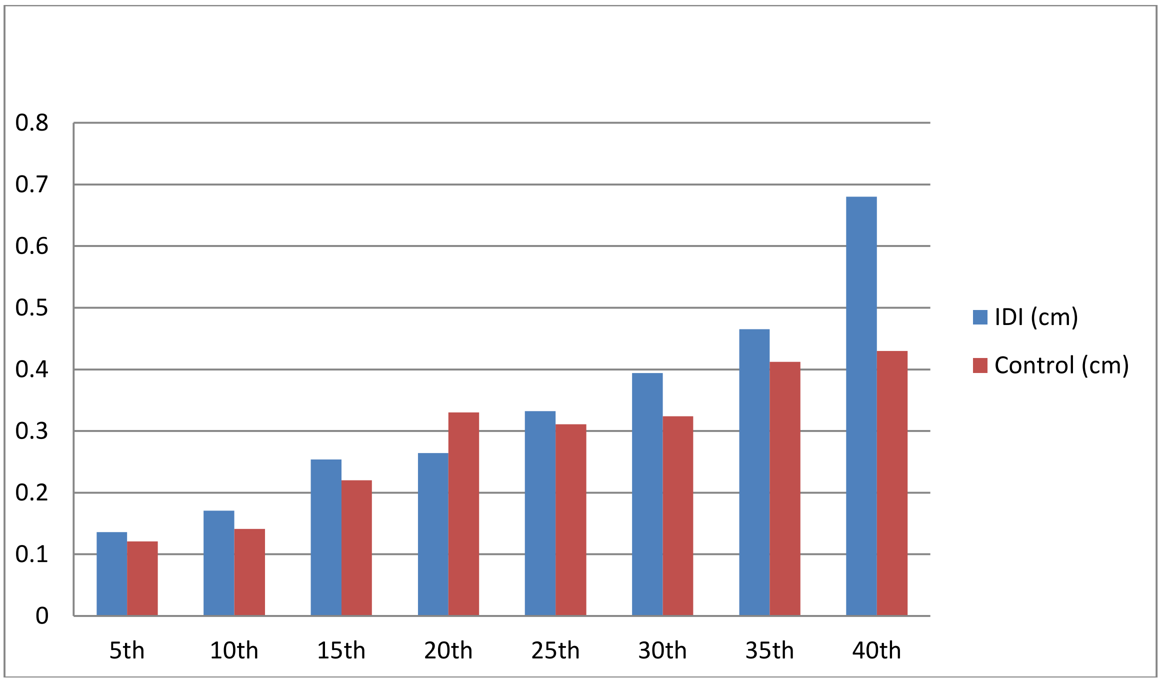
Table 1: Growth performance under Improvised Drip Irrigation system (IDI).

	Weight of Okra (kg)		Height of Okra (cm)		Stem girth (cm)		Number of leaves (cm)		Okra yield (cm)	
DAP	IDI	Control	IDI	Control	IDI	Control	IDI	Control	IDI	Control
5th	6.30	2.10	0.136	0.121	34	15	34	0	1.07	0
10th	12.20	6.30	0.171	0.141	50	30	344	0	5.07	0.84
15th	16.03	5.45	0.254	0.222	68	44	519	30	5.14	1.40
20th	17.49	9.54	0.264	0.330	101	99	415	37	5.20	1.20
25th	20.13	9.55	0.332	0.311	115	99	393	44	6.96	2.72
30th	22.13	9.56	0.394	0.324	201	101	650	72	6.18	1.72
35th	27.00	10.12	0.465	0.412	231	104	528	62	5.55	1.84
40th	30.40	10.70	0.680	0.430	251	106	587	47	10.45	0.88



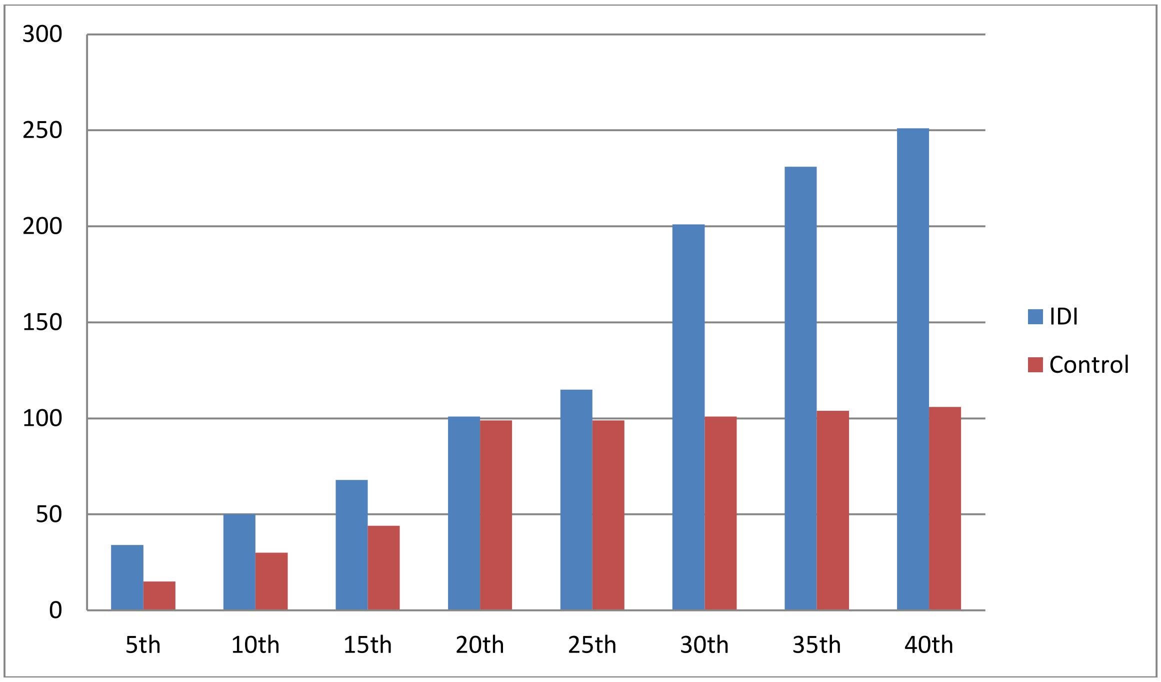
Okra varieties (DAP)

Figure 1: Height of Okra production (cm) against Day after Planting



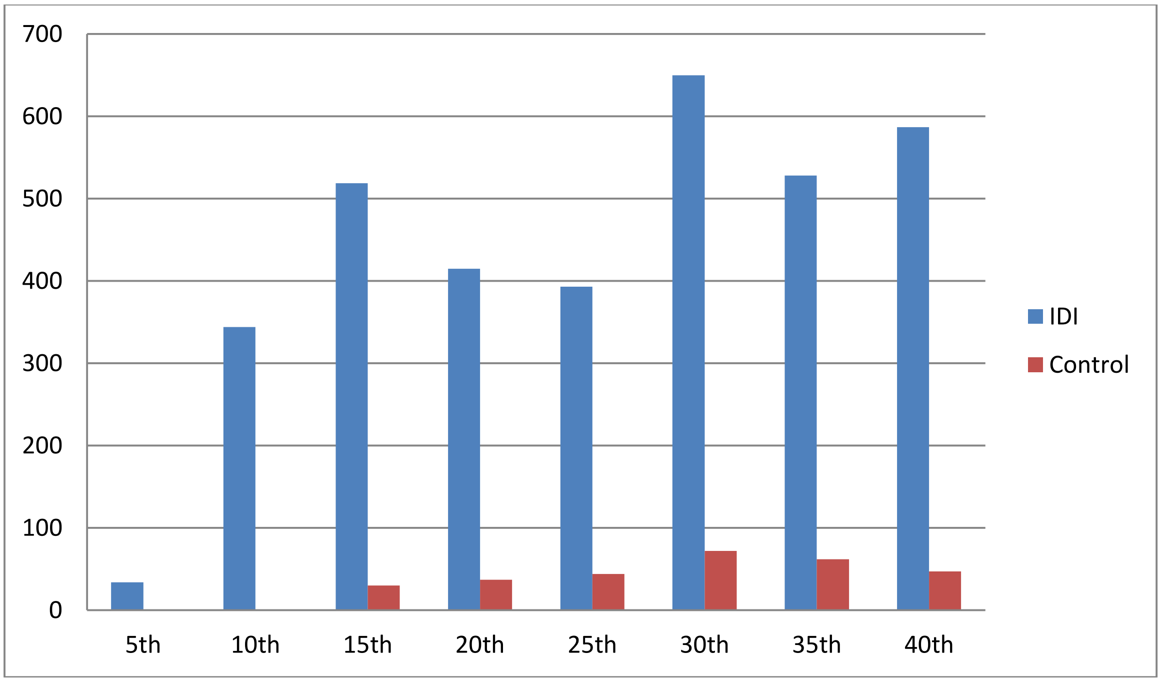
Okra varieties (DAP)

Fig. 2: Stem girth of Okra (cm) against Days after Planting (DAP)



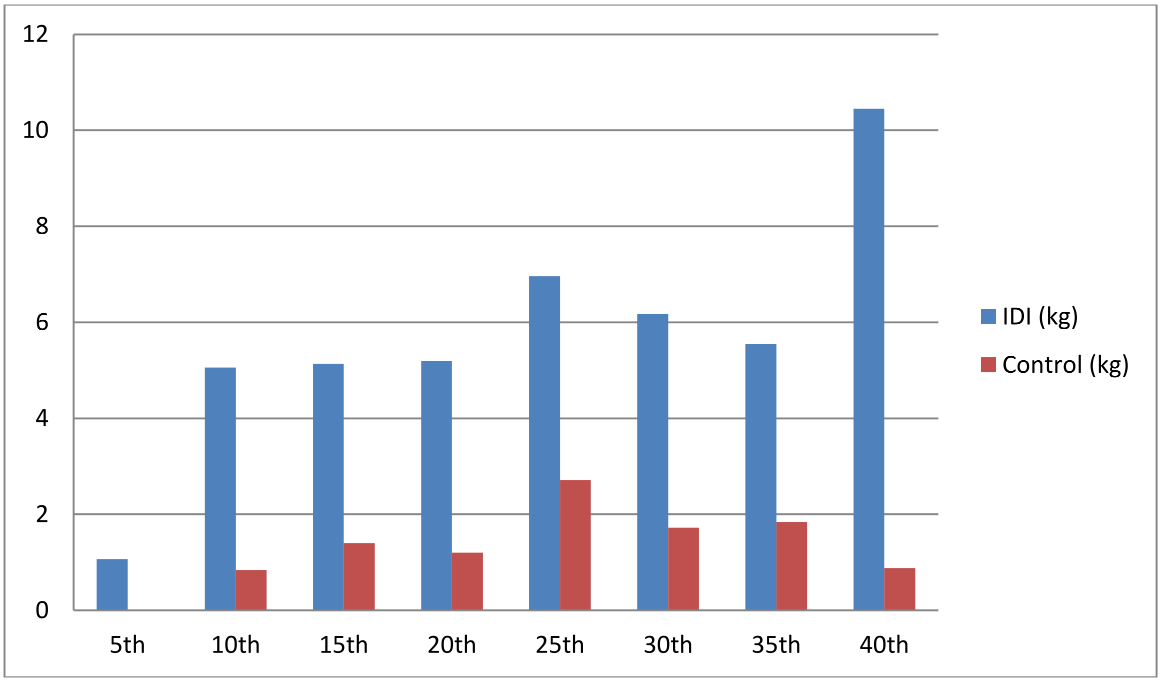
Okra varieties (DAP)

Fig. 3: Number of leaves (cm) against Days after Planting (DAP).



Okra varieties (DAP)

Fig. 4: Number of Okra yield performance (cm) against Days after Planting (DAP)



Okra varieties (DAP)

Fig. 5: Weight of Okra production (kg) against Days after Planting (DAP)

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The growth performance characteristic of Okra on improvised drip irrigation system was investigated, this leads to minimized of water usage, fertilizers, land utilization and increased fruit yields as well as production of okra calls for an effective irrigation system. Growth occurs through the effect of soil types and watering treatments had no significant different on its. Therefore, okra may not require much water for maximum growth germination at the initial stage.

4.2 Recommendation

Based on the results obtained from the study, Improvised Drip Irrigation system (IDI) is highly recommended for the effective cultivation of okra seeds and the amount of water required to irrigate is low compared to other irrigation systems.

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Effects of Soil Moisture Stress on Growth and Yield of Okra (*Abelmoschus Esculentus*) Under Drip Irrigation

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ABSTRACT

The growth and yield responses of okra (*Abemoscus esculentus*) to water stress under four water regimes of 100%, 80%, 60% and 40% field capacity were examined under drip irrigation for two varieties of okra; Clemson's spineless variety and B35 variety at Federal College of Agricultural Research Farm Ibadan. A Latin Square Design was used for the test plot of 10m by 6m ($60m^2$). The water requirements of Clemson's spineless and B35 varieties were determined from field capacity of the soil. Tensiometer and soil moisture meter were used to determine the amount of moisture present in the soil. Irrigation was applied at an interval of three days, and the analysis of variance at a level of significance of 5 % indicated significant differences in yield with level of irrigation, and also with growth.
Results indicated that, moisture stress had significant influence on growth and yield components of okra. Numbers of leaves, plant height, stem girth, and yield were affected by water deficit. For Clemson's spineless, the yield followed in the order; 100%FC (2.04t/ha) > 80%FC (1.44t/ha) > 60%FC (1.31t/ha) > 40FC% (1.0t/ha). For B35 variety, the yield followed in the order; 100%FC (1.77t/ha) > 80%FC (1.35t/ha) > 60%FC (1.13t/ha) > 40%FC (0.99t/ha). The variation observed in the yield of the two might be due to their different degree of tolerance to drought level. The results of the study could be useful in designing effective water scheduling for irrigation system for okra production.

Keywords: Okra, Drip, Irrigation, Tensiometer, Field capacity, Moisture stress.

1. INTRODUCTION

Okra *(Abelmoschus esculentum L)* is an annual herb and vegetable crop grown throughout the tropical and subtropical parts of the world either as the sole crop or intercroped with maize or another (Emuh *et al.,* 2006). The nutritional importance of okra pod has reawakened interest in bringing the crop into commercial production. The fruits are used in making soup, salad and for flavor when dried and in powdered form. The tender fruits contain minerals especially calcium, magnesium, iron and phosphorus; protein, vitamin A and C including riboflavin as well as high mucilage (Ndaeyo *et al.,* 2005). Mature okra seeds are good sources of protein and oil (Oyelade *et al*., 2003). Its ripe fruit and stems contain crude fiber, which is used in the paper industry. Despite the nutritional value of okra, its optimum yields (2-3 t /ha) and quality have not been attained in the tropical countries partly because of a continued decline in soil fertility and soil moisture (Pettigrew, 2004).

Water deficits and insufficient water are the main limiting factors affecting worldwide crop production (Nuruddin, 2001). Plants growing under suboptimal water levels are associated with slow growth and, in severe cases, dieback of stems; such plants are more susceptible to disease and less tolerant of insect feeding (Wilson, 2009). In crops, water stress has been associated with reduced yields and possible crop failure. The effects of water stress however vary between plant species. As the plant undergoes water stress, the water pressure inside the leaves decreases and the plant wilts. The main consequence of moisture stress is decreased growth and development caused by reduced photosynthesis, a process in which plants combine water, carbon dioxide and light to make carbohydrates for energy. Water deficit inhibits photosynthesis by causing stomata closure and metabolic damage. Stomata of the leaves that are slightly deficient in water opened more slowly in light and close more quickly in the dark (Nuruddin, 2001). Soil moisture stress reduces leaf water potential which in turn may reduce transpiration (Shibairo *et al.,* 1998). Kirnak *et al*. (2001) have found that water stress results in significant decreases in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress have less fruit yield and quality.

Okra plants need a controlled supply of water throughout the growing period for optimal quality and higher yield. Drip irrigation with its ability of small and frequent water applications have created interest in view of decreased water requirements, possible increased production, and better product quality (Connor *et al.,*1981; Mohammed *et al.,*2006). Edoga and Edoga (2006) also reported that with drip irrigation, the soil is maintained continuously in a condition which is highly favorable to the crop growth. Controlled irrigation is essential for high yields because the crop is sensitive to both over and under irrigation (Al-Harbi *et al.,* 2008). Therefore, this research can be designed to investigate the possible impacts of soil moisture stress using drip irrigation on the growth and yield of Okra.

2. MATERIALS AND METHOD

2.1 Experimental Design

This experiment was conducted at the Agricultural Research farm of the Federal College of Agriculture, Moor Plantation, Ibadan. The experimental site is located between 7.365° N and 3.859° E with an altitude of 400meters above sea level. The experiment was conducted on sandy- loam soil having a pH of 5.99. The average annual maximum and minimum temperatures are 36.70^{o}C and 22.3^{o}C, respectively.

Two varieties of okra were used as planting materials. These were Clemson's spineless and B35 varieties. These varieties were collected from the Institute of Agricultural Research and Training (IAR&T). The cultivar has been used by farmers in the region and it takes 45-60 days to mature under field condition.

The experimental field was laid in a latin square block design. Four moisture levels of 100%FC, 80%FC, 60%FC and 40%FC (Field Capacity) irrigation were applied**.** The treatments were replicated twice for the two varieties. The 100%FC was used as control. A simple drip irrigation technology was adopted for the experiment. Each water regime has two rows. Drip laterals were laid out at 1.0m spacing between the rows. The drippers/emitters were placed at 0.75m apart along the lateral line with a discharge capacity of 4.0 l/hr each.
The gross plot size of the experimental field was measured to be 10m by 6m (60m^{2}). Each bed was placed at 1m apart. The soil was ploughed and the beds were constructed. For sowing, three seeds were planted per hole with a spacing of 0.75m.

2.2 Field Capacity Determination

The field capacity of the soil was determined using the core method (Mbah, 2012). A 100 cm^3 soil cores were used to take sample from the plot. The sample was wetted to saturation and leave to dry for 24hours. The weight of the wetted core was measured. The sample was oven dried to a constant weight at 105°C (ASTM, 1987). The field capacity was calculated as follows:

$$F.C = \frac{W_{WC} - W_{OS}}{W_{OS} - W_C} \times Bulk\ density \qquad \ldots\ldots\ldots\ldots\ldots.. (1)$$

Where: W_{wc} = Weight of wetted core after 24hrs

W_{OS} = Weight of oven dry sample

W_C = Weight of core sampler.

The planting was carried out on 8th of November, 2016. For sowing, three seeds were planted per hole with a depth of 3cm and a spacing of 75cm. The number of stands per bed was 8. Weeding was carried out weekly which was done with bare hand by uprooting the weeds.

2.3 Irrigation Scheduling

The goal of irrigation scheduling was to make the most efficient use of water and energy by applying the right amount of water to cropland at the right time and in the right place. Proper irrigation scheduling requires a sound basis for making irrigation decisions. Methods of irrigation scheduling are based on soil water measurements, meteorological data or monitoring plant stress. Tensiometers measure the soil water tension that can be related to the soil water content. The tensiometer gauge reads the tension between soil and water particles. Soil moisture tension increases when there is less water in the soil. As a result, the tensiometer gauge reads high for dry soils and low for wet soils.

For most soil types, readings under 10 cbars indicate a wet soil, and above 50 cbars indicate a dry soil (Fabura and Nkakini 2015). The following steps were considered when determining a watering schedule for a drip irrigation system

1. Determination of the crop Root zone Depth (RD)
2. Determination of the soil type
3. Determination of the Available soil Water Storage Capacity (AWSC) or Field Capacity(FC)
4. Determination of the Total Available Water Storage Capacity (TAWSC)

   TAWSC = Rooting depth x AWSC
5. Determination of 80% FC, 60%FC and 40%FC respectively,

80% FC of moisture depletion = Total AWSC x 80%

60% FC of moisture depletion = Total AWSC x 60%

40% FC of moisture depletion = Total AWSC x 40%

Once the percentage depletion of moisture content was noticed through the use of soil moisture meter and tensiometer for each regime, the amount of missing water was replaced by drip irrigation

2.4 Water Use Efficiency

Irrigation Water Use Efficiency (WUE) can be defined as the increase in production per unit increase in Evapo-Transpiration (ET) due to irrigation (Ogedengbe, 2015). This is expressed as shown in equation 2.

$$WUE_i = \frac{Y_i - Y_d}{W_{si} - W_{sc}} \qquad (2)$$

Where

Y_i = Yield due to irrigation
Y_c= Contol yield
w_{si}= Water supplied to the irrigation regime
w_{sc}= Water supplied to the control
The total amount of water supplied (irrigation and effective rainfall) to each crop on each regime was computed, the differences between the values of water supplied to each irrigated regimes and the control regime was calculated. Also, the average total yield (okra yield, stem yield and leaf yield) of each of the two okra varieties planted on each regime was computed and the differences between the values of total yield of each irrigated regimes and the control regime was calculated.

2.5 Data Collection

Seedling emergence:
The number of seedlings that emerged per treatment was obtained through daily counts of shoots showing above the soil surface at 5-14 days after planting (DAP).

Plant height:
Plant height was determined by measuring the height of the plant. A 30-cm ruler was used to take measurements from the soil surface to the topmost stretched leaf of each plant. Measurements were taken every week, starting from nine (DAP).

Stem diameter:
A vernier caliper was used to measure seedling diameter at 5-cm height above the soil. Measurements of stem diameter started when all plants from the different treatments had grown above 5-cm height.

Number of leaves
This was done by physical counting of leaves on a plant. Growth parameters mentioned above are monitored and recorded on weekly basis after first two weeks of emergence.

Yield
Five plants were randomly selected from the middle area of each replicate of the treatments in order to eliminate border effects. The fruits from these plants were harvested manually in five pickings at two day intervals. These fruits were weighed and the yield was determined.

Data Analysis
Data obtained were subjected to statistical analysis using Analysis of Variance (ANOVA) to determine if the treatments have any significant effect on parameters measured at 5% confidence level.

3. RESULTS AND DISCUSSION

3.1 Soil Sample Analysis

The results of the soil physical analysis showed that the textural class of the soil used for the experiment was sandyloam, with a pH that indicates that it is acidic. The soil is low in almost all the essential nutrients. Apart from exchangeable Ca and Mg, all the other essential elements such as total N, available P, exchangeable K and Na are below the critical levels recommended for crop production. The soil moisture content is also low, thus resulting in low available water.

Table 1: Soil Test Analysis

Parameters	Values
pH(H_2O)	5.99
% of Sand	47.52
% of Clay	13.56
% of Silt	38.92
Textural class	Sandy-loam
B.Density g/cm^3	1.57
Ca (cmol/kg)	2.04
Mg (cmol/kg)	1.34
CEC (cmol/kg)	4.51
H+	0.11
Average P (ppm)	14.95
Total Nitrogen %	0.15
Organic carbon %	1.86
Organic matter %	3.20
Electrical conductivity	138.80

3.2 Plant Height of Clemson's Spineless and B35 Varieties

Height of clemson's spineless and B35 okra varieties planted on the four water regimes (100, 80, 60, and 40%FC regime) were being recorded on weekly basis, the result is represented in Figure 1 and 2. The figure shows that there is a uniform increase in height of clemsom's spineless okra planted on all the four regimes until 42 DAP after which there was an increase in the rate at which the heights were increasing. 60%FC produced the highest plant height value of 45cm and 40cm at 70 DAP respectively, 100%FC have the second highest value of 42cm and 37cm at 70 DAP respectively, 40%FC have the third highest value of 35cm and 30cm at 70 DAP respectively, and 80%FC produces the least plant height at 32cm and 35cm. The increase in Clemson's variety plant height with days of planting was in line with Puneet *et al.*, (2016) who reported that plant height increases with time. The result obtained below shows that the variations on the effects of soil moisture stress was insignificant on the plant height.

Comparing the plant height of the two varieties, 100%FC of Clemson spineless gives 42cm while B35 variety gives 37cm, 80%FC of Clemson spineless gives 32cm while B35 variety gives 35cm, 60%FC of Clemson spineless gives 45cm while B35 variety gives 40cm, 40%FC of Clemson spineless gives 35cm while B35 variety gives 30cm.

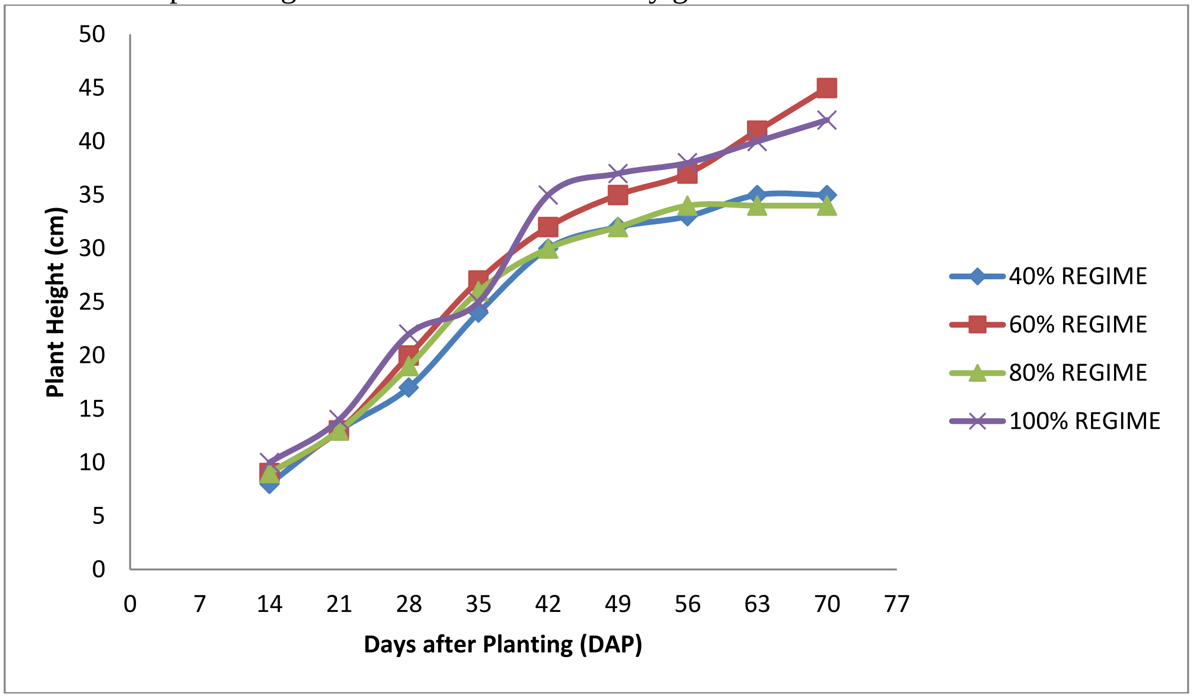

Figure 1: Changes in Heights of Clemson's spineless Variety with Days After Planting (DAP)

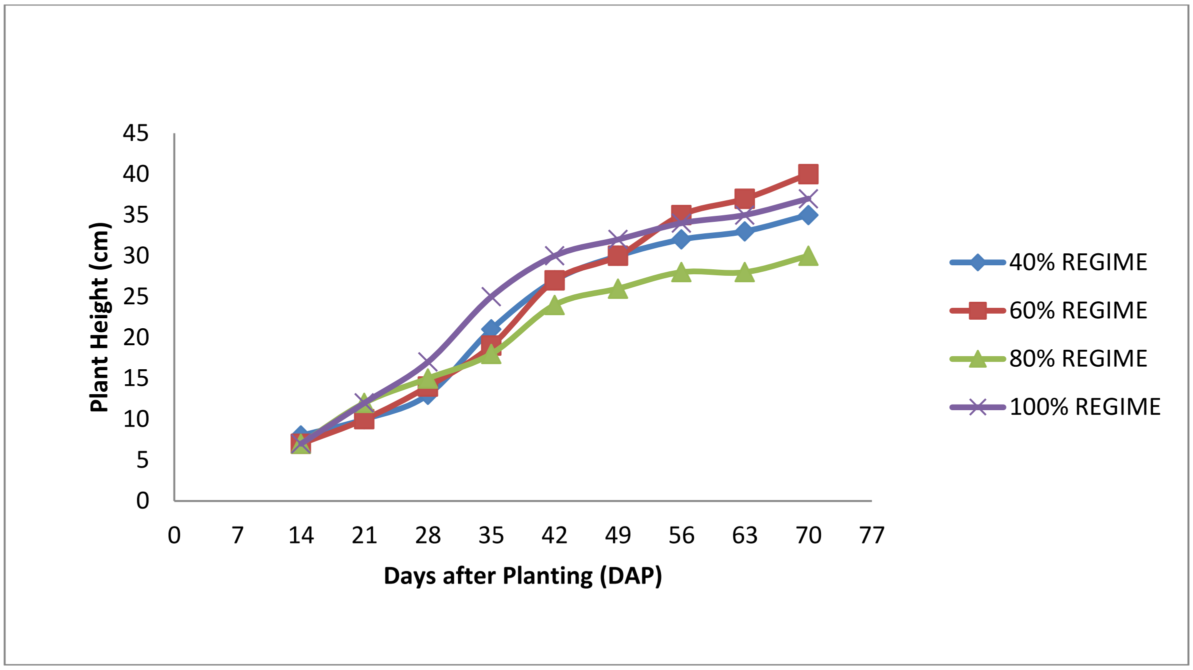

Figure 2: Changes in Heights of B35 Variety with Days After Planting (DAP)

3.3 Stem Girth of Clemson's Spineless Variety

The stem girth of Clemson's spineless okra planted on the four water regimes (100, 80, 60, and 40%FC regime) were recorded on weekly basis, the result is represented in Figure 3.The figure shows that there was a uniform increase in stem girth of clemsom's spineless okra planted on all the four regimes until week 7 after which there was an increase in the rate at which the stem girth were increasing. 60%FC produced the highest stem girth value of 12.12mm at 70 DAP, 100%FC produced the second highest value of 10.12mm at 70 DAP, 80%FC produced the third highest value of 8.23mm at 70 DAP, followed by 40%FC which produced the least value of 7.84mm.

3.4 Stem Girth of B35 Variety

The stem girth of B35 okra planted on the four water regimes (100, 80, 60, and 40%FC regime) were recorded on weekly basis, the result is represented in Figure 4. The figure shows that there was a uniform increase in stem girth of B35 okra planted on all the four regimes until week 6 after which there was an increase in the rate at which the stem girth were increasing. 80%FC produced the highest stem girth value of 8.78mm at 70 DAP, 100%FC produced the second highest value of 8.61mm at 70 DAP, 60%FC gave the third highest value of 8.43mm at 70 DAP, followed by 40%FC which produced the least stem girth of 8.01mm.
Comparing the stem girth of the two varieties, 100%FC of Clemson's spineless gives 10.12mm while B35 variety gives 8.61mm, 80%FC of Clemson's spineless gives 8.23mm while B35 variety gives 8.78mm, 60%FC of Clemson's spineless gives 12.12mm while B35 variety gives 8.43mm, 40%FC of Clemson's spineless gives 7.84mm while B35 variety gives 8.01mm. Hence Clemson spineless produces greater value in stem girth in all the regimes except in 80%FC.

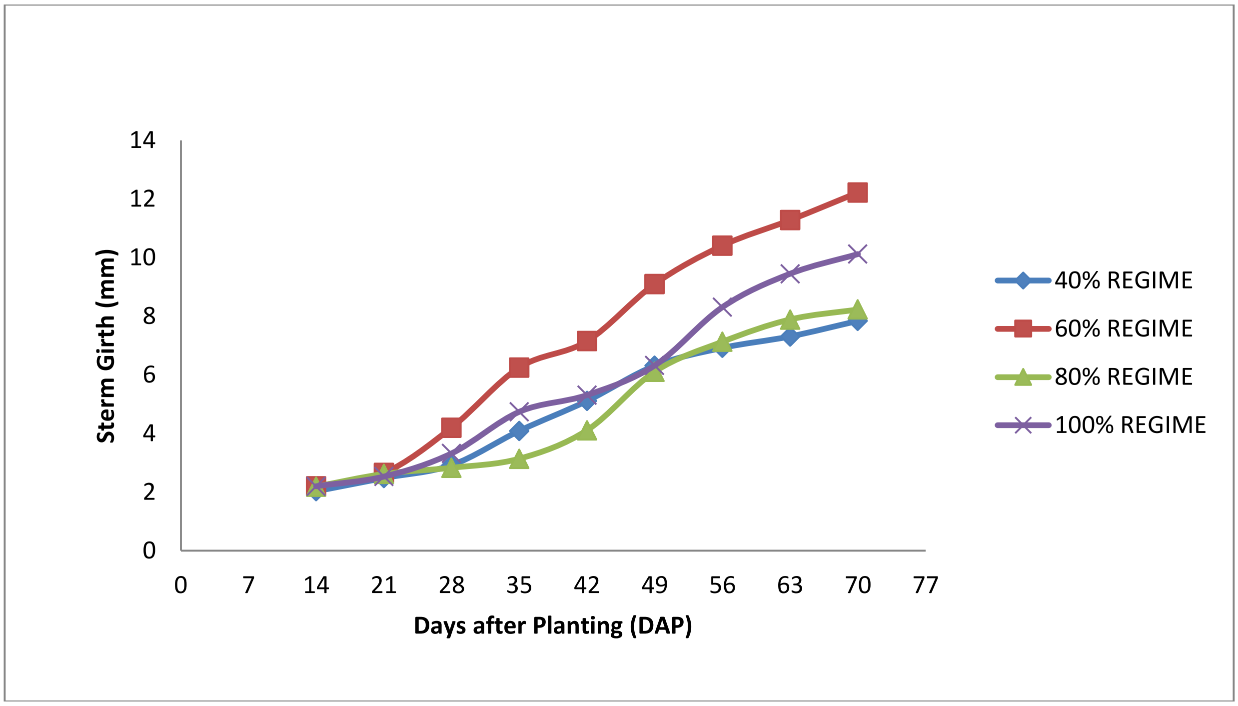

Figure 3: Changes in Stem Girth of Clemson’s spineless Variety with Days After Planting (DAP)

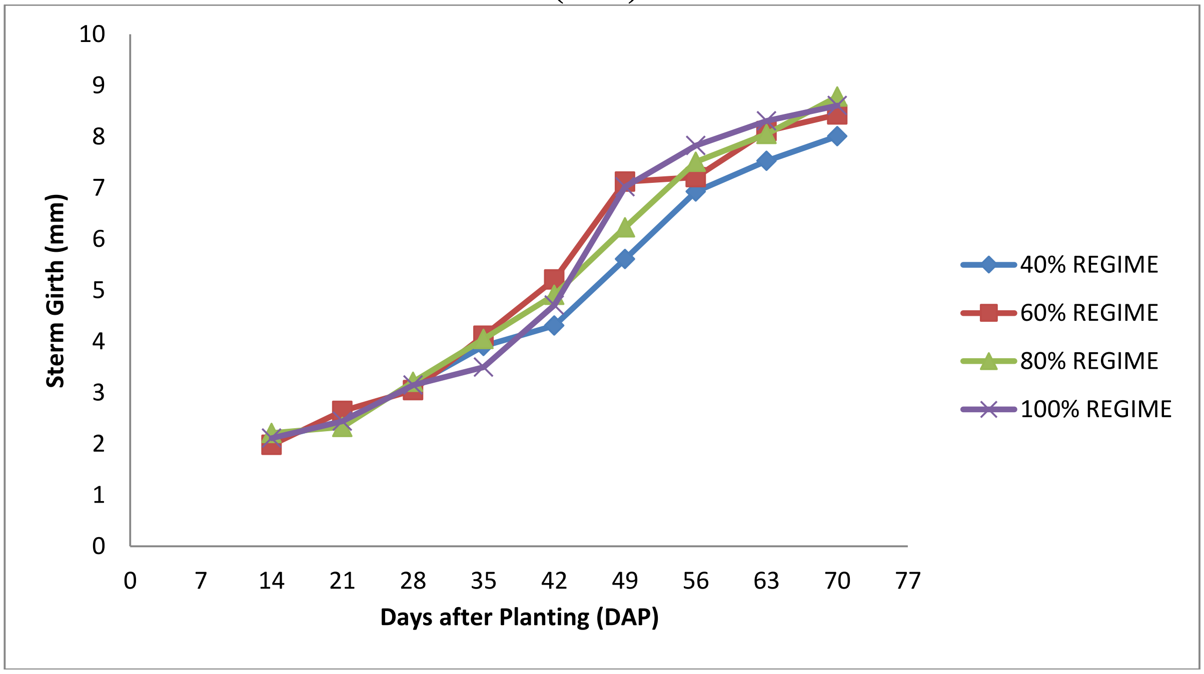

Figure 4: Changes in Stem Girth of B35 Variety with Days After Planting (DAP)

3.5 Plant Leaves of Clemson’s Spineless Variety

The plant leaves of Clemson’s spineless okra planted on the four water regimes (100, 80, 60, and 40%FC regime) were recorded on weekly basis, the result is represented in Figure 5.The figure shows that there was a uniform increase in plant leaves of Clemson’s spineless okra variety planted on all the four regimes until week 7 after which there was an increase in the rate at which the plant leaves were increasing. 100%FC regime produced the highest plant leaves number of 26 at 70 DAP, 60%FC produced the second highest number of 23 at 70 DAP, 80%FC produced the third highest number of 20 at 70 DAP, followed by 40%FC which produced the least number of 17 at 70 DAP.

3.6 Number of Leaves of B35 Variety

The plant leaves of B35 okra planted on the four water regimes (100, 80, 60, and 40%FC Regime) was recorded on weekly basis, the result is represented in Figure 6. The figure shows that there is a uniform increase in plant leaves of B35 okra planted on all the four regimes until week 7 after which there was an increase in the rate at which the plant leaves were increasing. 100%FC produced the highest plant leaves number of 24 at 70 DAP, 80%FC produced the second highest value of 20 at 70 DAP, 60%FC produced the third highest number of 16 at 70 DAP, followed by 40%FC which produced the least number of 14 at 70 DAP. The result obtained shows that the variations on the effects of soil moisture stress is not much felt on the plant leaves.

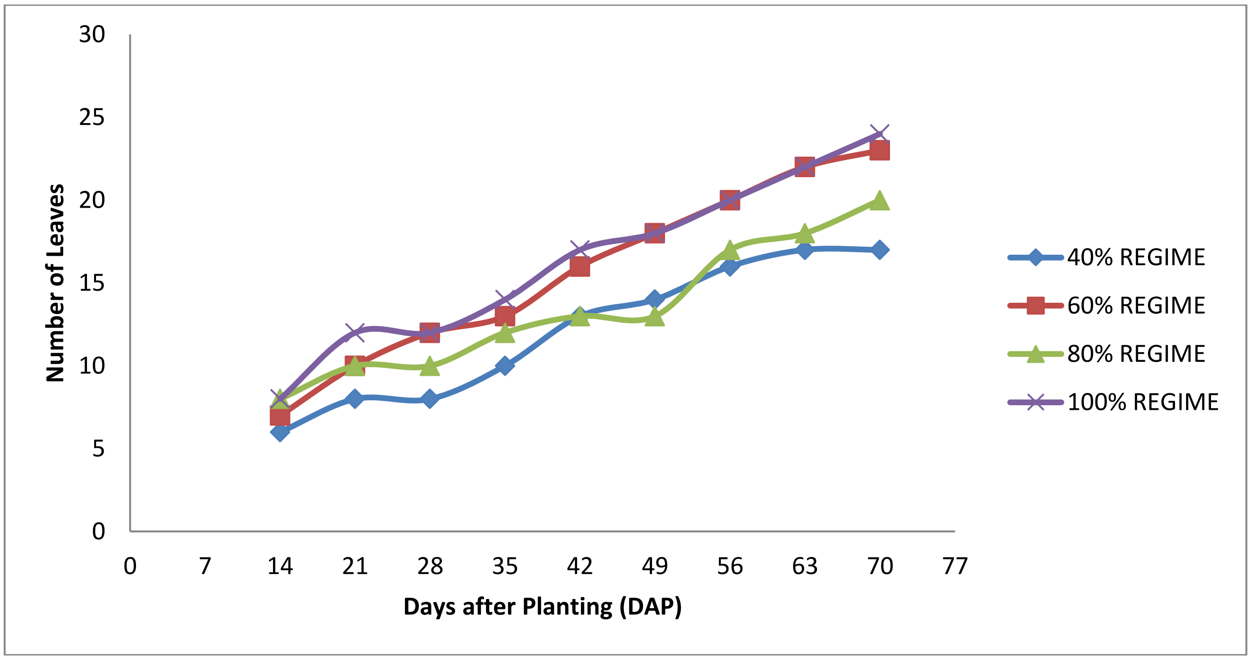

Figure 5: Changes in Number of Leaves of Clemson's spineless Variety with Days After Planting (DAP)

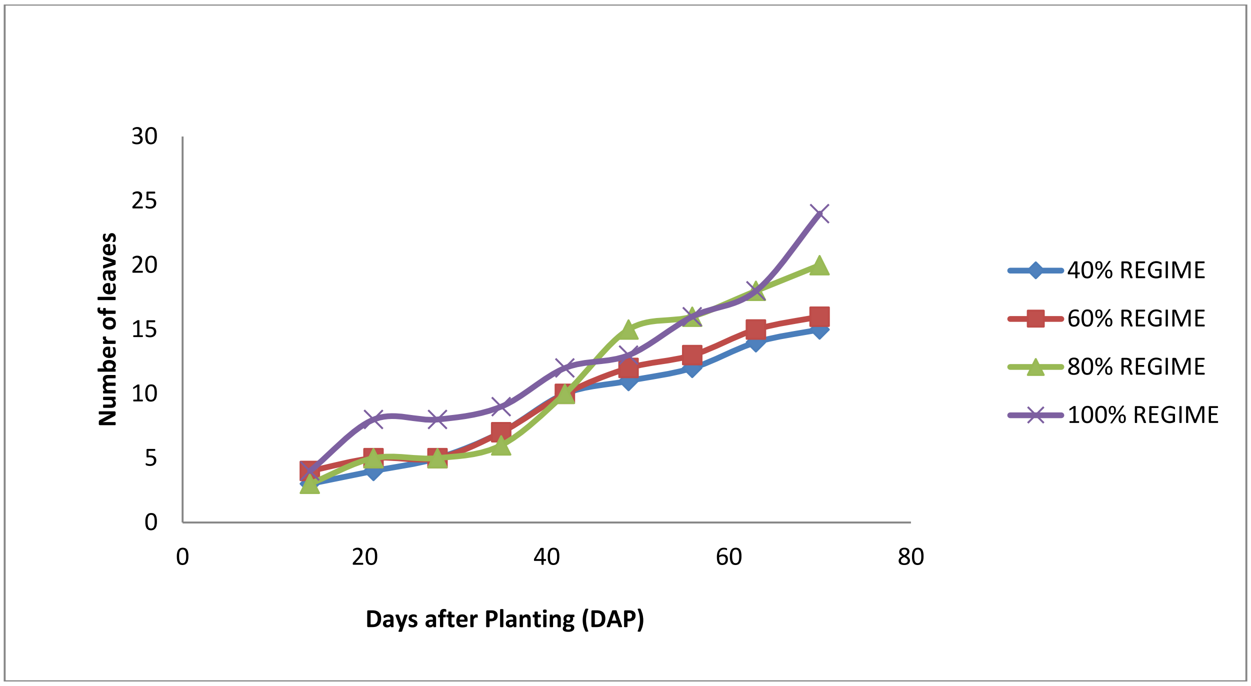

Figure 6: Changes in Number of Leaves of B35 Variety with Days After Planting (DAP)

3.7 Okra Yield

The variations of yields in the four treatments for the two varieties are shown in Figures 7 and 8. Okra fruits of Clemson spineless and B35 varieties were harvested at 70DAP. The yield of each regime was harvested and recorded.

For Clemson's spineless variety, the 100%FC gave the highest yield value of 2.04tons/ha, 80%FC gave the second highest value of 1.44tons/ha, 60%FC gave the third highest value of 1.31tons/ha, and 40%FC gave the least value of 1.0tons/ha.

For B35 variety, the 100%FC gave the highest yield value of 1.77tons/ha, 80%FC gave the second highest value of 1.35tons/ha, 60%FC gave the third highest value of 1.13tons/ha, and 40%FC gave the least value of 0.99tons/ha.

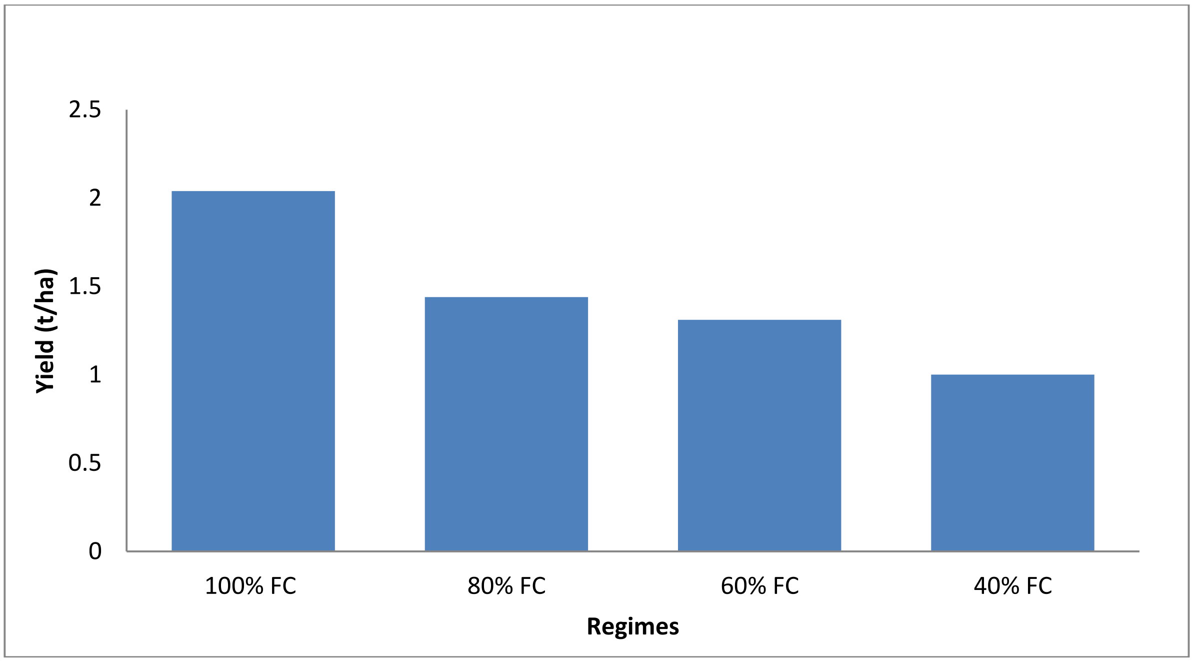

Figure 7: Trend in Yield of Clemson's Spineless Variety for Different Irrigation Regimes

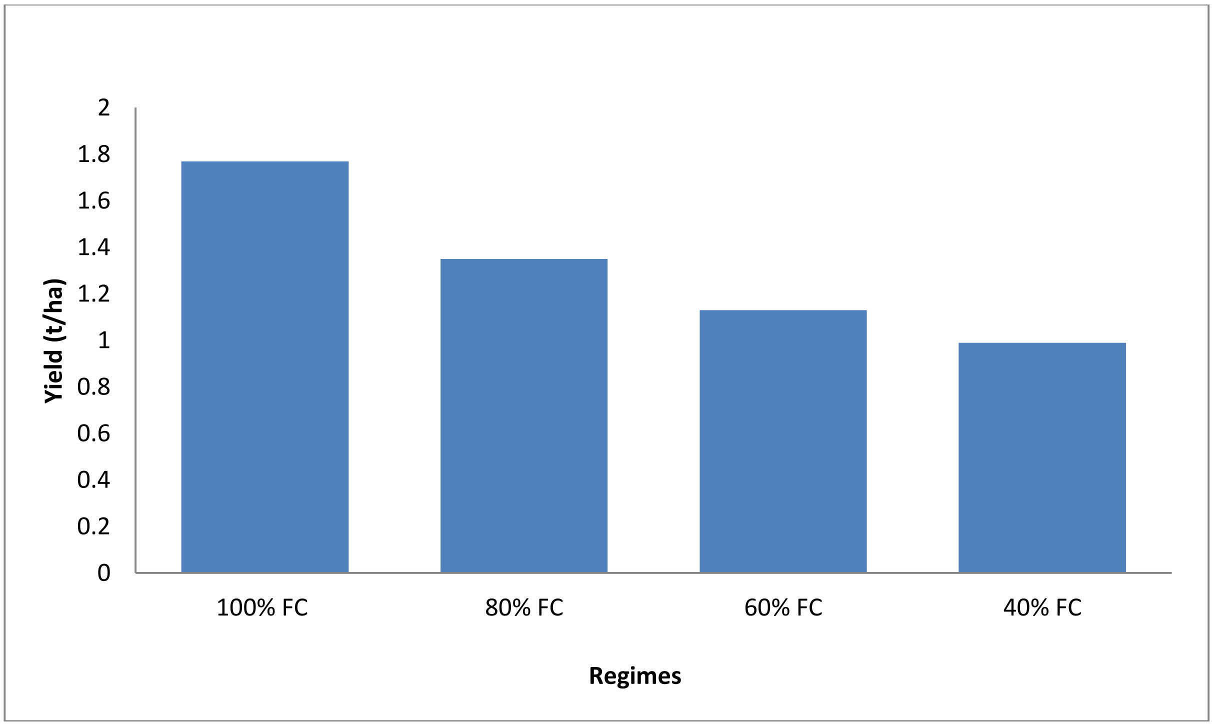

Figure 8: Trend in Yield of B35 Variety for Different Irrigation Regimes

3.8 Discussion

The variation in the yield value of both Clemson's spineless and B35 varieties shows that at high regime of water application, high yield can be obtained and vice versa. This also implies that the more the moisture stresses on okra plant, the more the reduction in yield. Also from the result obtained, Clemson's spineless variety gave high yield as compared to B35 variety. The results obtained corroborated the findings of Al-Harbi *et al.*, (2008) and Abdul Naveed *et al.*, (2009) that increase in the amount of water use leads to increase in okra yield. This result is also in agreement with the findings of Kurunç and Ünlükara, (2009) who reported increased yield of okra with increasing irrigation water application. According to Calvache and Reichardt (1999), water deficit during vegetative growth leads to decline in yield. This was evident from the results obtained from the two varieties at different application regime of water.

3.9 Irrigation Water Use Efficiency

The total amount of water supplied to each crop on each regime was computed at 70 days after planting, this corresponds to the time the harvest was carried out. The values obtained for the 100%FC, 80%FC%, 60%FC and 40%FC are 736m^3/ha, 591.87m^3/ha, 447.73m^3/ha and 306.67m^3/ha respectively. Also, the average total yield (Okra yield) of each of the two varieties planted on each regime was computed. Irrigation water use efficiency was calculated for each variety of each regime.

3.9.1 Irrigation Water Use Efficiencies for Clemson's Spineless

Figure 4.9 shows the variation in efficiencies obtained for the four irrigated regimes. The figure shows that 40%FC had the highest irrigation water use efficiency (3.26 Kg/m^3), 60%FC had the second highest value (2.92 Kg/m^3), 100%FC had the third highest value (2.77 Kg/m^3) while 80%FC had the lowest irrigation water use efficiency (2.43 Kg/m^3).

3.9.2 Irrigation Water Use Efficiencies for B35 Variety

Figure 4.10 shows the variation in efficiencies obtained for the four irrigated regimes. The figure shows that 40%FC had the highest irrigation water use efficiency (3.22 Kg/m^3), 60%FC had the second highest value (2.53 Kg/m^3), 100%FC had the third highest value (2.41 kg/m^3) while 80%FC had the lowest irrigation water use efficiency (2.27 kg/m^3).

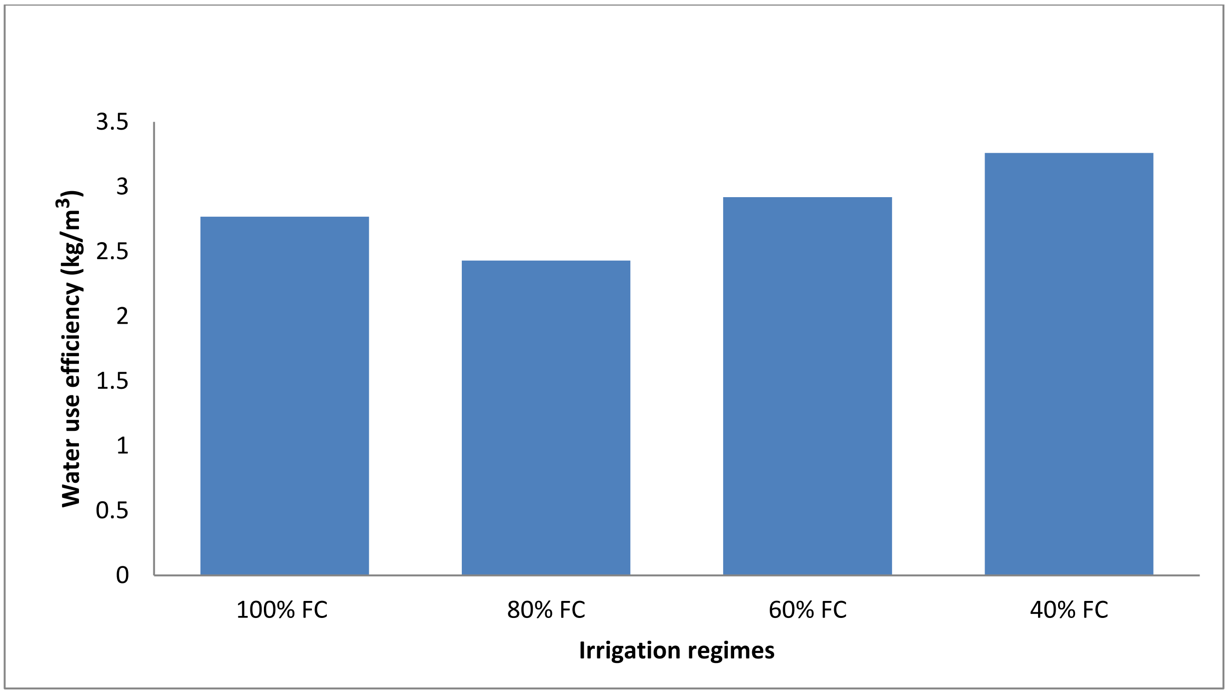

Figure 9: Water Use Efficiency of Clemson's Spineless for Different Irrigation Regimes

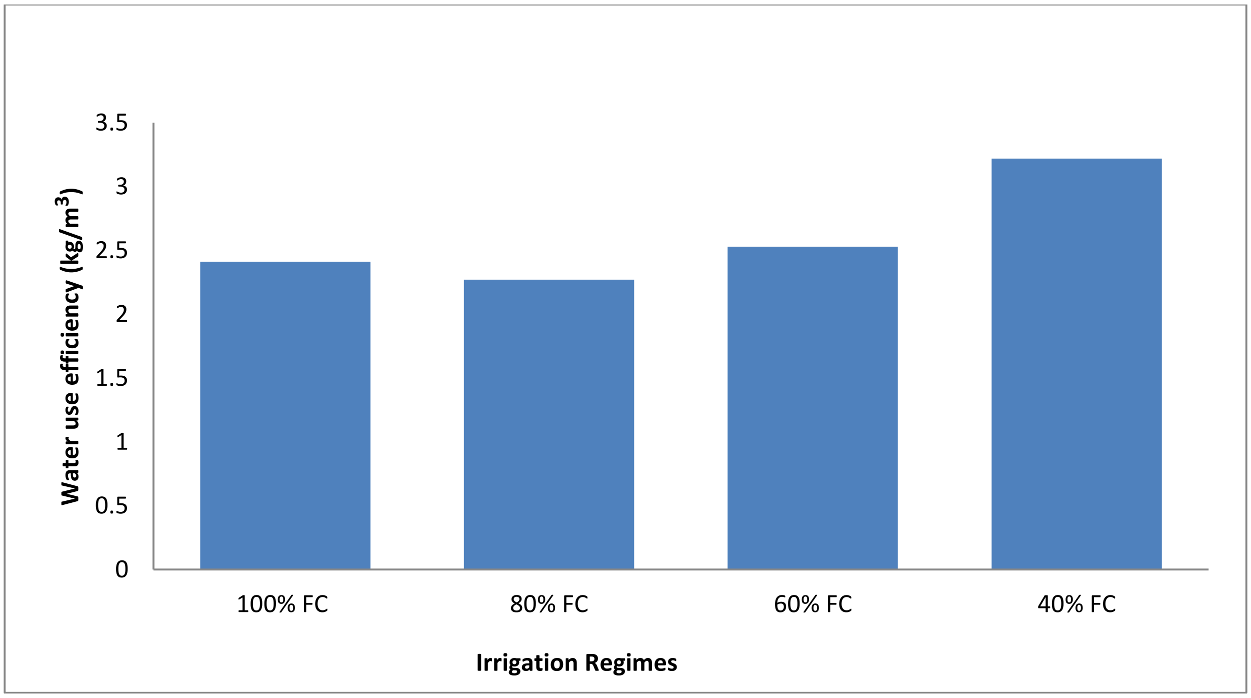

Figure 10: Water Use Efficiency of B35 Variety for Different Irrigation Regimes

4. CONCLUSION

The two different okra varieties obtained from IAR&T was planted and monitored under drip irrigation condition. From the analyzed data, there was a uniform increase in the stem diameter, plant height and number of leaves in the two varieties of okra planted and also there was a slightly significant difference across the four regimes at 5% significance difference. The effect of soil moisture stress on plant height, plant leaves and stem girth was insignificant. Clemson's spineless had the best result value in terms of okra yield, okra productivity, plant height, plant leaves and stem girth as compared to B35 variety. It can be concluded that, okra plant are tolerant to drought even though they produce better when they get the sufficient amount water as recorded in the 100%FC.

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Factors Influencing Tractor Fuel Consumption during Harrowing Operation on a Sandy Loam Soil

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ABSTRACT

Tractor fuel consumption is an important factor in farm machinery management. Factors influencing tractor fuel consumption in litres per hectare (L/ha) during harrowing operation on a sandy loam soil was undertaken using available information gathered from the National Centre for Agricultural Mechanization (NCAM)Tractor Test Reports. The tractors used were categorized into 39 – 60, 61 – 80 and 81 – 100 horsepower groups with unequal replicates provided for each of the group. Effects of operation parameters on fuel consumption for harrowing operation were investigated for the three tractor categories using One-Way Repeated Measures Analysis of Variance. The findings of the study showed that at 0.05 significance level, horsepower groups had no effect on tractor fuel consumption during harrowing operation. The results further showed that operation parameters had significant effect on tractor fuel consumption during harrowing operation. It was concluded that the study had identified factors influencing tractor fuel consumption during harrowing operation in a sandy loam soil.

KEYWORDS: Harrowing, influencing, factors, tractor, fuel, consumption

1. INTRODUCTION

In Nigeria, agricultural mechanization is one of the greatest contributions of technological advancements to agricultural production (Adewoyin and Ajav, 2013). The use of tractors plays a vital role in agriculture, both in developed and developing nations (Mahmood and Gee-Clough, 1989). The application of machines to agricultural production has been one of the outstanding developments in agriculture. With the increasing use of farm machinery, farm tractors play an important role in enhancing agricultural productivity (Kazmi and Ahmad, 1996). Tractors and farm machinery are important sources of modern technology (Singh, 2000; Xinan *et al.*, 2005). According to Panam *et al.* (2010), tractors are one of the fastest farm machines used by farmers for tillage operations instead of human tools and animal-drawn implements. Machinery contributes a major capital input cost in most farm businesses.

Singh (2006) observed that the effect of tractor power on agriculture is considerable. The primary purpose of agricultural tractors, particularly those in the middle to high power range, is to perform drawbar work (Zoz and Grisso, 2003). Land preparation is one of the most energy consuming operations in the field. Energy utilized in tillage is governed by such factors as soil type and condition, depth of cut, operating speed and hitch geometry. Field practices have shown that land preparation constitutes the major cost of farm operation due to the high level of energy expended during tillage. Fuel consumption plays a significant role in the selection and management of tractors and equipment. Two of the common tillage implements widely used by farmers in the southern part of Nigeria are the disc plough and disc harrow. Tillage operations require the most energy and power spent on farms (Al-Suhaibani and Ghaly, 2010).

Soil tilling, according to Oni (1991), is the most intensive of all processes involved in crop production. Tillage of soil is considered to be one of the biggest farm operations (Al-Suhaibani and Ghaly, 2010). There are several tillage implements used by farmers to prepare seedbed. However, the selection of tillage implements for seedbed preparation and weed control depends on soil type and condition, type of crop, previous soil treatments, crop residues and weed type (Upadyaya *et al.*, 2009). The demand for tractor power generally increases with farm size. Tractor fuel consumption is an important factor in farm machinery management. The study aims at identifying factors influencing fuel consumption in diesel operated tractors.

2. MATERIALS AND METHODS

2.1 Experimental procedure

Information gathered from the National Centre for Agricultural Mechanization (NCAM) Tractor Test Reports on agricultural tractors tested during harrowing operation on a sandy loam soil as compiled by Oyelade (2016) for 37 agricultural tractors were used for this study. Each tractor was tested on an area of 0.25 hectare (25 m x 100 m) in a randomized complete block design (RCBD). The implement used for the trials was tractor mounted off-set disc harrow. Parameters measured during harrowing operation include draught force, the width of cut, depth of cut, duration of operation, the speed of operation, field capacity, field efficiency, fuel consumption, wheel slip, soil moisture content, soil bulk density and soil cone index. All the parameters of the tractor-implement performance were measured and recorded in line with the recommendations of RNAM test codes and procedures for farm machinery technical series (1983). Results of measured parameters gathered from each tractor test report on a sandy loam soil during harrowing operation were subjected to Analysis of Variance (ANOVA) in studying the measured parameters that contributed significantly to tractor fuel consumption in litres per hectare during harrowing operation.

2.2 Description of the Study Area

The study was carried out at the research farm of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State. It is located in the Southern Guinea Savanna ecological zone of Nigeria. The particle size analysis of the soil where each tractor was tested was carried out using the hydrometer method described by Gee and Or (2002). The textural class of the soil was determined using USDA Textural Triangle. The various test locations where these tractors were tested fall under the sandy loam soil textural class with the following fractions: sand - 56.79% to 69.92%, silt - 15.33% to 28.64% and clay - 6.44% to 18.33%. The soil in the various test locations was classified as *Alfisols* (Soil Survey Staff, 1975) under the USDA soil order.

2.3 Test Parameters

2.3.1 Draught of implement

The draught of implement was measured using the trace tractor technique described by Oyelade (2016).

2.3.2 Duration of operation

The duration of operation measured in h/ha is the time spent in completing the whole operation and was mathematically expressed as:

$$X_9 = \frac{1}{X_5} \tag{1}$$

where,

X_9 = Duration of operation (h/ha)
X_5 = Effective field capacity (ha/h)

2.3.3 Depth and width of cut

The depth and width of cut during field operation were measured using a steel rule and measuring tape, respectively.

2.3.4 Speed of operation

The speed of operation was determined by placing two poles 20 m apart in-between 100 m which serves as the longest distance of the test plot. The speed of operation for each tractor evaluated during field operation was mathematically expressed as:

$$V_s = 3.6\left(\frac{20}{t_1}\right) \tag{2}$$

where,

V_s = Speed of operation (km/h)
t_1 = Time taken to cover 20 m (sec)

2.3.5 Theoretical field capacity

Theoretical field capacity measured in ha/h was expressed mathematically as:

$$G = \frac{E\,(3600)}{T_a} \tag{3}$$

where,

G = Theoretical field capacity (ha/h)
E = Area of field (ha)
T_a = Actual time taken in doing the main tillage work (sec)

2.3.6 Effective field capacity

Effective field capacity measured in ha/h was expressed mathematically as:

$$X_5 = \frac{E\,(3600)}{T_t} \tag{4}$$

where,

X_5 = Effective field capacity (ha/h)
E = Area of field (ha)
T_t = Total time taken in completing the whole tillage operation (sec)

2.3.7 Field efficiency

Field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed in percent. It was expressed mathematically as:

$$H = \frac{X_5}{G} x 100\% \qquad (5)$$

where,

H = Field efficiency (%)
X_5 = Effective field capacity (ha/h)
G = Theoretical field capacity (ha/h)

2.3.8 Fuel consumption

The filling of fuel tank before the operation and then refilling after completing the operation as used in this study is a common method used in the field for determining tractor fuel consumption in litres per hectare. This same method was as reported by (Ajav and Adewoyin, 2011; Ikpo and Ifem, 2005; Kudabo and Gbadamosi, 2012; Meshack-Hart, 1997; Sirelkatim *et al.*, 2001; Udo and Akubuo, 2004) in determining tractor fuel consumption in litres per hectare.

Fuel consumption measured in either L/ha or L/h was expressed mathematically as:

$$I = \frac{J}{E} \qquad (6)$$

$$K = X_5 x I \qquad (7)$$

where,

I = Fuel consumption (L/ha)
J = Volume of fuel consumed (L)
E = Area of field (ha)
K = Fuel consumption (L/h)
X_5 = Effective field capacity (ha/h)

2.3.9 Tractive efficiency

Tractive efficiency measured in % is the ratio of drawbar power to wheel power and was expressed mathematically according to (Macmillan, 2002) as:

$$Q_t = \frac{Q_p}{Q_w} x\ 100\% \qquad (8)$$

where,

Q_t = Tractive efficiency (%)
D_p = Drawbar power (kW)
Q_w= Wheel power (kW), power losses in the transmission from engine to the wheels of, say 10% is assumed, it can be written as:

$$Q_t = \frac{D_p}{0.9\ x\ Q_e} x\ 100\% \qquad (9)$$

where,

Q_e = Engine power (kW)

2.3.10 Travel reduction (wheel slip)

In determining wheel slip (travel reduction), a mark was made on the tractor drive wheel with coloured tapes. This was used to measure the distance covered by the tractor drive wheel at every 10 revolutions under no load and the same revolution with a load on the same surface. The travel reduction (wheel slip) measured in % was expressed mathematically as:

$$L = \frac{M_2 - M_1}{M_2} x\, 100\% \qquad (10)$$

where,

L = Travel reduction (wheel slip) (%)

M_2 = Distance covered at every 10 revs of the wheel at no-load condition (m)

M_1 = Distance covered at every 10 revs of the wheel at load condition (m)

2.4 Soil Parameters

2.4.1 Soil moisture

Klenin *et al.* (1985) defined soil moisture content as the amount of liquid, usually water that is present in the soil. It is expressed as a percentage of the mass of water in the soil to the mass of the dried soil (for dry weight classification) or mass of water to mass of wet soil (for wet weight classification). The soil moisture content (in dry basis) measured in %, can be expressed mathematically as:

$$M_c = \frac{W_w}{W_s}\ x\, 100\% \qquad (11)$$

where,

$M_c = Soil\ moisture\ content\ (\%)$

$W_s = Mass\ of\ oven\ dried\ soil\ (g)$

$W_w = Mass\ of\ water\ present\ in\ soil\ (g)$

2.4.2 Soil bulk density

Soil bulk density (ρ_b) is a measure of the mass of soil per unit volume and is usually reported on an oven-dry basis. The soil bulk density was determined by the core method described by Anwanane (2014). The core samples were oven dried at a temperature of 105^0C to a constant weight.

$$\rho_b = \frac{M_s}{V_T} \qquad (12)$$

where,

ρ_b = Soil bulk density (g/cm^3)

M_s = Mass of dry soil (g)

V_T = Total volume of soil (cm^3)

2.4.3 Soil cone index

The soil cone index (CI) is the soil resistance to penetration and was measured using a cone penetrometer.

2.5 Statistical Tool

2.5.1 Experimental design

The statistical analysis adopted for this study, involving one factor at three levels was the One-Way Repeated Measures Analysis of Variance (ANOVA) experimental design with unequal replicates. The 37 tractors involved in this study were tested between 2005 and 2011. These tractors were grouped into three tractor horsepower groups namely, 39 – 60, 61 – 80 and 81 – 100 horsepower tractors which were termed as a medium, low-high and high range tractors, respectively. The 39 – 60, 61 – 80 and 81 – 100 tractor horsepower groups were provided with 14, 19 and 4 replicates, respectively. The year each tractor was tested serves as a replicate in each of the tractor horsepower group.

Using version 3.1.1 of the R software package (R Development Core Team, 2014) for statistical computing and graphics, the One-Way Repeated Measures ANOVA was used to study the effects of tractor horsepower groups on tractor fuel consumption in litres per hectare due to harrowing operation parameters. It was also used to study the effects of harrowing operation parameters on tractor fuel consumption. As a result of this, the following hypotheses were drawn.

Hypothesis: Test of Significance of Tractor Horsepower
Null hypothesis (H_0): Effects of the three tractor horsepower groups on tractor fuel consumption due to harrowing operation parameters are the same
Alternative hypothesis (H_1): Effects of the three tractor horsepower groups on tractor fuel consumption due to /harrowing operation parameters are not the same
Test statistic: ANOVA F-test
Decision rule: Reject H_0 in favour of H_1 at 0.05 level of significance if p-value < 0.05, otherwise do not reject H_0
Hypothesis: Test of Significance of Harrowing Operation Parameters
Null hypothesis (H_0): Effects of the harrowing operation parameters on tractor fuel consumption in litres per hectare are the same
Alternative hypothesis (H_1): Effects of the harrowing operation parameters on tractor fuel consumption in litres per hectare are not the same
Test statistic: ANOVA F-test
Decision rule: Reject H_0 in favour of H_1 at 0.05 level of significance if p-value < 0.05, otherwise do not reject H_0

3. RESULTS AND DISCUSSION

3.1 Experimental Design

Table 1 presents the mean values of measured parameters in the three horsepower groups. Based on the design structure of the harrowing operation data set and interest in investigating the effects of the three levels of the factor (tractor horsepower group) on tractor fuel consumption, there is need to conduct a single factor design with repeated measures ANOVA. The justification for the choice of repeated measures ANOVA lies in the fact that observations under the three groups were gathered over time. Another reason for the choice of the method is that the 13 harrowing operation parameters (treatments) are nested within the three levels of tractor horsepower groups. The R statistical package for data analysis and computing, version 3.1.1 was utilized for analysis. Table 1was subjected to One-Way Repeated Measures ANOVA. The ANOVA result for effects of tractor horsepower groups on harrowing operation parameters is presented in Table 2.

Table 1. Summary Table of Mean of measured Parameters during Harrowing Operation in the Three Horsepower Groups

Treatment	Horsepower Group			Total
	1	2	3	
Tractor power rating	51.04	73.05	88.30	212.39
Width of cut	177.08	175.76	203.59	556.43
Depth of cut	17.63	18.47	19.25	55.35
Draught force	3.48	3.74	3.79	11.01
Effective field capacity	0.9445	1.015	1.079	3.0385
Tractive efficiency	21.76	17.05	12.49	51.3
Field efficiency	73.52	73.35	75.13	222
Wheel slip	12.51	10.05	9.19	31.75
Duration of operation	1.098	1.007	1.044	3.149
Speed of operation	7.37	7.96	6.97	22.3
Average moisture content	9.61	9.38	9.38	28.37
Average bulk density	1.42	1.39	1.36	4.17
Average cone index	28.13	19.93	15.51	63.57
Total	405.5925	412.152	447.083	**1264.8275**

Table 2. ANOVA Table for Effects of Tractor Horsepower Groups on Harrowing Operation Parameters

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**F-value**	**P-value**
Horsepower Group	2	76.53	38.265	0.733	0.491
Residuals	24	1253.017	52.209		

Decision: Since p-value = 0.491 > 0.05, we do not reject H_0

Based on the results presented in Table 2which gave a p-value of 0.491 > 0.05, implies that the effects of the three tractor horsepower groups on tractor fuel consumption value in litres per hectare on a sandy loam soil due to harrowing operation parameters are not significantly different. From the ANOVA results presented in Table 3, it is safe to conclude that the effects of the 13 harrowing operation parameters on tractor fuel consumption in litres per hectare on a sandy loam soil are not the same. As a result of this, there is a need to conduct multiple comparison tests using a pair-wise t-test to know which harrowing operation parameters are actually significantly different in terms of their effects on tractor fuel consumption. The result of the pair-wise t-test is presented in Table 4.

Table 3. ANOVA Table for Effects of Harrowing Operation Parameters on Tractor Fuel Consumption

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**F-value**	**P-value**
Parameters	12	97717.207	8143.101	155.97	<2e-16
Residuals	24	1253.017	52.209		

Decision: Since p-value = 2e-16 < 0.05, we reject H_0

Table 4. Pair-Wise Comparison result of Harrowing Operation Parameters

	X_{12}	X_{13}	X_{11}	X_9	X_3	X_4	X_5	X_7	X_1	X_{10}	X_6	X_8
X_{13}	0.760	-	-	-	-	-	-	-	-	-	-	-
X_{11}	**0.004***	0.865	-	-	-	-	-	-	-	-	-	-
X_9	0.196	0.760	**0.003***	-	-	-	-	-	-	-	-	-
X_3	0.051	1.000	0.159	0.050	-	-	-	-	-	-	-	-
X_4	0.133	0.760	0.053	0.123	**0.043***	-	-	-	-	-	-	-
X_5	0.755	0.760	**0.012***	1.000	**0.040***	**0.034***	-	-	-	-	-	-
X_7	**0.005***	0.241	**0.006***	**0.004***	**0.003***	**0.004***	**0.004***	-	-	-	-	-
X_1	0.760	0.865	0.760	0.760	0.760	0.760	0.760	1.000	-	-	-	-
X_{10}	0.128	0.865	0.755	0.131	0.156	0.252	0.131	**0.011***	0.760	-	-	-
X_6	0.760	0.865	0.865	0.760	1.000	0.760	0.760	0.150	0.865	0.865	-	-
X_8	0.414	0.865	1.000	0.392	0.760	0.760	0.414	**0.034***	0.760	0.865	0.865	-
X_2	0.134	0.225	0.138	0.134	0.138	0.134	0.134	0.236	0.158	0.138	0.196	0.150

* Significant at $p < 0.05$

Key:
X_1 = Tractor power rating (hp), X_2 = Width of cut (cm), X_3 = Depth of cut (cm), X_4 = Draught force (kN), X_5 = Effective field capacity (ha/h), X_6 = Tractive efficiency (%), X_7 = Field efficiency (%), X_8 = Wheel slip (%), X_9 = Duration of operation (h/ha), X_{10} = Speed of operation (km/h), X_{11} = Average soil moisture content (%), X_{12} = Average soil bulk density (g/cm^3) and X_{13} = Average soil cone index (N/cm^2).

density, average soil moisture content and effective field capacity, average soil moisture content and field efficiency, average soil moisture content and duration of operation, average soil bulk density and field efficiency, depth of cut and draught force, depth of cut and effective field capacity, depth of cut and field efficiency, draught force and effective field capacity, draught force and field efficiency, effective field capacity and field efficiency, wheel slip and field efficiency, and duration of operation and field efficiency within a particular tractor horsepower group are significantly different. This implies that within that particular tractor horsepower group they have different impact on tractor fuel consumption i.e. one cannot use one treatment to replace another.

5. CONCLUSION

A study was carried out to investigate the factors influencing tractor fuel consumption during harrowing operation in a sandy loam soil using information gathered from NCAM Tractor Test Reports. The tractors involved were categorized into 39 – 60, 61 – 80 and 81 – 100 horsepower groups. The One-Way Repeated Measures ANOVA was used to study the effects of tractor horsepower groups on tractor fuel consumption in litres per hectare due to harrowing operation parameters. Likewise, it was used to study the effects of harrowing operation parameters on tractor fuel consumption.

It is safe to conclude from the results obtained from the One-Way Repeated Measures ANOVA for harrowing operation that tractor fuel consumption in the three tractor horsepower groups used in this study were statistically significantly the same. Likewise, the same ANOVA result showed that harrowing operation parameters had an effect on tractor fuel consumption.

6. ACKNOWLEDGEMENT

We want to thank members of NCAM tractor testing team for the tremendous work they have been doing over the years in the testing of agricultural tractors imported into the country for use in Nigerian agriculture.

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ABSTRACT

In the study of agricultural machinery management, fuel consumption is considered as a very important factor that plays a significant role in the selection and management of tractors and equipment. In Nigeria, there are no tractor fuel consumption models developed for harrowing operation. Considering the importance of harrowing operation to tillage practice in Nigerian agriculture, it became necessary to embark on the study on the modelling of tractor fuel consumption in litres per hectare (L/ha) during harrowing operation in a sandy loam soil using available information gathered from the National Centre for Agricultural Mechanization (NCAM) Tractor Test Reports. A multiple linear regression method was used to develop the model. A 10-repeated 10-fold cross-validation method was used to validate the model. The study revealed that the model developed for harrowing operation had a R^2-value of 0.477 showing tractor power rating as the only operation parameter contributing to the model development. Cross-validation revealed that the harrowing operation model had a test error value of 0.986 L/ha. The study also identified other contributing factors to tractor fuel consumption during harrowing operation in a sandy loam soil. The model developed for tractor fuel consumption during harrowing operation in a sandy loam soil is recommended for use in budgeting for diesel consumption.

KEYWORDS: Fuel, harrowing, evaluation, prediction, tractor, consumption

1. INTRODUCTION

Tillage of soil is considered to be one of the biggest farm operations (Al-Suhaibani and Ghaly, 2010). It is also a conventional farming system involving the use of the tractors which results in high energy costs. The sustainability of such a system requires a well-controlled resource management leading to a significant reduction in crop production costs derived from savings in fuel consumption (Serrano et al., 2009). Agricultural machinery has become increasingly important in carrying out farm work. The application of machines to agricultural production has been one of the outstanding developments in agriculture. Machinery contributes a major capital input cost in most farm businesses.

In agriculture, the tractor remains a very important machine due to its ability to provide mechanical power to farm implements both on and off the farm. The choice of a tractor based on field performance can be very challenging due to limited information with regards to performance on the field. According to Sirelkatim *et al*. (2001), land preparation is one of the most energy demanding operations in agriculture, it involves soil cutting, turning and pulverizing and thus demands high energy, hence there is need to optimize tractor performance in order to utilize the available energy. This energy utilization depends on many factors such as soil type and condition, operating depth and speed, and hitch geometry.

The use of models for budgeting of tractor fuel consumption has been of great use to farmers in developed nations. Most studies on model development for tractor fuel consumption centres mainly on ploughing operation which is the first tillage operation carried out on the soil. Harrowing operation has been considered as a very important tillage operation that needs to be carried out during land preparation in Nigerian agriculture.

Considering the importance of harrowing operation to tillage practice in Nigerian agriculture, there is a need to develop a simple model equation for predicting tractor fuel consumptioninlitres per hectare (L/ha) during harrowing operation. The study is aimed at developing a statistical model for predicting tractor fuel consumption during harrowing operation in a sandy loam soil.

3. MATERIALS AND METHODS

2.1 Experimental procedure

The study involves the use of information gathered from the National Centre for Agricultural Mechanization (NCAM) Tractor Test Reports on 41 agricultural tractors compiled by Oyelade (2016) which were tested during harrowing operation on a sandy loam soil. Each tractor was tested on an area of 0.25 hectare (25 m x 100 m) in a randomized complete block design (RCBD). The implement used for the trials was tractor mounted off-set disc harrow. Parameters measured during harrowing operation include speed of operation, fuel consumption, field capacity, field efficiency, wheel slip, duration of operation, draught force, the width of cut, depth of cut, soil cone index, soil moisture content, and soil bulk density. The three soil properties, namely, soil cone index, soil moisture content and soil bulk density were all measured at depths 0 – 7 cm, 7 – 14 cm and 14 – 21 cm. The resulting average values of these three soil properties were part of the data collated. All the parameters of the tractor-implement performance were measured and recorded in line with the recommendations of RNAM test codes and procedures for farm machinery technical series (1983). Out of the 41 tractor test data, 37 tractor test data termed model development dataset was used to generate multiple regression for use in future predictions of tractor fuel consumption in litres per hectare during ploughing operation on a sandy loam soil. The remaining four tractor test data termed model validating dataset were used to validate the model developed.

2.2 Description of the Study Area

The study was carried out at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State which is located at 370 m above sea level in the Southern Guinea Savanna ecological zone of Nigeria by Longitude 4° 30′ E and Latitude 8° 26′ N. The various test locations where these tractors were tested fall under the sandy loam soil textural class with the following fractions: sand - 56.79% to 69.92%, silt - 15.33% to 28.64% and clay - 6.44% to 18.33%. The soil in the various test locations of the study area were classified as *Alfisols* (Soil Survey Staff, 1975) under the USDA soil order.

2.3 Particle Size Analysis

Particle size analysis was carried out using the hydrometer method described by Gee and Or (2002). Sodium hexametaphosphate (calgon) was used as the dispersant. The textural class of the soil was determined using the USDA Textural Triangle.

2.4 Test Parameters

2.4.1 Speed of operation

The speed of operation was determined by placing two poles 20 m a part in-between the longest distance of the test plot. On the opposite side of the test plot, two poles were placed in a similar position 20 m apart. The speed of operation for each tractor evaluated during harrowing operation was mathematically expressed as:

$$V_s = 3.6\left(\frac{20}{t_1}\right) \qquad (1)$$

where,

V_s = Speed of operation (km/h)

t_1 = Time taken to cover 20 m (sec)

2.4.2 Depth and width of cut

The depth and width of cut during field operation were measured using a steel rule and measuring tape, respectively.

2.4.3 Draught of the implement

The draught of implement was measured using the trace tractor technique described by Oyelade (2016).

2.4.4 Theoretical field capacity

Theoretical field capacity measured in ha/h was expressed mathematically as:

$$G = \frac{E\,(3600)}{T_a} \qquad (2)$$

where,

G = Theoretical field capacity (ha/h)

E = Area of field (ha)

T_a = Actual time taken in doing the main tillage work (sec)

2.4.5 Effective field capacity

Effective field capacity measured in ha/h was expressed mathematically as:

$$X_5 = \frac{E\,(3600)}{T_t} \qquad (3)$$

where,

X_5 = Effective field capacity (ha/h)

E = Area of field (ha)

T_t = Total time taken in completing the whole tillage operation (sec)

2.4.6 Field efficiency

Field efficiency, according to ASAE (2000), is the ratio of effective field capacity to theoretical field capacity, expressed in percent. It was expressed mathematically as:

$$H = \frac{X_5}{G} x 100\% \quad (4)$$

where,

H = Field efficiency (%)
X_5 = Effective field capacity (ha/h)
G = Theoretical field capacity (ha/h)

2.4.7 Fuel consumption

The fuel required for each tillage operation was determined by filling the tank to full capacity before and after the test. Amount of refueling after each test is the fuel consumption for the test. The filling of fuel tank before the operation and then refilling after completing the operation in determining the amount of fuel consumed during operation is a common method used in the field for determining tractor fuel consumption in litres per hectare. This same method was as reported by (Ajav and Adewoyin, 2011; Ikpo and Ifem, 2005; Kudabo and Gbadamosi, 2012; Meshack-Hart, 1997; Sirelkatim *et al.*, 2001; Udo and Akubuo, 2004) in determining tractor fuel consumption in litres per hectare.

Fuel consumption measured in either L/ha or L/h was expressed mathematically as:

$$I = \frac{J}{E} \quad (5)$$

$$K = X_5 x I \quad (6)$$

where,

I = Fuel consumption (L/ha)
J = Volume of fuel consumed (L)
E = Area of field (ha)
K = Fuel consumption (L/h)
X_5 = Effective field capacity (ha/h)

2.4.8 Travel reduction (wheel slip)

In determining the wheel slip (travel reduction), a mark was made on the tractor drive wheel with coloured tapes. This was used to measure the distance covered by the tractor drive wheel at every 10 revolutions under no load and the same revolution with a load on the same surface. The travel reduction (wheel slip) measured in % was expressed mathematically as:

$$L = \frac{M_2 - M_1}{M_2} x 100\% \quad (7)$$

where,

L = Travel reduction (wheel slip) (%)
M_2 = Distance covered at every 10 revs of the wheel at no-load condition (m)
M_1 = Distance covered at every 10 revs of the wheel at load condition (m)

2.4.9 Tractive efficiency

Tractive efficiency measured in % is the ratio of drawbar power to wheel power and was expressed mathematically according to (Macmillan, 2002) as:

$$Q_t = \frac{Q_p}{Q_w} \; x \; 100\% \qquad (8)$$

where,

Q_t = Tractive efficiency (%)
D_p = Drawbar power (kW)
Q_w = Wheel power (kW), power losses in the transmission from engine to the wheels of, say 10% is assumed, it can be written as:

$$Q_t = \frac{D_p}{0.9 \; x \; Q_e} \; x \; 100\% \qquad (9)$$

where,

Q_e = Engine power (kW)

2.4.10 Duration of operation

The duration of operation measured in h/ha which is the time spent in completing the whole operation was mathematically expressed as:

$$X_9 = \frac{1}{X_5} \qquad (10)$$

where,

X_9 = Duration of operation (h/ha)
X_5 = Effective field capacity (ha/h)

2.5 Soil Parameters

2.5.1 Soil bulk density

Soil bulk density (ρ_b) is a measure of the mass of soil per unit volume and is usually reported on an oven-dry basis. The soil bulk density was determined by the core method described by Anwanane (2014). The core samples were oven dried at a temperature of 105^{0}C to a constant weight.

$$\rho_b = \frac{M_s}{V_T} \qquad (11)$$

where,

ρ_b = Soil bulk density (g/cm^3)
M_s = Mass of dry soil (g)
V_T = Total volume of soil (cm^3)

2.5.2 Soil moisture

Klenin *et al.* (1985) defined soil moisture content as the amount of liquid, usually water that is present in the soil. It is expressed as a percentage of the mass of water in the soil to the mass of the dried soil (for dry weight classification). The soil moisture content (in dry basis) measured in %, can be expressed mathematically as:

$$M_c = \frac{W_w}{W_s} \; x \; 100\% \qquad (12)$$

where,

$M_c = Soil\ moisture\ content\ (\%)$
$W_s = Mass\ of\ oven\ dried\ soil\ (g)$
$W_w = Mass\ of\ water\ present\ in\ soil\ (g)$

2.5.3 Soil cone index

The soil cone index (CI) is the soil resistance to penetration and was measured using a cone penetrometer.

2.6 Statistical Tool

2.6.1 Regression analysis

Multiple linear regression method which is a form of regression analysis was used for establishing the relationship that existed between fuel consumption (the model response variable) and other factors (or predictors of fuel consumption) identified to be factors influencing tractor fuel consumption in litres per hectare during harrowing operation. Multiple regression is when there is one dependent variable but more than one independent variables. In this study, tractor fuel consumption in litres per hectare was the dependent variable while other factors identified as factors influencing tractor fuel consumption in litres per hectare stands as the independent variables.

In developing this model, the following hypotheses were drawn:

Test of Hypothesis about Full Regression Model of Harrowing Operation
Hypothesis 1: [Test of significance about all regression parameters]
$\mathbf{Nullhypothesis(H_0):}$ The model does not fits the data/ The model is not adequate
$\mathbf{Alternativehypothesis(H_0)}$:The model fits the data/ The model is adequate
Mathematically,
$\mathbf{Nullhypothesis(H_0):}\ \beta_j = 0$ [None of the predictors contributes significantly to the model]
$\mathbf{Alternativehypothesis(H_0)}$: $\mathbf{:}\ \beta_j \neq 0\ foratleastonej$ [At least one of the predictors contributes significantly to the model]
Tests statistic: $\boldsymbol{F_{ratio}} = \frac{\boldsymbol{MS_{Regression}}}{\boldsymbol{MS_{Error}}}$ [Global F-test]

Decision rule: Reject thenull hypothesis in favour of the alternative hypothesis at 0.05 significance level if $\mathrm{P-value} < 0.05$, otherwise do not reject the null hypothesis.
Hypothesis 2: [Test of significance about individual regression coefficient]
$\mathbf{Nullhypothesis(H_0):}\ \beta_j = 0$ [Predictor x_j is not statistically significant in the model given that others are included in the model]
$\mathbf{Alternativehypothesis(H_0)}$: $\mathbf{:}\ \beta_j \neq 0$ [Predictor x_j is statistically significant in the model given that others are included in the model]
Tests statistic: $\boldsymbol{t_{value}} = \frac{\beta_j}{\sqrt{\boldsymbol{C_{jj}\sigma^2}}}$ [Individual t-test]
$\boldsymbol{C_{jj}} = diagonalelementofthecovariancematrixcorrespondingto\beta_j$
$\sigma^2 = varianceof\beta_j$

This same tests statistic was also used by James *et al.* (2013)

Decision rule: Reject the null hypothesis in favour of the alternative hypothesis at 0.05 significance level if $\mathrm{P} - \mathrm{value} < 0.05$, otherwise do not reject the null hypothesis.

2.7 Developing models without an intercept term

Models with intercept term are common to all models built round multiple linear regression models. In this study, the assumption was whether a tractor could consume some amount of fuel before commencement of harrowing operation if such variable as air (ambient) temperature could constitute measurable parameters. The study was therefore governed by building models without intercept term because it is the most appropriate model type that fits this study based on the cylinder method of measuring fuel consumption.

2.8 Model validation

The model validation method adopted for this study is the cross validation method. This validation method is an extremely flexible and powerful technique and widely used approach in validation work for estimating prediction error. The measure of error for cross-validation is the mean square error (MSE) for a quantitative response. The 10-fold cross-validation is commonly used. According to Bouckaert (2003), 10-fold cross-validation remains the most widely used validation procedure.

4. RESULTS AND DISCUSSION

3.1 Model Development and validation

One model with p-value < 0.05 was statistically developed for harrowing operation on a sandy loam soil. Details of the pair-wise correlation analysis showing the result of the correlation strength of the developed model for harrowing operation is presented in Table 1. Results obtained for parameter estimates and Analysis of Variance (ANOVA) for the model developed for harrowing operation are presented in Tables 2 and 3, respectively.

Table 1. Pair-wise Correlation result of Fuel Predictive Values of Model 2 with Observed Fuel Values during Harrowing Operation

Models developed	Observed
Model 2 of Harrowing operation	0.690468*

* = significant at 5% level when r-value ≥ 0.338788

Table 2. Table of Parameter Estimates for Model 2 of Harrowing Operation

P-value of Model	**Model Multiple R-square value**	**Model Adjusted R-square value**	**Coefficients**	**Estimates**	**Std. Error**	**t value**	**P-value**
1.519e-07	0.4767	0.1778	Tractor power rating	0.055996	0.059842	0.936	0.3601
			Width of cut	-0.050569	0.029628	-1.707	0.102
			Depth of cut	0.059737	0.062936	0.949	0.3533
			Draught force	-0.698953	0.954827	-0.732	0.4722
			Effective field capacity	10.673913	8.512772	1.254	0.2237
			Tractive efficiency	0.250983	0.190038	1.321	0.2008
			Field efficiency	-0.031328	0.059421	-0.527	0.6036
			Wheel slip	-0.060759	0.054501	-1.115	0.2775
			Duration of operation	5.464993	3.336067	1.638	0.1163
			Speed of operation	-1.523374	0.598055	-2.547	0.0188 *
			Average soil moisture content	-0.085734	0.115415	-0.743	0.4658
			Average soil bulk density	2.768087	2.346524	1.180	0.2513
			Average soil cone index	0.003298	0.028825	0.114	0.9100

*significant at 5% level

Table 3. ANOVA Table for Model 2 of Harrowing Operation

Source of Variation	Degree of Freedom	Sum of Squares	Means Squares	F-value	P-value
Tractor power rating	1	234.430	234.430	151.6806	4.503e-11 *
Width of cut	1	6.257	6.257	4.0487	0.05721
Depth of cut	1	3.660	3.660	2.3684	0.13875
Draught force	1	4.110	4.110	2.6594	0.11785
Effective field capacity	1	3.300	3.300	2.1349	0.15879
Tractive efficiency	1	11.101	11.101	7.1828	0.01401 *
Field efficiency	1	4.096	4.096	2.6499	0.11847
Wheel slip	1	1.576	1.576	1.0200	0.32401
Duration of operation	1	0.086	0.086	0.0556	0.81594
Speed of operation	1	11.162	11.162	7.2223	0.01379 *
Average soil moisture content	1	0.750	0.750	0.4851	0.49378
Average soil bulk density	1	2.365	2.365	1.5301	0.22975
Average soil cone index	1	0.020	0.020	0.0131	0.90999
Residuals	21	32.457	1.546		

*significant at 5% level

Model 2 of harrowing operation with p-value < 0.05 recorded a R-squared value of 0.4767. The model explains 48% of the proportion of variance in the mean squared errors of tractor fuel consumption for harrowing operation with only speed of operation showing statistical significance with a p-value of 0.0188 in the model. In terms of marginal (individual) significance of the predictor variables, results in Table 4 reveal that we reject the null hypothesis about only tractor power rating, tractive efficiency and speed of operation with corresponding p-values of 4.503e-11, 0.01401 and 0.01379, respectively. This means that each of these variables is statistically significant in the model provided others are included in the model. It also implies that they cannot be removed from the model.

The equation used for expressing Model 2 of harrowing operation as contained in Table 2 was given as:

$$\hat{Y} = 0.055996\mathrm{X}_1 - 0.050569\,\mathrm{X}_2 + 0.059737\mathrm{X}_3 - 0.698953\mathrm{X}_4 + 10.673913\mathrm{X}_5 + 0.250983\mathrm{X}_6 - 0.031328\mathrm{X}_7 - 0.060759\mathrm{X}_8 + \quad (13)$$

$$5.464993X_9 - 1.523374X_{10} - 0.085734X_{11} + 2.768087X_{12} + 0.003298X_{13}$$

where, $\widetilde{Y}$ = Tractor fuel consumption (L/ha), X_1 = Tractor power rating (hp), X_2 = Width of cut (cm), X_3 = Depth of cut (cm), X_4 = Draught force (kN), X_5 = Effective field capacity (ha/h), X_6 = Tractive efficiency (%), X_7 = Field efficiency (%), X_8 = Wheel slip (%), X_9 = Duration of operation (h/ha), X_{10} = Speed of operation (km/h), X_{11} = Average soil moisture content (%), X_{12} = Average soil bulk density (g/cm^3) and X_{13} = Average soil cone index (N/cm^2).

The model equation generated for Model 2 of harrowing operation was used for predicting tractor fuel consumption using the 37 model development dataset. Results obtained from the fuel prediction values of Model 2 of harrowing operation is presented in Table 4. The values for both observed and predicted tractor fuel consumption of Model 2 of harrowing operation as shown in Table 4 were correlated together and gave a correlation coefficient of 0.690468 as shown in Table 1.According to the rule of thumb as provided in http://www.westgard.com/lesson42.html for evaluating correlation coefficient, noted that size of r with correlation values between 0.50 and 0.69 are said to be moderate. It indicates that tractor fuel consumption predictions of Model 2 of harrowing operation is moderately correlated with the observed tractor fuel consumption values obtained during harrowing operation on a sandy loam soil. Figure 1 shows the graph plot of observed and predicted tractor fuel consumption using Model 2 of harrowing operation.

Table 4. Results of Predicted Tractor Fuel Consumption values during Harrowing Operation on a Sandy Loam Soil using Model 2 of Harrowing Operation

Tractor Observations	Observed fuel values (L/ha)	Predicted fuel values (L/ha)	Residuals (L/ha)
1	3.28	2.711058	0.568942
2	4.12	3.783405	0.336595
3	5.47	4.624426	0.845574
4	1.44	1.972107	-0.53211
5	4.76	3.74173	1.01827
6	5.26	3.453034	1.806966
7	3.2	3.192731	0.007269

8	0.9	2.68324	-1.78324
9	3.8	2.452152	1.347848
10	3.53	4.300108	-0.77011
11	3	2.040149	0.959851
12	0.85	1.749665	-0.89966
13	3.92	3.35114	0.56886
14	0.92	1.557942	-0.63794
15	2.32	2.938795	-0.6188
16	2.24	1.525242	0.714758
17	1.84	2.549917	-0.70992
18	0.8	1.956347	-1.15635
20	1.68	2.904075	-1.22407
21	1.04	1.58534	-0.54534
22	0.9	1.847902	-0.9479
24	3.4	2.173657	1.226343
25	3	2.561103	0.438897
26	4	3.364288	0.635712
27	1.6	3.417445	-1.81745
28	1.9	2.857485	-0.95749
29	2.8	3.153878	-0.35388
30	2.1	1.820463	0.279537
32	2.88	1.907434	0.972566
33	2	2.748966	-0.74897
34	4.53	5.363732	-0.83373
35	4	2.156639	1.843361
36	1.2	1.338286	-0.13829
37	4.13	3.083001	1.046999

Note: Tractor observations 19, 23 and 31 for DONFENG 700, ZECTOR (PROXIMA 75) and AGROLUX 75e tractors were not included because they contain potential outliers

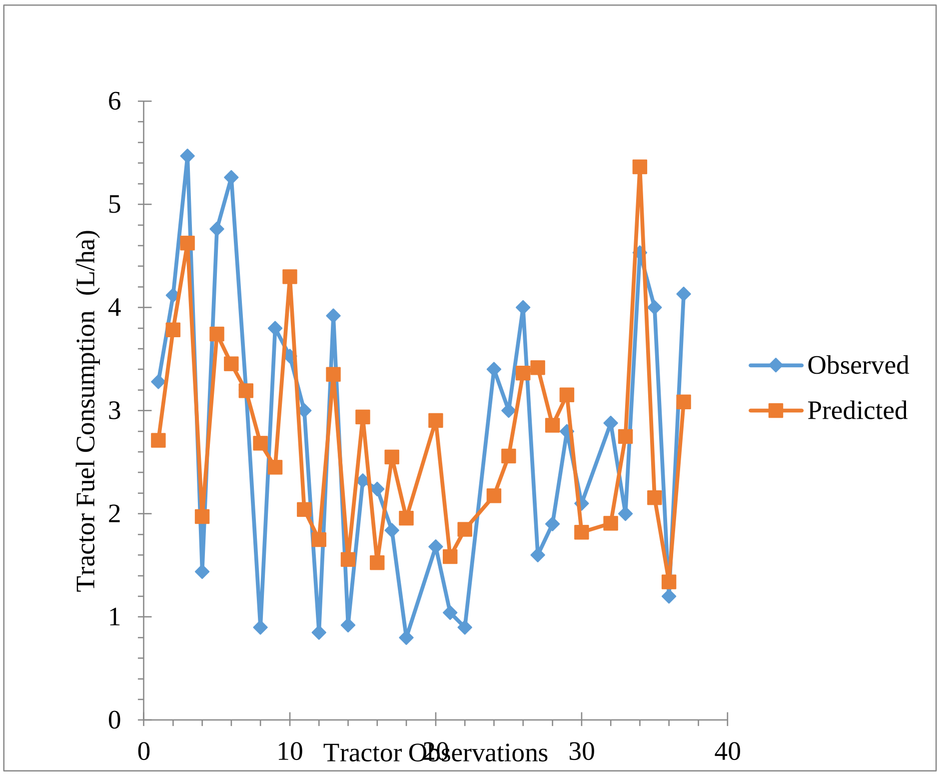

Figure 1. The plot of Observed and Predicted Tractor Fuel Consumption using Model 2 of Harrowing Operation

3.2 Model predictors for harrowing operation

The results of the parameter estimates and Analysis of Variance (ANOVA) for the only model developed for harrowing operation on a sandy loam soil as shown in Tables 2 and 3, respectively, have revealed that the only developed model for harrowing operation contains some important predictors found to be significant at 5% level. These predictors include tractor power rating, tractive efficiency and speed of operation. These three set of predictors are harrowing operation parameters affecting tractor fuel consumption in litres per hectare during harrowing operation on a sandy loam soil. Among these three factors affecting tractor fuel consumption during harrowing operation on a sandy loam soil, only tractor power rating contributed highly to the model developed. Therefore, tractor power rating, strongly determine tractor fuel consumption in litres per hectare during harrowing operation on a sandy loam soil.

3.3 Model validation for harrowing operation model

Results of 10-repeated 10-fold cross-validation method were used for validating the model developed for harrowing operation on a sandy loam soil is presented in Table 5.

It can be deduced from Table 5, that Model 2 of harrowing operation recorded a root mean square error of 0.98643 L/ha serving as the model's test error value using the four model validating datasets presented in Table 6.

Table 5. Results of 10-repeated 10-fold Cross-validation for Model 2 of Harrowing Operation

Replicate No.	MSE Value
1.	0.967218
2.	1.023916
3.	0.967739
4.	0.96743
5.	0.967155
6.	0.967337
7.	0.967429
8.	0.967726
9.	0.967282
10.	0.967218
Average MSE (L^2ha^{-2})	0.973045
Average RMSE (Lha^{-1})	0.98643

Key:

MSE – Mean Square Error

RMSE – Root Mean Square Error

Note that each replicate contains the average mean square error value of 10-fold cross-validation

Table 6. Results of Fuel Predictive and Residual values of Model 2 of Harrowing Operation used for Model Validation data

Observed fuel values (L/ha)	Predicted Fuel values (L/ha)	Residual (L/ha)
4.00	3.384845	0.61516
1.60	3.1639	-1.5639
2.60	1.671801	0.9282
1.42	0.802705	0.6173

5. CONCLUSION

A study was carried out to develop a model for future prediction of tractor fuel consumption during harrowing operation in a sandy loam soil using information gathered from NCAM Tractor Test Reports. From the outcome of this study, it can be concluded that:

1. One effective model with p-value < 0.05 was developed for harrowing operation. Model 2 of harrowing operation developed for future prediction of tractor fuel consumption in litres per hectare during harrowing operation on a sandy loam soil recorded a coefficient of multiple determination (R-squared) value of 0.4767.
2. Harrowing operation parameters such as tractor power rating, the speed of operation and tractive efficiency were found to be statistically significant at 5% level in Model 2 of harrowing operation with only tractor power rating contributing highly to the model developed.
3. The model for harrowing operation based on cross-validation result had a test error of 0.98643 L/ha.

5. ACKNOWLEDGEMENT

We want to thank members of NCAM tractor testing team for the tremendous work they have been doing over the years in the testing of agricultural tractors imported into the country for use in Nigerian agriculture.

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Relationships between Water Loss, Sediment Deposition, and Pond Age in Lagos State, Nigeria

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ABSTRACT

The issue of sediment in aquatic environments has been a topic of concern for many decades because it harbouring pathogen and decrease water depth. The investigation was carried out to identify and proffer solutions to some environmental and management problems that have hitherto affected fish production sub-sector of the economy, using Lagos State, (Western) Nigeria as a case study. Both surveying and experimental methods were used. The results indicated that water loss from ponds resulting from evaporation and seepage ranged from 2.5 – 4.6 mm day^{-1}. Percentage reduction in pond water depth during dry season ranged from 70 – 81 % as compared to the observed percentage increase during rainy season with range of values as, 17 – 34%. The mean rise and fall in water depth were 24.7 ± 3.8 % and 47.6 ± 11.7% respectively. The fall in water depth during dry season was almost twice its rise during rainy season with average percentage difference 24.4 % and 47.6 % respectively. The degree of variation among ponds was found to be significant ($t = 2.11$ at $p = 0.05$). The mean rate of soft sediment depth was 10.5 ± 1.8 cm yr^{-1}, while the soft sediment depth in silty sand ponds doubled those from mixed sandy ponds. The predictive equation indicated that soft sediment accumulation might increase with year of pond operation. The results showed significant correlation ($t = 1.988$. $p = 0.05$) between soft sediment and year of pond operation. All the earthen ponds were prone to seepage

Keywords: Sediment, water depth, water loss, pond age, seepage.

1. INTRODUCTION

The issue of sediment in aquatic environments has been a topic of concern for many decades. In assessing sedimentation, evaluation of environmental change will help to identify other factors such as precipitation, discharge, shear stress, or a change in channel pond or geometry that may also accompany the sedimentation changes (Boyd, 2009). Other factors of importance in determining sediment impacts are the temporal variations of sediment yield especially stream or river sources of water for pond impoundment (Singh, 2007). The bed load is often referred to as "sediment" by fisheries biologists and its size class was most interest and concern in fisheries studies such as suspended load (Boyd, 2009). Subaqueous plants will be significantly affected by increased suspended sediment loads because primary plant production is reduced with increases in turbidity (Shaw and Maga, 2003). The sediment decreases benthic organism diversity and density because of a limited food supply (Statzner and Higler, 2006).

Fish production from culture fisheries has been all time low in Nigeria (Ajana, 2003). Omofunmi (2010) highlighted that fish ponds are faced many problems among which are seepage, overtopping, and sediment accumulation. The sediment- water interface in aquatic system, including aquaculture ponds, was a bridge connecting bottom sediments with the overlying water column. Nutrient concentrations in pond bottom soil are typically two to four orders of magnitude higher than in water (*Ram et al., 2007; Lee, 2005; Boyd, 2009);* that was , the amounts of most chemical components in a 1-cm surficial pond soil layer are generally higher than those present in 1 m of overlying water (Lee, 2005). Materials settling from the water column to the sediment can be derived from two sources. First, particulate organic matter, consisting of biogenic material with specific gravities greater than water such as senescent algae, fish excreta, and feed residues, continuously settle from the water column (*Lee, 2005; Boyd, 2009*). In some cases, sedimentation from the water column includes suspended matter imported with water supply. Particles resuspended from the pond bottom are a second source of sedimenting material. Ponds have external and internal sediment loads. Freshwater ponds filled by runoff from denuded watersheds and brackish water ponds filled from estuaries are laden with suspended soil particles. Internal sediments result from turbulence that erodes pond bottom soils, levees and suspended particles. Sources of turbulence are wind action, aquatic animal activity, mechanical aeration and harvest operation (Boyd, 2009). Long residence time favours sedimentation of suspended particles and ponds behave as sediment basins (Ram et al., 2007). Studies on the soil as they affect fish pond performance and productivity have been carried out by researchers such as Sinha and Ramachandran, 2001; Jhingram, 2002 and Kumar, 2004. The important of climatological data was highlighted by Coche, (2006) that it helps in the estimation of height, size and capacity of dike and also influences the choice of pond depth and pond location. In the coastal area, the presence of vegetation has sometimes been used for the assessment or an indicator of soil property. Evaporation rates, temperature and wind velocity are among climate parameters that are important in pond design and operation. Coche (2006) suggested that addition of annual evaporation allowance of 1250 mm to the water budget for pond operation. Evaporation contributes to the fall in water depth, rise in water temperature and reduction in dissolved oxygen content of the pond (Huet, 2000 and Kumar, 2004). Boyd (2009) highlighted that most ponds are static water system, while others are characterised by copious water exchange. Water seldom exceeds 20 – 30 % of pond volume per day and it is usually much less. Physical problems were identified by Sinha and Ramachandran, (2001); Jhingram, (2002); Coche, (2006), and Kumar. (2004) include, seepage, piping, flood hazard, leakage of dike. Rot (corrosion) of construction materials, siltations, cracking of dike and drying of pond. Sinha and Ramachandran, (2004) estimate indicated that about 20 % rises in normal water depth in ponds sited in swamp areas of India attributed to seepage. Similarly, Jhingram, (2002) findings indicated about 20 – 60 % fall in normal water depth of ponds sited in swamp areas and also stated that about 5 % loss in fish farm investment was attributed to seepage. Flood effects in the pond performance have been examined by several investigators such as Kumar, 2004; Huet, 2000 and Pillay, 2003. They reported that the flood accelerated the erosion of ponds, aid the quick collapse of pond structures, introduce predator to ponds, increase the cost of maintenance of ponds, enhance siltation (sediment deposition) and increase loss of fish pond investment. Sediment is a resource out of place whose dual effect is to deplete the land from which came and impair the quality of the water it enters. Sediment accumulations apart from harbouring pathogens (bacteria) and chocked fries and eggs, it also decreases water depth and leading to temperature variations especially during dry season (Boyd, 2009). Sediment also causes off flavour in the fish, produces distinct odour and reduces water volume (Chapman, 2006). The bacteria found in sediments, dependent on the content of organic substances and the particle size of the sediment. The smaller the particle size, the higher the bacterial counts. With the expansion of pond culture system in Nigeria, the importance and crucial role of engineering expertise cannot be over- emphasized. Planning for the site selection, design, and construction of a pond is one of the most important steps in the pond management process (Whitis, 2002). Common design and construction mistakes can result in pond seepage. Poor selections of sites, lack of hydrological data and defective design and construction of pond structures have often been the cause of failures of fish pond (Coche and Muir, 2002). The objectives of this study are:

(i) To assess the variation of pond water depth during dry and rainy seasons
(ii) To examine the relationship between sediment deposition and age pond operation.

2. MATERIALS AND METHODS

2.1 Study Area

Lagos State, southern Nigeria falls within longitudes $03^{O}50^{!}$ E and $03^{O}38^{!}$ E and latitudes $06^{O}20^{!}$ N and $06^{O}38^{!}$ N. It has an area of 3,577 km^2 with about 20% of this covered by lagoon and associated creeks. The area is characterized by humid climate with distinct dry and wet seasons lasting November to March and April to October respectively (Fig. 1).

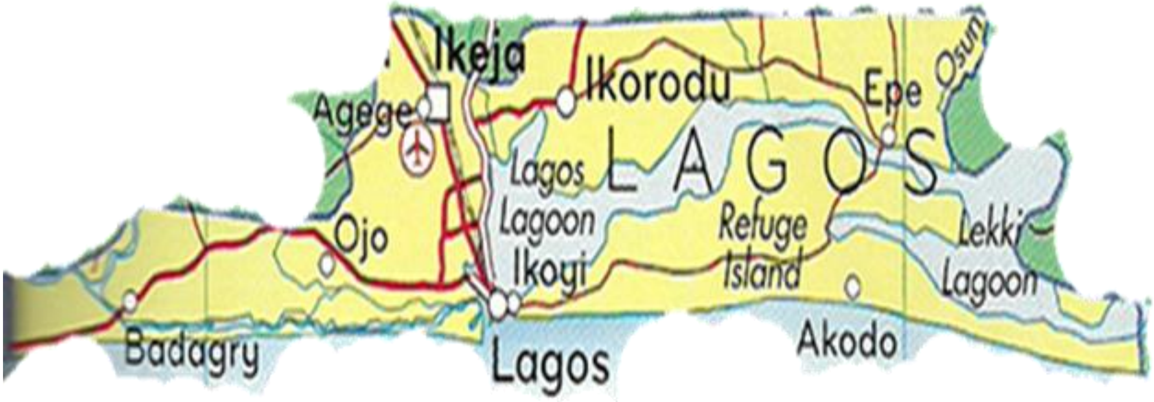

Figure 1: Map of Lagos State showing the study area.

2.2 Field Survey and Data Collection

Forty five fish ponds were chosen for this study .The rationale for the choice of ponds was predicated on the assumption that such ponds are sited in geographical areas fairly represented of the soil and climate characteristics in Lagos State. Monthly trips were made to the selected ponds during the rainy and dry season respectively. Primary data collections for the study were based on both on-the-spot assessment of selected fish farms and administration of structured questionnaire designed for fish farm operators. Secondary data on climatology were collected from associated government agencies. Data on temperature and evaporation are presented in Tables 1 and 2 respectively. Pond water depth was determined by sounding technique employing an improved 5m long graduated bamboo pole fitted at the base with a wooden disc of 5cm diameter. Simultaneously; sediment accumulation was measured with the same device, but a 10 cm diameter disc. Data on sediment deposition and years of pond operation is presented in Table 3.

2.2 Data Analysis

Data were analyzed using descriptive statistics. Student's t-test was applied to determine the differences between soft sediment deposition and length of pond operation and also change in water level amongst the ponds.

3. RESULTS AND DISCUSSION

The maximum temperature in the study area ranged between 27.6 ^{O}C and 31.8 ^{O}C in February, while the minimum temperature ranged between 23 ^{O}C and 26.8 ^{O}C with the least being in July (Table 1). The temperature is one of the factors for determination of water budget in the fish pond.

Table 3: Mean Daily Minimum and Maximum Temperature (^{O}C) the Period (1982 – 2016)

Month	Minimum Temp. (^{0}C)	Maximum temp. (^{O}C)	Average temp. (^{0}C)
January	24.0	30.9	27.5
February	24.8	31.8	28.3
March	25.5	31.4	28.5
April	25.0	28.2	26.6
May	24.9	27.6	26.3
June	23.4	28.7	26.1
July	23.1	27.0	25.1
August	23.2	27.3	25.3
September	23.3	27.9	25.6
October	23.6	29.1	25.7
November	24.5	30.5	27.5
December	24.4	30.9	27.7

Table 2: Mean Daily Evaporation (mm) the Period (1982 – 2016)

Month	Maximum evaporation. (mm)	Minimum evaporation (mm)	Average evaporation (mm)
January	6.1	2.8	4.0
February	5.4	4.0	4.8
March	4.7	4.1	4.5
April	4.2	3.4	3.8
May	3.7	3.4	3.5
June	3.1	2.8	2.9
July	2.9	2.1	2.8
August	2.7	2.2	2.6

September	2.6	2.2	2.5
October	3.0	2.6	2.8
November	3.9	3.2	3.8
December	3.6	3.5	3.6

The mean rise in water depth in the rainy season was 24.7 ± 3.8 % with a range of 17 – 34 %. While the mean fall in water depth in the dry season was 47.6 ± 11.7 % with a range of 70 – 81%. The fall in water depth during drought was almost twice its rise during rainy season and this is buttressed by the degree of variations among ponds which was found to be statistically significant ($p = 0.05$). The falls in water level during dry season was caused by seepage and evaporation; conversely, the rise in water level was caused by seepages as well as flood (Jhingram 2002). Rapid change in water level appears to be serious in almost all the ponds in the study area (Fig. 2). Values of water loss from the ponds resulting from evaporation and seepage ranged from 2.5 – 4.6 mm day^{-1}. Evaporation and seepage are important factors for determination of water budget in the fish pond. Our observation that the fall in water depth during drought was almost twice its rise during rainy season, this is in agreement with the findings of Jhingram (2002) who reported that fall in water depth during dry season was more severed when compared with the rise in water level during the rainy season. However, our finding differs slightly from the observations made by Sinha and Ramachandran, (2001) which might be attributed to variability in installation modes. For the avoidance of doubt, Sinha and Ramachandran, (2001) estimated about 20 % rise in normal water depths in ponds sited in swampy area, while an average value of 24.7 ± 3.8 % was obtained in this study with a range of 17 – 34 %. This difference might be due to different soil types, different degree of pudding or compaction especially during construction and level of treatment applied to the ponds. Besides, evaporation and seepage, the observed trends in the rise and fall in the pond water level in the study area and characterised by marked seasonal variations, may be attributed to such factors as, excessive fertilization with organic manure, soil types which allow for infiltration of water through the organic laden pond dikes and embankments. Besides, high insolation for most of the year which enhance high level of evapotranspiration in the height of the pond walls as a result of rapid decomposition of the material used. Similarly, organic sediments in the ponds originate primarily from plankton while other sources include; manure application, uneaten feed, aquatic animal faeces and aquatic vegetation. An understanding of sediment sources and the principles of sedimentation are of practical value to pond managers

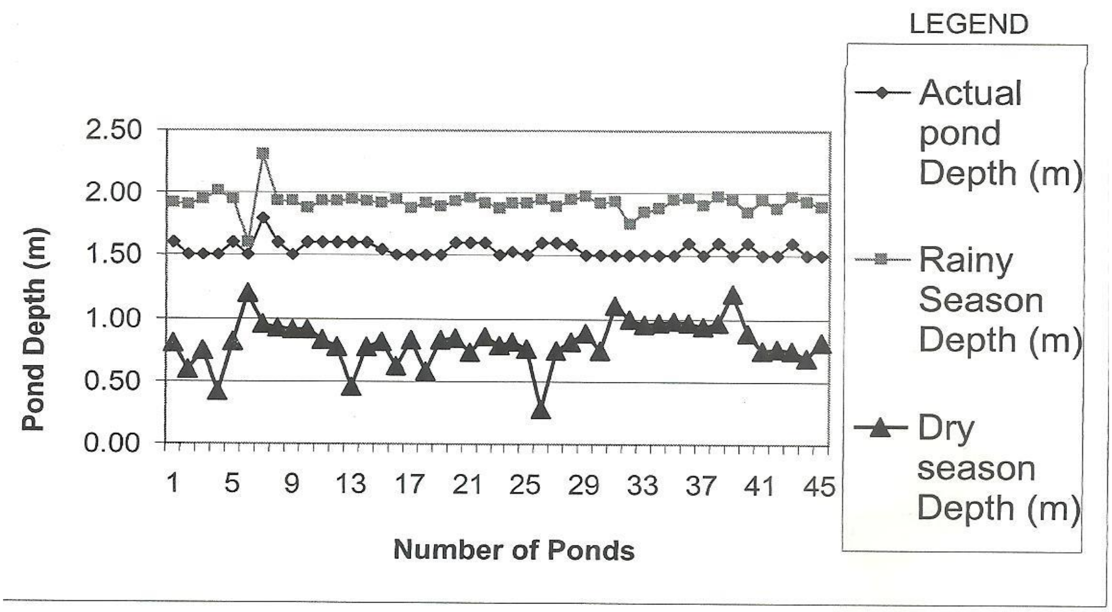

Fig.2. Ponds water depth variation during dry and wet seasons

Coding

1 – 10	Badagry Location
11 – 15	Ojo Lacation
16 -17	Ajeromi Ifelodun Location
18 – 25, 30 – 40	Ikorodu/ Majidun Location
26 – 29	Ibeju Lekki Location
41 – 45	Agege/ Iju Location

The mean rate of soft sediment depth was 10.5 ± 1.8 $cmyr^{-1}$. The result shows significant relationship ($p = 0.05$) between soft sediment and deposition and year of pond operation. Equation (1) shows the predictive equation between soft sediment deposited and length of pond operation. Figure 3 shows a graphical representation of the relationship between soft sediment accumulation and years of pond operation.

Table 3: Relationship between Soft Sediment Depth and Year of pond operation of selected
Fish Ponds in Lagos State

Code	Years of Operation (yr)	Soft Sediment Depth (cm)
001	3	30.5
002	6	42.1
003	5	40.1

004	4	32.5
005	3	28.4
006	4	46.3
006	5	50.3
008	4	31.6
009	4	36.3
010	5	43.6
011	4	49.3
012	6	45.4
013	3	26.4
014	2	18.2
015	3	24.3
016	3	26.4
017	4	33.6
018	5	43.3
019	1.5	20.9
020	4	46.3
021	3	28.6
022	3	19.6
023	6	58.3
024	2	21.6
025	3	36.3
026	4	43.6
027	2	22.1
028	3	33.8
029	1.5	20.4
030	4	48.3
031	3	36.3
032	5	40.1
033	2	19.8
034	3	27.9
035	4	41.3
036	3	40.2
037	2	19.8
038	4	46.3
039	2	20.6
040	3	39.8
041	4	43.8
042	3	38.8
043	3	39.8
044	3	38.3
045	2	24.2

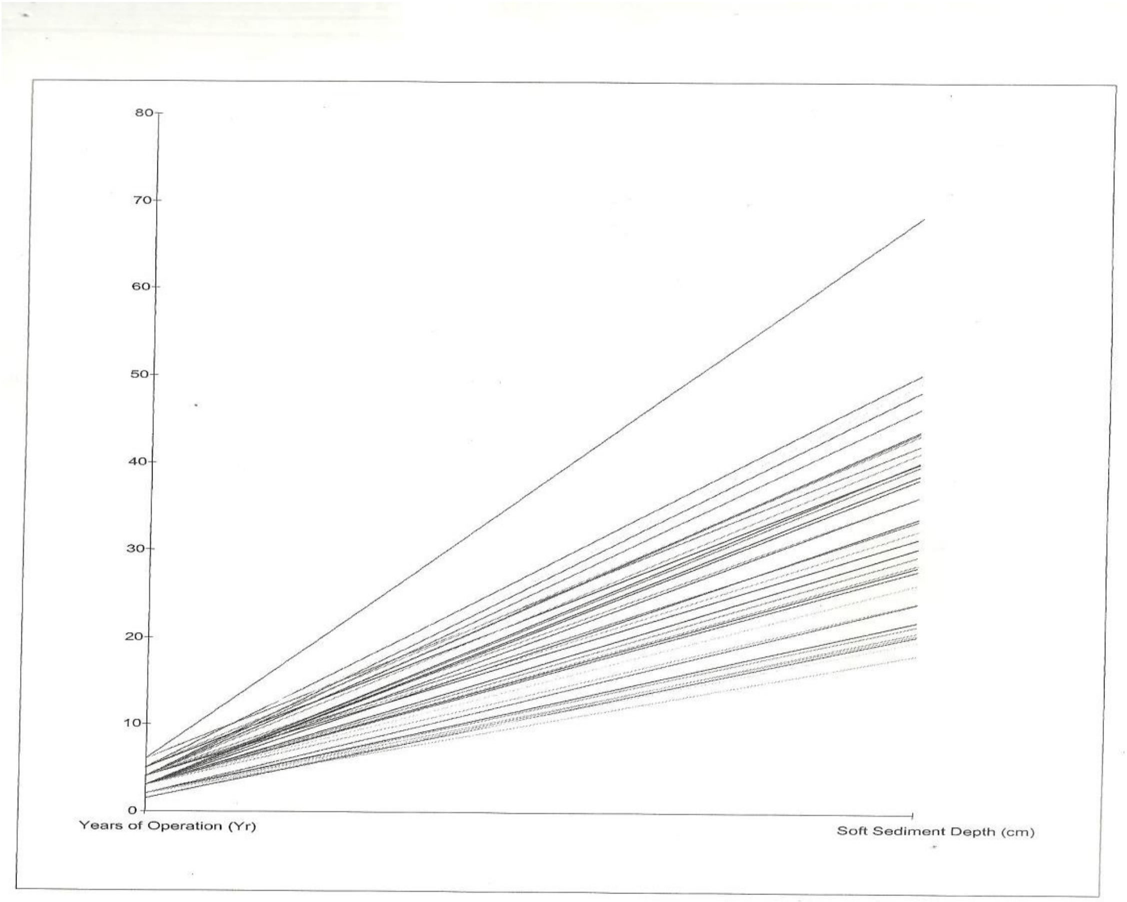

Fig. 3: Relationship between soft sediment accumulation and years of pond operation

The relationship between soft sediment depth and year of pond operation was presented by a predictive equation as follows:

$S = 9.3 + 7\ (y - n)$ (1)

Where,

S = Soft sediment depth (cm)

y = Year of pond operation

n = Sediment coefficient factor, was used with consideration for the soil types and their corresponding sediment coefficient factors (See Table 4).

Table 4: Sediment Coefficient factors of soil types

Soil Type	Sediment Coefficient factor (n)
Mud bottom	-
Sandy bottom	1.0
Sandy clay	0.9
Loam	0.5
Loam clay	0.6
Clay	0.8

Over a period of several years, sediments can fill ponds and severely interfere with pond operation. This scenario in Lagos State is not too different from our result as a sediment depth of 43.4 cm for five-year old operations. Average sediment depth of 45 cm was observed for a five-year old shrimp pond in Ecuador (Boyd, 2009). This high value of sediment depth can be attributed to some fish ponds that are heavily treated with manure. Application rates normally ranges from 50 – 100 kg per month as extracted from the administered. It has been observed from structured questionnaires even though manure stimulates phytoplankton production, the life span of phytoplankton cells range from 1–2 weeks with resultant dead cells settling at the pond bottom. Most of the ponds investigated in this study have never been denuded since they came into operation, and this accounts for accumulation of silt with reduction in pond depth. In consequence, low level of dissolved oxygen can prevail because of high temperature resulting from quick light penetration of the shallow pond water besides high biological oxygen demand (BOD) occasioned by the degradation of the organic load. Long hydraulic residence time averaging 250 days in the ponds investigated, presupposed a semi-intensive method of fish culture, hence the high level of organic sedimentations. The predictive equation indicated that soft sediment accumulation was found increase with year of pond operation. The results showed significant correlation ($p = 0.05$) between soft sediment and year of pond operation.

4. CONCLUSION AND RECOMMENDATIONS

The following conclusions were made. There are variations in water depth and sediment depositions in the pond of the same years in operation; Variation in water depth and sediment deposition was greater in the ponds located in the swampy areas than inter-land and variation in water depths were greater during dry season than rainy season. All the ponds were prone to seepage. The effects of seepage and soft sediment deposition on the biological, physical and chemical proportion of pond water can to a great extent affect fish production except appropriate management tools are employed.

Excessive application of organic manure especially, poultry droppings by direct deposition in the pond as direct or indirect food by farmers should be discouraged.

The following are recommended for both erosion and sediment preventions:

(i) Erect a wide barrier of vegetation around the edge of pond to prevent erosion and intercept sediment
(ii) Rip rap: Utilize stones to Preserve the Shoreline of the pond
(iii) Fencing the pond to keep pasture animals away
(iv) Berms: building earthen berm around the edge of pond
(v) Vegetative Buffers: Planting thick vegetation along the pond
(vi) Sediment flushing: It is a technique whereby sediment previously accumulated and deposited in a pond is hydraulically eroded and removed by accelerated flows created when the bottom outlets of a pond are opened
(i) Consults experts such as Aquacultural Engineering or others related professionals
(ii) Installation of retention pond (settling basin) at inlet pond
(iii) Aerate the pond to increase concentration of oxygen and reducing organic sediment
(iv) Application of Bioaugmentation (adding beneficial microbes to a pond to breakdown or organic matter)
(v) Dredging and Physical modifications.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

A Mathematical Model for Predicting the Cutting Energy Requirements of Okra *(Abelmoschus Esculentus L.)*

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ABSTRACT

Cutting energy requirements for vegetable crops is a prerequisite in the engineering design of appropriate cost effective cutting systems consuming minimum amount of energy while still providing high quality products. This study attempts the development of predictive equations describing the cutting energy for okra *(Abelmoschus esculentus L.)***.** Dimensional analysis based on the Buckingham pi theorem was used to obtain the functional relationship between the cutting energy of the selected vegetable and the independent variables such as tool weight (w), height of tool drop (H_d), tool edge thickness (t), cutting speed (v), crop size (s), crop moisture content (φ), crop contact area (A) and crop density (σ). The developed model was validated with experimental data. A high coefficient of determination of R^2 value of 0.973 between the predicted and measured energy values showed that the method is good. Hence the obtained predictive model is appropriate for determining the cutting energy requirements of okra up to 97%.

Keywords: Modeling, okra *(abelmoschus esculentus l.)*, cutting energy, dimensional analysis, crop size, Nigeria.

1. INTRODUCTION

Agricultural products often occur in sizes too large to be used, and therefore they need to be reduced and put into different sizes and shapes like cubes, thin slices or rings to facilitate further processing. Cutting, which is a size reduction activity, is an energy consuming operation. However, the cutting energy requirements of vegetables have been estimated using different cutting systems and approaches (McGorry *et al.*, 2003, Blahovec, 2007; McCarthy *et al.*, 2007 and Atkins, 2009) with the following objectives; to know the most efficient cutting conditions necessary for optimization of the cutting process; to determine the optimal energy required to cut and to achieve an overall efficient cutting operation. Ciulica and Rus 2011, Elżbieta and Agnieszka, 2012; and Singh *et al.,* 2016 have identified blade sharpness, slicing angle, contact area, depth of cut, cutting speed, and the engineering properties of vegetables such as crop variety, maturity stage, moisture content, orthogonal dimensions and fiber orientation as some of the parameters affecting the energy requirements for cutting of vegetables.

Okra *(Abelmoschus esculentus L.)* is a fruit vegetable of interest in this work. Okra or lady's finger, deriving its name from the 'Igbo' word 'ọ́kụ̀rụ̀' (*McWhorter, 2000)* is a widely cultivated vegetable crop in most parts of the world and one of the most popular vegetables in many West African markets and some other regions of the world (Oyelade *et al.*, 2003; Andras *et al.,* 2005; Saifullah and Rabbani, 2009). About 10% of the world's annual okra production comes from West Africa with Nigeria as the leading producer (Burkil, 1997). In South-Western Nigeria, the three known cultivars of okra are *yaaya* or *kògbóyè*, which has long slender pods; *kúdìkán* or *ilá-òjò,* which has short, sturdy pods and *ilá-ìròkò* which has long sturdy pods (Farinde *et al.*, 2007).

Okra is a multipurpose crop due to the various uses of the fresh leaves, buds, flowers, pods, stems and seeds. The benefits derivable from the okra fruit include nutritional benefits; a good source of minerals, vitamins, carbohydrate, protein and essential amino acids; (Adeboye and Oputa, 1996; Adom *et al.,*1996; Okra Food, 2003; Sobukola, 2009), medicinal benefits; detoxifies and aids digestion in human nutrition (Makose and Peter, 1990; Owolarafe and Shotonde, 2004) industrial benefits; valuable material for gum, paper glazing and quality soap making, contains glycans used in aqueous suspensions, an excellent source of iodine and raw material for flocculant used for removal of solid wastes from tannery effluent (Owoeye *et al.*, 1990; Agarwal *et al.*, 2003; Falade and Omojola, 2010) and economically it is a high income earner for vegetable farmers in producing countries (Schippers, 2000). Okra, like many other vegetables is highly perishable due to its relatively high moisture content, soft texture and high respiration rate. (Atanda *et al.*, 2011) and the traditional method of preserving fresh okra pods which involves spreading it in the air for few hours during cold weather only makes it preserve for just 3-4 days (Schippers, 2000 and Sobukola, 2009) after which, it becomes tough and unsuitable for use as a fresh vegetable. The unsold lots are processed by manually cutting into slices and sun-drying to preserve it, thereby extending its availability from one season to the other, improves the shelf life and also forestalling seasonal wastage. This manual cutting operation is a most laborious, time consuming one with the challenges of contaminations of the product and injury to the hand. There have been efforts made by some researchers at developing equipment for handling the cutting operation (Owolarafe *et al*., 2007, Ogbobe *et al.*, 2007).

However, in spite of its many industrial, medicinal, economic and nutritional benefits, studies reveal that it is among the least studied vegetables, which portends a danger of gradual disappearance from our meal menu and eventual extinction unless urgent attention is given to it. Also, it suffers a lot of postharvest losses due to inadequate post-harvest handling technologies which makes the crop scarce and expensive when it is not in season. Hence cutting of okra as a postharvest handling operation will enhance further processing such as drying, packaging and preparation into several food forms.

Furthermore, extensive documentation on the properties of foods and food products exist, however data related to the cutting energy of different vegetables such as okra is scarce, even though such data is important in the design of cutters. This observation is affirmed by researchers like Saravacos and Kostaropoulos (2002) in their assessment that less work has been performed on energy involved for cutting of different food materials, and Brown *et al.* (2005) who opined that limited published literatures on specific energy requirement in cutting of fruits and vegetables are available. Also, Mitcham *et al.* (1996) agreed that literature related to cutting of fruits and vegetables are limited, Hence the need to intensify research activities in this post harvest area of cutting and determining the energy requirements for cutting vegetables such as the (*ilá-ìròkò)* variety of okra.

1.1 Modeling Agricultural Processes

Modeling, simply defined is a representation in mathematical terms of the behavior of real devices and objects, or a system of postulates, data and inferences presented as a mathematical description of an entity or state of affairs. It could be descriptive, explanatory or predictive. In the prediction part, which can be envisaged as organized thinking of the possible, models are exercised to give information on a yet-to-be-conducted experiment. These predictions are then followed by observations that serve either to validate the model or to suggest reasons that the model is inadequate (Dym and Ivey, 1980; Dym, 1994 and Cha *et al.*, 2000). Various mathematical modeling techniques that are in use include: dimensional homogeneity and analysis, abstraction and scaling, conservation and balance principles and consequences of linearity.

However, Dimensional analysis has become a widely applicable and very powerful technique that is adopted in mathematical modeling. This is due to its simplicity in planning, presentation, and interpretation of experimental data, providing an organised way to plan and carry out experiments, and enables one to scale up results from model to prototype (Bahrami *et al.,* 2006). The dimensional analysis is a mathematical technique used in identifying the factors involved in a physical situation or phenomenon and forming a relationship between them. It offers a method for reducing complex physical problems to the simplest form prior to obtaining a quantitative answer (Andrzej, 2015). Although there are other methods of performing dimensional analysis, notably the indicial method, the method based on the Buckingham pi theorems gives a well organized procedure for obtaining a solution. The Buckingham pi theorem states that the number of dimensionless and independent quantities required to express a relationship among variables in any phenomenon is equal to the number of quantities involved minus the number of dimensions in which those quantities may be measured'(Fox and McDonald, 1992). Mathematically speaking, if there is a physically meaningful equation involving a certain number (*n)* of physical variables, then the original equation can be rewritten in terms of a set of $\boldsymbol{p = n - k}$ dimensionless parameters ($\boldsymbol{\pi_1, \pi_2, ..., \pi_p}$) constructed from the original variables (Hart, 1995), (Here *k* is the number of physical dimensions involved; which in this situation, (K = 3 i.e. Mass, Length and Time).

The application of mathematical models in different aspects of agricultural engineering including tillage operations (Fielke, 1999), spraying machines (Teske *et al.,* 1991), crop handling machines (Gorial and O'Callaghan, 1991), harvesting (Baruah and Panesar, 2005*a and b*) and many versatile topics on post harvesting aspects have been successfully attempted such as; modeling flow rate of egusi-melon (*Colocynthis citrullus*) through circular horizontal hopper orifice (Asoegwu *et al*., 2010); modeling the grain cleaning process of a stationary sorghum thresher (Simonyan *et al.,* 2006) , modeling the drying process of a hybrid convective vegetable crop dryer (Nwakuba, 2018) and development of a model to describe infrared radiative and convective drying characteristics of onion slices for optimum management of operation parameters (Jain and Pathare, 2004).

Although a few research attempts have been made to model cutting processes like mathematical models and laboratory tests of Impact cutting behaviour of forage crops, (McRandal and McNulty, 1978); performance modeling of the cutting process in sorghum harvesting (Mohammed, 2002), mathematical modeling of laser based potato cutting and modeling yield efficiency of peeling (Ferraz *et al.*, 2007, Somsen *et al.*, 2004), much is left undone on modeling the energy requirement for cutting vegetables.

Some researchers used the dimensional analysis based on the Buckingham's pi theorem as veritable instrument in establishing a prediction equation of various systems which include the development of screw-conveyor performance models using dimensional analysis, (Degrimencioglu and Srivastava, 1996); a mathematical model for predicting output capacity of selected stationary grain threshers (Ndirika, 2006); a mathematical model for predicting the cracking efficiency of vertical-shaft centrifugal palm nut cracker (Ndukwu and Asoegwu, 2011); and modeling flow rate of egusi-melon (*Colocynthis citrullus*) through circular horizontal hopper orifice (Asoegwu *et al.*, 2010).

The size reduction operation by cutting in most postharvest processes is a most laborious, time wasting and energy consuming task which deserves research attention. These studies are necessary in order to discover methods of efficiently improving the cutting process by maximizing the scarce energy, time and resources available and optimally enhancing the post harvest operations concerned. Hence the need to undertake the present study which will establish a mathematical model using dimensional analysis based on the Buckingham's pi theorem to predict the cutting energy requirements for okra *(Abelmoschus esculentus L.).* The mathematical model will become a design tool for machine designers in the development of energy saving and cost effective cutting systems that will provide good quality cut products.

2. MATERIALS AND METHODS

2.1 Theoretical Development

Factors affecting the cutting energy requirements of vegetables obtained from literature include tool parameters like (materials of construction, sharpness, rigidity of cutting tools, knife speeds, etc.) and physical properties of the plant material like (crop variety, size, maturity stage, crop moisture content , crop density, fibre orientation, etc.) (Nadulski, 2001; Szot *et al.*, 1987; Atkins, 2009; Blahovec, 2007; McCarthy *et al.*, 2007; and McGorry *et al.*, 2003). In the development of the model, dimensional analysis based on the Buckingham pi theorem was employed which is a technique used in identifying factors involved in a physical situation and forming a relationship among them. The Buckingham pi theorem states that the number of dimensionless and independent quantities required to express a relationship among variables in any phenomenon is equal to the number of quantities involved minus the number of dimensions in which those quantities may be measured (Fox and McDonald, 1992).

i.e. if N = number of variables involved in a physical situation

x = number of dimensions in which quantities may be expressed = (3), M, L, T

M = Mass; L = Length; T = Time

n =number of dimensionless groups as given in Equation 1.

Hence, n = N - x …1

However, due to the large number of variables influencing the energy of cut of the selected fruit vegetable, assumptions will be made in order to bring these large numbers to a reasonable and manageable number. (Simonyan *et al.*, 2006).

2.2 Assumptions made in Model Development

- Variables that are design parameters which are measurable were considered.

- Variables that are functions of other variables were not considered e.g. volume which is a function of crop size. However, cutting speed which is a function of time was considered instead of time.
- The fiber orientation, textural properties (inner hollow texture) and crop variety are considered negligible in the model development, since only the horizontal orientation of the okra fruit is considered.

2.3 Development of the Functional Energy Equation.

These assumptions helped in reducing the number of variables involved to the underlisted as these were considered to have greater influence on the energy of cut of the selected vegetable (okra) and are measurable. The chosen variables are: tool weight (w), height of tool drop (H_d), tool edge thickness (t), cutting speed (v), crop size(s), crop moisture content (φ), crop contact area (A) and crop density (σ).

Having identified the core variables influencing the energy required for cutting the selected vegetable, Equation 2 represents the functional equation of the predictive model.

i.e $E = f(w, H_{d,} t, v, s, \varphi, A, \sigma)$ …. (2)

Where E is the cutting energy of the okra crop (J) w = Tool weight; H_d = Height of tool drop; t = Tool edge thickness; v = Cutting speed; s = Crop size; φ = Crop moisture content; A = Crop contact area and σ = Crop density. Three primary dimensions M= Mass, L= Length, T= Time were chosen in the description of the variables. From the Buckingham pi theorem (Fox and McDonald, 1992) the total number of dimensionless groups to be formed is as given in Equation 1 above.

i.e $n = N - x$

N = number of variables involve in the situation studied = 9

x = number of dimensions for describing these variables = 3

Hence $n = 9 - 3 = 6$ $\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6$

Hence six dimensionless groups were formed namely; Π_1, Π_2, Π_3, Π_4, Π_5 and Π_6. In determining the dimensionless groups, the following procedure was adopted (Fox and McDonald, 1992).

The variables utilized in the establishment of the model equation for the cutting energy of the selected vegetable were expressed in terms of their dimensions as shown in Table 1.

Table 1. List of variables and their dimensions

S/N	VARIABLE	SYMBOL	UNIT	DIMENSION
1	Energy	E	kgm^2s^{-2}	ML^2T^{-2}
2	Tool weight	w	$kgms\text{-}^2$	MLT^{-2}
3	Height of tool drop	H_d	m	L
4	Tool edge thickness	t	m	L
5	Cutting speed	v	ms^{-1}	LT^{-1}
6	Crop size	s	m	L
7	Crop moisture content	φ	φ	$M^0L^0T^0$
8	Crop contact area	A	m^2	L^2
9	Crop density	σ	kgm^{-3}	ML^{-3}

The dimensional matrix of the variables is shown in Table 2. This is needed to develop the indices of the involved variables.

Table 2. Dimensional matrix of variables

S/N	VARIABLE	SYMBOL	M	L	T
1	Energy	E	1	2	-2
2	Tool weight	w	1	1	-2
3	Height of tool drop	H_d	0	1	0
4	Tool edge thickness	t	0	1	0
5	Cutting speed	v	0	1	-1
6	Crop size	s	0	1	0
7	Crop moisture content	φ	0	0	0
8	Crop contact area	A	0	2	0
9	Crop density	σ	1	-3	0

From the above matrix, φ is dimensionless and therefore excluded from the dimensionless terms determination and is to be added later (Simonyan *et al*, 2006) while the other variables were combined to form the Π groups. Cutting speed (v), tool weight (w) and crop size (s) were selected as the major parameters (i.e. recurring set) because they contain all the primary dimensions involved in this problem and their combination does not form a dimensionless group. Having selected w, v and s as the recurring set, the exponents a, b and c are attached to them respectively so that when their product $w^a v^b s^c$ divide the remaining variables E, H_d, t, σ and A, the dimensionless groups Π_1, Π_2, Π_3, Π_4 and Π_5 are obtained as given in Equations 3 to 7 (Ndirika, 2006; Simoyan *et al.*, 2006; Asoegwu *et al.*, 2010; Ndukwu and Asoegwu, 2011) .This is the basis of the Buckingham pi theorem of dimensionless groups.

$$\Pi_1 = \frac{E}{w^a v^b s^c} \quad \ldots 3$$

$$\Pi_2 = \frac{H_d}{w^a v^b s^c} \quad \ldots 4$$

$$\Pi_3 = \frac{t}{w^a v^b s^c} \quad \ldots 5$$

$$\Pi_4 = \frac{A}{w^a v^b s^c} \quad \ldots 6$$

$$\Pi_5 = \frac{\sigma}{w^a v^b s^c} \quad \ldots 7$$

Where a, b, and c are exponents needed to make the groups non-dimensional. The variables are substituted with their dimensions and the non-dimensional Πs are replaced with $M^0L^0T^0$ which is a dimensionless group. In order to obtain values for the exponents, the principle of dimensional homogeneity is used to equate the dimensions on each side of the equations of the Π groups.

Equation 3 being expressed in terms of the dimensions on both sides becomes Equations 8

$$M^0L^0T^0 = \frac{ML^2T^{-2}}{(MLT^{-2})^a(LT^{-1})^bL^c} \qquad \ldots 8$$

Cross- multiplying Equation 8 gives Equation 9.

$$M^0L^0T^0((MLT^{-2})^a(LT^{-1})^bL^c) = ML^2T^{-2} \qquad \ldots 9$$

Using dimensional homogeneity for M, L and T, the exponents a, b and c are got in equations 10, 11, 12 and 13.

For M; $M^{0+a} = M^1$

0 + a = 1

a = 1 …10

For L; $L^{0+a+b+c} = L^2$

0+a+b+c = 2; from 3.10, a = 1

1+b+c =2

b+c = 2-1 =1

b+c = 1 …11

for T; $T^{0-2a-b} = T^{-2}$

-2a – b =-2

Since a =1

-2(1) – b = -2

-b = -2+2 =0, b = 0 …12

From Equation 11, b + c = 1, put b=0

0+c=1; c=1 …13

Hence, a = 1, b = 0, c = 1; replacing the exponents with their values,

Π_1 becomes Equation 14

$$\Pi_1 = \frac{E}{w^1 v^0 s^1} = \frac{E}{ws} \qquad \ldots 14$$

Similarly, solving for the remaining Π groups, we obtain Equations 15 to 19.

$$\Pi_2 = \frac{H_d}{s} \qquad \ldots 15$$

$$\Pi_3 = \frac{t}{s} \quad \ldots 16$$

$$\Pi_4 = \frac{A}{s^2} \quad \ldots 17$$

$$\Pi_5 = \frac{\sigma v^2 s^2}{w} \quad \ldots 18$$

$$\Pi_6 = \varphi \quad \ldots 19$$

Combining these equations gives Equation 20, whose components are dimensionless.

i.e. $\frac{E}{ws} = f\left(\frac{H_d}{s}, \frac{t}{s}, \frac{A}{s^2}, \frac{\sigma v^2 s^2}{w}, \varphi\right)$ …20

Combining the dimensionless terms to reduce it to a manageable level (Shefii *et al.* 1996) by multiplication and/or division, we obtain Equations 21 to 23 which are dimensionless.

$$\Pi_{12} = \frac{\Pi_1}{\Pi_2} = \frac{E}{ws} \times \frac{s}{H_d} = \frac{E}{wH_d} \quad \ldots 21$$

$$\Pi_{34} = \frac{\Pi_3}{\Pi_4} = \frac{t}{s} \times \frac{s^2}{A} = \frac{ts}{A} \quad \ldots 22$$

$$\Pi_{56} = \frac{\Pi_5}{\Pi_6} = \frac{\sigma v^2 s^2}{w} \times \frac{1}{\varphi} = \frac{\sigma v^2 s^2}{w\varphi} \quad \ldots 23$$

The new dimensionless functional relationship becomes Equations 24 and 25.

$$\Pi_{12} = f(\Pi_{34}, \Pi_{56}) \quad \ldots 24$$

$$\frac{E}{wH_d} = f\left(\frac{ts}{A}, \frac{\sigma v^2 s^2}{w\varphi}\right) \quad \ldots 25$$

From Equation 25, the Equations for E are obtained as Equations 26 and 27.

$$E = wH_d\left(\frac{ts}{A}, \frac{\sigma v^2 s^2}{w\varphi}\right) \quad \ldots 26$$

$$E = f\left(\frac{tswH_d}{A}, \frac{\sigma v^2 s^2 H_d}{\varphi}\right) \quad \ldots 27$$

Equation 27 gives the cutting energy E, with all the parameters in Equation 2, as a function of two energy components $\frac{tswH_d}{A}$ and $\frac{\sigma v^2 s^2 H_d}{\varphi}$ which are represented as P and Q in Equation 28.

$$E = f(P, Q) \quad \ldots 28$$

2.4 Experimental Procedure

Green, mature and freshly harvested okra fruits (*ilá-ìròkò* variety) that were healthy and free from mechanical injuries were purchased from a local farmer in Owerri west Local government area of Imo state, Nigeria. They were thoroughly cleaned of all impurities and unwholesome fruits and thereafter sorted into four size ranges of 10 fruits each and some physical properties were obtained at an initial moisture content of 89.41± 0.4% (wb) (AOAC, 2000). With an automated vegetable cutter, at a preset speed of 30mm/min, the cutter drops from a height of 20cm, cutting the sample as it travels through it. The force-time relationship displayed on the monitor was used to calculate the cutting energy. Plate 1.0 shows the experimental set-up of the cutting mechanism.

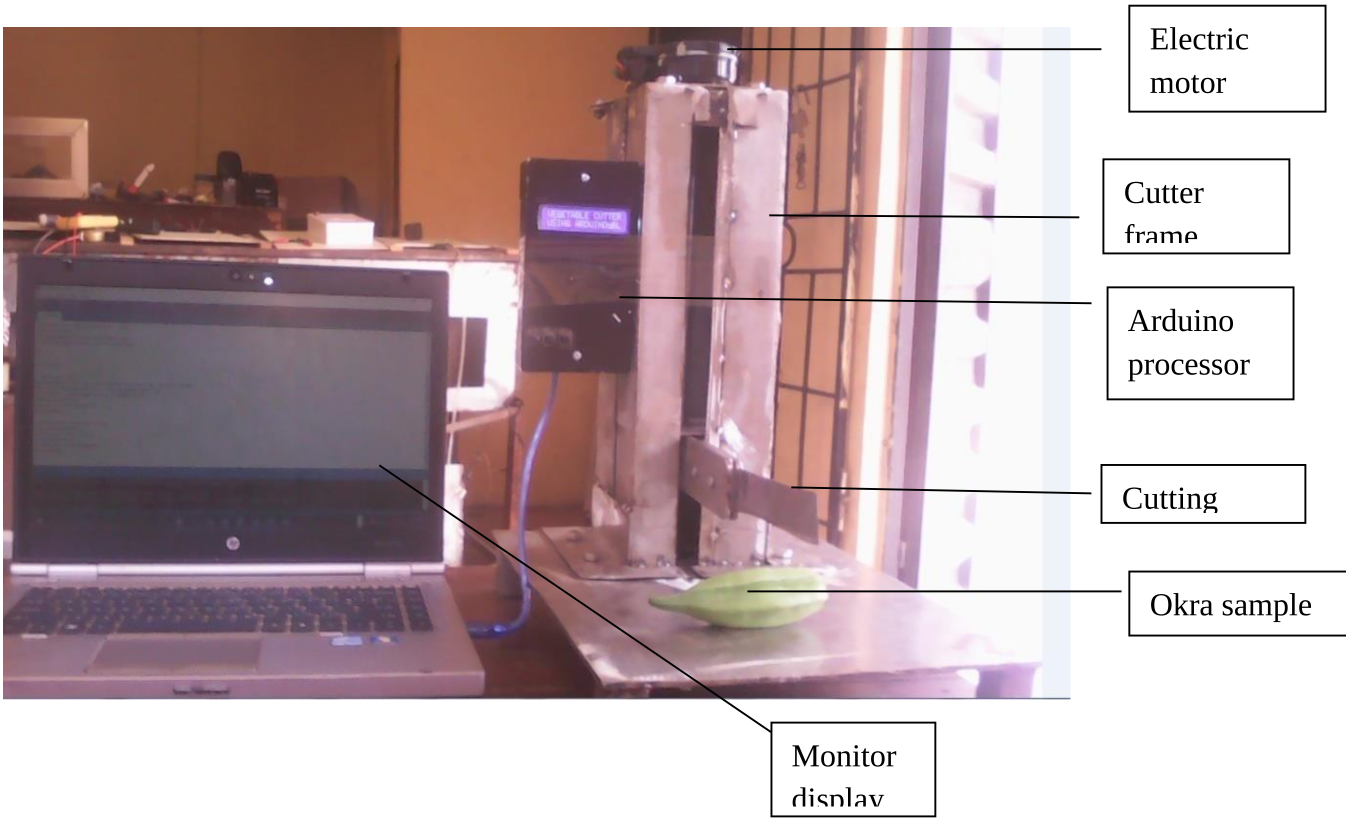

Plate 1.0: Experimental set-up of the cutting mechanism

The automated vegetable cutter consists of the hardware and software components. Arduino controlled processors automatically and effectively measures, records and stores cutting variables and other basic parameters with minimum human supervision, thus making the entire cutting process automated. Connecting to an electric power source switches on the cutter and a predetermined speed value is selected on the keypad. As the knife presses against the sample, the reactive force exerted on the load cell is amplified and measured. Connecting to a computer using USB port the measured values are relayed and MATLAB intercepts the values and plots the resulting graph of force of cut against time travelled which is used in calculating the energy of cut.

2.5 Determination of Validation Parameters

In the determination of validation parameters, every other parameter was held constant while the crop size varied. The selected tool edge thickness (t) measured with a digital venier caliper (Model 500-196, Mitutoyo Products, America) was 0.1cm. The weight (w) of the cutting tool determined with an electronic weighing balance (Model GF-200, A & D company Ltd, Japan of an accuracy of ±0.01) was 23.1g.

The cutting tool was dropped from a pre-determined height (h) of 20cm measured with a meter rule. The crop density (σ) determined by dividing the weight of the crop by the volume of water displaced when sample is placed inside a measuring cylinder was taken as 1.107g/cm^3. The orthogonal dimensions of the sample were determined with the digital venier caliper (Model 500-196, Mitutoyo Products, America). The crop contact area (A) taken as 28.75cm^2 was determined by multiplying the circumference at the point of cut (obtained by winding round with a tape and measuring out on the meter rule) with the major diameter of the crop sample. The moisture content of the crop sample determined with the method described in AOAC (2000) was taken as 89.41± 0.4% (wb).

2.6 Prediction Energy Equation

The prediction energy equation was established by allowing $P\ or\ Q$ to vary at a time while keeping the other constant and observing the resulting changes in the function (Shefii *et al.*, 1996). This was achieved by plotting the experimental values of E against P = $(\frac{tswH_d}{A})$ while keeping Q constant. P = $(\frac{tswH_d}{A})$ was evaluated by substituting the measured values for tool edge thickness (t), crop size(s), tool weight (w), height of tool drop (H_d) and crop contact area (A) into P. Also, E against $Q = (\frac{\sigma v^2 s^2 H_d}{\varphi})$ was plotted while keeping P constant. Values for $Q = (\frac{\sigma v^2 s^2 H_d}{\varphi})$ were obtained by substituting the measured values for crop density (σ), cutting speed (v), crop size(s), height of tool drop (H_d) and crop moisture content (φ).

3. RESULTS AND DISCUSSION

Average values and standard deviation of the measured physical parameters of the okra fruits are shown in Table 3.

Table 3. Average values for physical properties of okra fruits at 89.41± 0.4% (w.b)

S/N	Okra	Mass (g)	Diameter(mm)	Circumference(mm)	Area(mm^2)
1	Ok_1	18.16±2.17	24.90±0.66	89.75±4.76	487.3±26.15
2	Ok_2	8.70±0.94	18.26±0.86	67.5±3.64	262.39±24.79
3	Ok_3	5.15±0.07	14.99±1.02	59.5±2.29	177.35±24.90
4	Ok_4	1.72±0.14	12.44±0.84	47.75±1.92	121.99±15.71

Table 4 shows the experimental values of the cutting energy obtained with the automated vegetable cutter and the calculated values of the cutting energy obtained by substituting values of the cutting variables into the energy equations $P = (\frac{tswH_d}{A})$ and $Q = (\frac{\sigma v^2 s^2 H_d}{\varphi})$.

Note : Crop size was varied while the other factors remained constant.

Table 4. Experimental values ($E_{measured}$) and calculated values of cutting energy for okra fruits.

S/N	okra	Crop size (mm)	(E_{meas})	$P = (\frac{tswH_d}{A})$	$Q(\frac{\sigma v^2 s^2 H_d}{\varphi})$
1	Ok_1	24.90±0.66	4.16	23.63	13.82
2	Ok_2	18.26±0.86	2.75	17.33	7.43
3	Ok_3	14.99±1.02	1.98	14.23	5.01
4	Ok_4	12.44±0.84	0.70	11.81	3.45

The plots of the cutting energy ($E_{measured}$) against P and Q are shown in Figures 1 and 2 with their linear equations and R^2 values expressed in Equations 29 and 30.

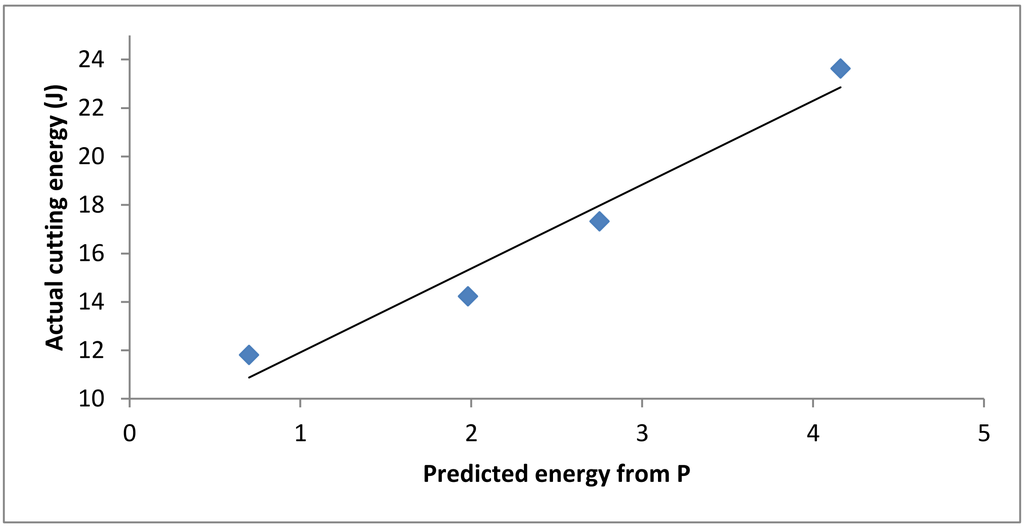

Figure 1. Variation of cutting energy against $P = \left(\frac{\mathrm{tswH_d}}{\mathrm{A}}\right)$, keeping $Q = (\frac{\sigma v^2 s^2 H_d}{\varphi})$ constant.

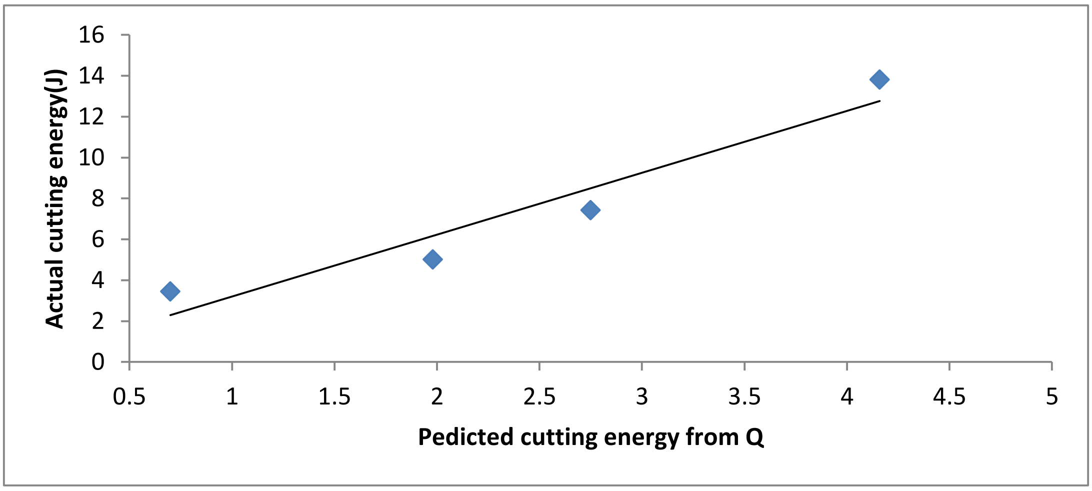

Figure 2. Variation of cutting energy with $Q = (\frac{\sigma v^2 s^2 H_d}{\varphi})$, keeping $P = (\frac{\mathrm{tswH_d}}{\mathrm{A}})$ constant.

E = 3.462P + 8.448 $R^2 = 0.961$ …29

E = 3.026Q + 0.170; $R^2 = 0.921$ …30

The plot of the P and Q terms in Figures 1 and 2 forms a plane surface in linear space and according to Mohammed (2002), it implies that their combination favors summation or subtraction. Therefore, the component equations formed by the subtraction and summation of Equations 29 and 30 give Equations 31 and 32 respectively.

$E = f_1\,(P, Q\,)\; - f_2\,(P, Q\,)\; + K$ ...31

$E = f_1\,(P, Q\,)\; + f_2\,(P, Q\,)\; + K$ ...32

It must be noted that;

at f_1, Q was kept constant while P varied

at f_2, P was kept constant while Q varied

Substituting Equations 29 and 30 into Equation 31 and performing some algebraic manipulations yields Equation 33.

E = 3.462P – 3.026Q + 8.278 …33

Also, Substituting Equations 29 and 30 into Equation 32 and performing some algebraic manipulations yields Equation 34.

E = 3.462P + 3.026Q + 8.618 …34

A further manipulation as permitted under the rules of the Burkingham pi theorem (Shefii *et al.*, 1996) is manipulating with a constant factor. Hence, Equations 33 and 34 were divided with a constant factor of 10 which yields the predicted model equations expressed in Equations 35 and 36 respectively. Dividing equations 33 and 34 with the constant factor of 10 yielded predicted values close to the actual ones.

E = 0.3462P – 0.3026Q + 0.8278 …35

E = 0.3462P + 0.3026Q + 0.8618 …36

Substituting the variables for P and Q into Equations 35 and 36 yield Equations 37 and 38 respectively.

$E = 0.3462\frac{tswH_d}{\mathrm{A}} - 0.3026\frac{\sigma v^2 s^2 H_d}{\varphi} + 0.8278$ …37

$E = 0.3462\frac{tswH_d}{\mathrm{A}} + 0.3026\frac{\sigma v^2 s^2 H_d}{\varphi} + 0.8618$ …38

However, the final predicted model equation will be either of the above two equations that gives the better statistical inference

3.1 Model Validation

The mathematical model was validated using the data generated from the vegetable cutter. The model validation was done at four ranges of crop sizes (23-26mm, 17-20mm, 14-17mm and 10-13mm) and a constant cutting speed of 30mm/min. The method of regression analysis as computed using Microsoft Excel environment was used to describe the relationships, plot the graphs and compute the coefficients of determination (R^2).

Measured values of parameters were substituted into Equations 37 and 38 to yield the predicted cutting energy values which were plotted against the experimental energy values on a regression curve in order to obtain the coefficients of determination as shown in Figures 3 and 4 respectively. Equations 39 and 40 express the relationship between the predicted cutting and experimental cutting energy with R^2 values of 0.973 and 0.945 respectively.

The high R^2 values of 0.961, 0.921 and 0.973 obtained for the individual predictions equations and the Equation for subtraction of component equations is an indication that the method adopted in the development of the mathematical models is acceptable and can be translated in the development of the other varieties of the okra fruit in particular and other vegetables in general. Table 4 presents values of the predicted and experimental cutting energy and Figure 3 presents the graphical relationship between the experimental and predicted cutting energy. Equation 35 expresses the relationship between the predicted cutting and the experimental cutting energy with a very high correlation with R^2 value of 0.973.

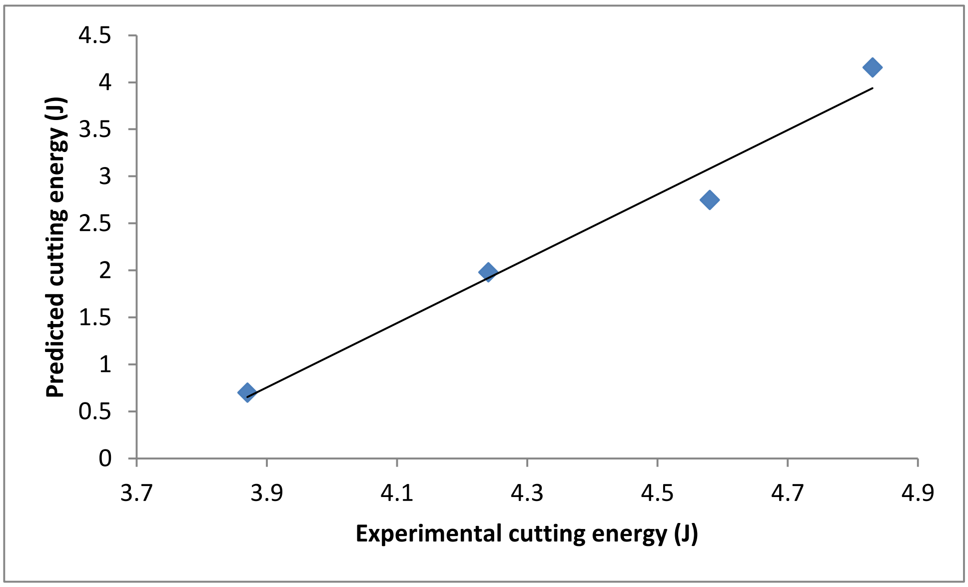

Figure 3. The graph of the relationship between experimental and predicted cutting energy (for subtraction of component energy equations)

$E_{pred} = 3.423\ E_{exp} - 12.59;$ $R^2 = 0.973$ …39

Where E_{pred} = predicted cutting energy

E_{exp} = experimental cutting energy

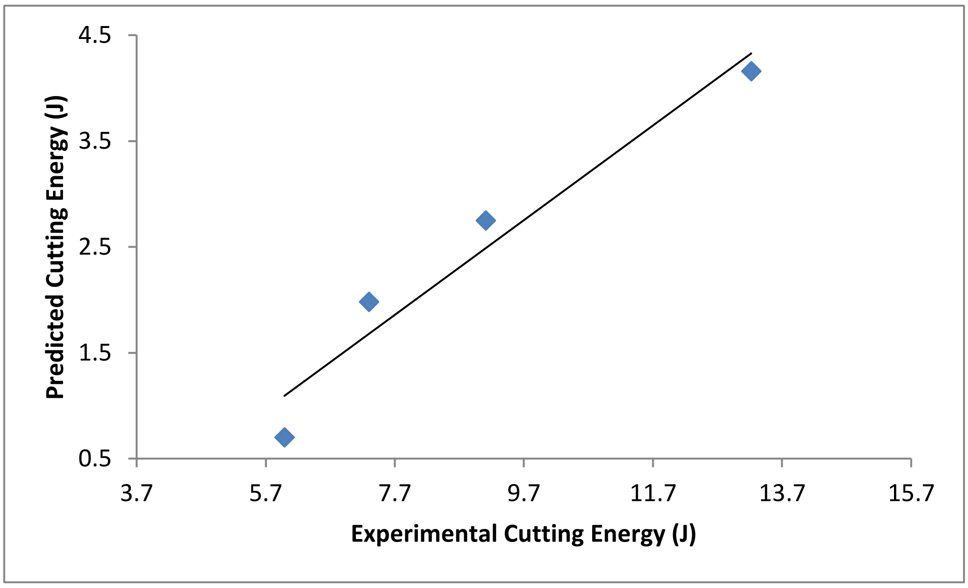

Figure 4. The graph of the relationship between experimental and predicted cutting energy. (for summation of component energy equations)

$E_{pred} = 0.447E_{exp} – 1.584$; $R^2 = 0.945$ …40

From the statistical inference carried out, the predictive model equation derived from the subtraction of component energy equations gave a higher coefficient of determination (R^2) value of 0.973, a lower mean difference of 1.983 between the predicted and experimental energy values and a lower standard error of 0.127 as compared to an R^2 value of 0.945 obtained from the summation of component energy equations, a mean difference of 6.508 between the predicted and experimental energy values and a standard error of 0.199. Hence, the predicted model equation which gives the better statistical inference of a higher R^2 value of 0.973 and lower values of 1.983 and 0.127 for mean difference and standard error respectively is chosen as the predicted model equation for the cutting energy requirement for okra (*Abelmoschus esculentus L.)* '*Ila-iroko*' variety and is given as Equation 41.

$$E = 0.3462\frac{tswH_d}{A} - 0.3026\frac{\sigma v^2 s^2 H_d}{\varphi} + 0.8278 \quad \ldots 41$$

4.0 CONCLUSION

A mathematical model for predicting the cutting energy of okra *(Abelmoschus esculentus L)* was presented using dimensional analysis based on the Buckingham's Π theorem. The model equation expressed as $E = 0.3462\frac{tswH_d}{A} - 0.3026\frac{\sigma v^2 s^2 H_d}{\varphi} + 0.8278$ was validated with data from an automated vegetable cutter. Results obtained showed a high coefficient of determination (R^2 = 0.973), a low mean difference of 1.983 between the predicted and experimental energy values and a low standard error of 0.127. This is an indication that the method adopted in the development of the mathematical model is acceptable and can be translated in the development of predictive models for the other varieties of the okra fruit in particular and other vegetables in general. Also, this expression will also help designers of the cutting equipment for okra (*ilá-ìròkò)* variety to avoid the rigors of experimentations and at the same time obtain efficient cutters. Hence, the developed model could be used to predict the cutting energy for okra (*ilá-ìròkò)* variety up to 97%.

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Effect of Beeswax and Cassava Starch Coatings on Weight Loss in Mango and Avocado Fruits

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ABSTRACT

This study investigated the effect of coating thickness of beeswax and cassava-starch on weight loss of harvested matured hard green mango and avocado fruits and compared their effectiveness as edible coating materials. Application of the coating materials was done by dipping the fruit samples in the wax and starch emulsions until the required thicknesses (0.96, 1.92, 2.88 mm) were achieved. The thicknesses of the thin layers of the coatings were certified using a Vernier caliper. All the experimental samples were stored in an incubator maintained at 13^{o} C. Results of the investigation after 16 days showed that percentage weight losses of mango fruits at the first level of coating (0.96 mm thick coat) were 6.57% and 7.09% for beeswax and cassava starch respectively, compared to 12.03% for the control. At the second level of coating (1.92 mm thick), the percentage weight losses were 4.89% and 5.30% for beeswax and cassava starch respectively, compared to 12.03% for control. The third level of coating (2.88 mm tick) resulted in 3.79% and 4.20% weight losses by the treated mango fruits compared to 12.03% by the control. The effect of beeswax and cassava starch coatings on avocado fruits were 7.29% and 7.69% for level one, 5.51% and 5.56% for level two, and 4.06% and 4.57% for level three, respectively compared to 13.64% for the control. At 5% level of significance, beeswax and cassava starch were found to significantly reduce weight loss in mango and avocado fruits. However, the effectiveness of beeswax and cassava starch as edible coating materials for mango and avocado fruits was not significantly different, even though beeswax preserved the fruits' weight better. Thus, depending on availability and cost, either beeswax or cassava starch can be used to delay or prevent excessive weight loss in stored fresh mango and avocado fruits.

Keywords: Avocado, beeswax, coating materials, mango, weight loss

1. INTRODUCTION

Mango (*Mangifera indica L.*) and avocado (*Persea americana*) are two widely cultivated tropical fruit species. They belong to different families and are believed to originate from different parts of the world. While mango is native to Southern Asia, avocado originated from South-Central Mexico. Globally, the mango industry is the fifth largest tropical fruit industry with production of over 34.3 million tons (FAOSTAT, 2008). Some fruits like banana and pineapple are seedless while mango and avocado and some other fruits like oranges and papaya are seed fruits. These fruits provide an abundant and inexpensive source of energy, body building nutrients, vitamins, antioxidants, and minerals (Kader, 2008). Their nutritional value is highest when they are fresh. These fruits are popular all over the world as they have attractive colors, delicious tastes and excellent nutritional properties and contents. However, mango and avocado fruits are climacteric and ripe rapidly after harvest. This behaviour seriously limits the longevity of these fruits after harvest, thereby making it difficult for commercial marketers and consumers to store or transport them for a long time or distance without losing their quality and usefulness. Fruit sensitivity to decay, low temperature and general fruit perishability due to the rapid ripening and softening limits the storage, handling and transport potential (Krishna *et al*., 2017).

Studies channeled to the prolongation of the shelf life of fruits or slowing down their ripening process while keeping their quality and flavour up to the required level has been reported in the literature (Hesham, 2008; Balochi *et al*., 2013; Sanaa, 2017). Shelf life is the length of time a product may be stored before it becomes unfit for consumption. According to Perez *et al*. (2004) shelf life is defined as the period in which a product should maintain a predetermined level of quality under specified storage conditions. The importance of good postharvest practices in minimizing postharvest losses cannot be overemphasized. There are different mechanisms to control post-harvest deterioration of fruits to extend the shelf life and also to keep the quality of which coating is one of them. Coating can generally be described as a thin layer that can cover something. Guilbert (1986) defined edible coatings as a thin application of material that form a protective barrier around an edible commodity and can be consumed along with the coated product. The essence of coating is to protect a product from foreign organic matters that may cause deterioration or loss of quality in any way. In fruits, the purpose of coating is mainly for storage, handling and safe transport. The coating of the fruit just after the harvesting process is becoming popular in this respect (Cohen *et al*., 1990). Although controlled atmosphere (CA) storage has been shown to extend the shelf life of fruits like mango (Bender *et* al., 2000), it is cost prohibitive. Modified atmosphere (MA) storage was also reported to slow some fruits ripening, but was often accompanied by high CO_2 and off-flavour (Gonzalez-Aquilar *et* al., 1997).

The extension of a fruit's shelf life and retention of its quality can only be achieved when there is atmospheric modification and control on the surface of the fruit which can be achieved through coating. Coatings have been used traditionally to improve appearance and to conserve food products. The most common examples are the wax coatings for fruits which were reportedly used in China years back. Edible coatings are used to create a modified atmosphere and to reduce weight loss, water loss and reduction of respiration rate and making fruits become disease-resistant during transport, handling and storage (Baldwin, 1994). To be most effective a fruit coating needs to be applied in a manner that gives an even coating to the fruit so that water is lost equally from all parts of the fruit to avoid partial ripening of the fruit. The respiration rate for fresh produce increases with increase in storage temperature. Therefore, a coating that allows adequate oxygen levels for chilled storage conditions might result in a product going anaerobic at ambient temperature storage. Furthermore, creation of a modified atmosphere of relatively low oxygen and high carbon dioxide can slow down ripening of climacteric fruits, thus extending their shelf life as long as the products do not undergo anaerobic respiration. To this end, the development of valuable postharvest technologies could improve the quality and consequently extend the shelf life of fruits locally and during export to distant markets.

The aim of this study was to investigate the effect of beeswax and cassava starch coatings on the shelf life of mango and avocado fruits. The specific objective of the study was to assess and compare the effect of different thicknesses of beeswax and cassava starch coatings on weight loss of mango and avocado fruits.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

The experiment was conducted in the Biomass Laboratory, Centre for Energy Research and Development, University of Nigeria, Nsukka.

2.2 Sample Fruits

Samples of mango and avocado fruits were harvested at hard green stage of maturity randomly from a farm in Nsukka, Enugu state, Nigeria. The fruits were cleaned carefully by washing them with water to remove all foreign matter such as dirt and dust. Maximum effort was made to select the fruits of the same initial mass of 0.85 kg for mango and 0.90 kg for avocado fruits. The harvested fruits were then stored in an incubator operating at a temperature of 13^{o} C.

2.3 Coating Materials

2.3.1 Beeswax emulsion

Beeswax emulsion was obtained from 20 kg of bee-comb bought from a local market (Ibagwa-Aka main market). The wax was extracted from the comb by heating the latter in a perforated pot placed in an unperforated pot. As the bee-comb on the perforated pot was heated, it melted and passed through the holes on the perforated pot and was collected in the unperforated pot. The beeswax emulsion solidified upon cooling. Finally, the beeswax emulsion was prepared by heating it again at a temperature of 90^{o} C.

2.3.2 Cassava starch

Cassava starch was extracted from cassava roots harvested from a farm in Ajuona Obukpa village, Nsukka, Enugu state, Nigeria. The cassava starch was extracted immediately after harvest using the method reported by Benesi *et al*. (2004).

2.4 Coating Application

The fruit samples were divided into four groups each, with respect to the level of coating. The first group had no coating (control), while the other three groups had coating thicknesses of 0.96 mm, 1.92 mm and 2.88mm. These thin layers of coating were measured using a Vernier caliper. Application of the coating was done by dipping the fruit samples in beeswax emulsion and cassava starch until the three levels of thicknesses were achieved.

2.5 Data Collection

Data on weight loss was collected by periodic weighing (four days interval) of the fruit samples during storage (sixteen days) and expressed as a percentage of original weight as reported by Amayogi and Alloli (2007).

$$PLW = \frac{IW - FW}{IW} \times 100 \qquad (1)$$

Where:
PLW = physiological loss in weight of fruit
IW = initial weight
FW = final weight

2.6 Data Analysis

The experiment was laid out in Completely Randomized Design with five replications and collected data on weight loss were subjected to two-factor Analysis of Variance (ANOVA) using SPSS version 20. Mean separation was done using Duncan Multiple Range Test (DMRT).

3. RESULTS AND DISCUSSION

3.1 Percent Weight Loss of Mango Fruits at Three Levels of Beeswax Coating

The mean percent weight losses of Mango fruits at different levels of coating with Beeswax after 16 days of storage under an average incubator temperature of 13^{o} C and relative humidity of 68% are shown in Table 1. The percent weight loss of uncoated fruits (control) ranged from 2.87% to 12.03%. The percent weight loss of coated fruits ranged from 0.78 to 3.79% for 2.88 mm thickness of coating, 1.11% to 4.89% for 1.92 mm coating thickness, and 1.48% to 6.57% for 0.96 mm coating thickness. These ranges clearly show that the greatest weight loss occurred in the uncoated Mango fruits, followed by those with 0.96 mm thick coating, and then by those with 1.92 mm thick Beeswax coating.

3.2 Percent Weight Loss of Mango Fruits at Three Levels of Cassava-starch Coating

The mean percent weight losses of Mango fruits at 0.96 mm, 1.92 mm and 2.88 mm thicknesses of Cassava starch coating for 16 days of storage are also shown in Table 1. The percent weight loss of uncoated fruits (control) ranged from 2.87% to 12.03%. The percent weight loss of coated fruits ranged from 1.05 to 4.20% for 2.88 mm thick coat; 1.35% to 5.30% for 1.92 mm thick coat and 2.16% to 7.09% for the 0.96 mm thick coat. These ranges of values clearly show that uncoated fruits lost more weight than the Cassava-coated fruits.

Table 1: Mean percent weight loss of mango fruits at different levels of coating

Day	First level of coating			Second level of coating			Third level of coating		
	Control (%)	**Beeswax (%)**	**Cassava Starch (%)**	**Control (%)**	**Beeswax (%)**	**Cassava Starch (%)**	**Control (%)**	**Beeswax (%)**	**Cassava Starch (%)**
1	0	0	0	0	0	0	0	0	0
4	2.87	1.48	2.16	2.87	1.11	1.35	2.87	0.78	1.05
8	5.44	3.58	4.18	5.44	3.18	3.53	5.44	2.58	2.92
12	7.38	5.26	5.94	7.38	3.76	4.13	7.38	2.99	3.58
16	12.03^{a}	6.57^{b}	7.09^{b}	12.03^{a}	4.89^{c}	5.30^{c}	12.03^{a}	3.79^{d}	4.20^{d}

3.3 Percent Weight Loss of Avocado Fruits at Three Levels of Beeswax Coating

The mean percent weight losses of Avocado fruits at different thicknesses of Beeswax coating for 4, 8, 12 and 16 days of storage are shown in Table 2. The percent weight loss of uncoated fruits (control) ranged from 3.22% to 13.64%.The percent weight loss of coated Avocado fruits ranged from1.08% to 4.06% for 2.88 mm thick coat; 1.85% to 5.51% for 1.92 mm thick coat, and 1.98% to 7.29% for 0.96 mm thick coat. These results show that uncoated Avocado fruits lost more weight than coated ones.

Table 2: Mean percent weight loss of Avocado fruits at different levels of coating

Day	First level of coating			Second level of coating			Third level of coating		
	Control (%)	**Beeswax (%)**	**Cassava Starch (%)**	**Control (%)**	**Beeswax (%)**	**Cassava Starch (%)**	**Control (%)**	**Beeswax (%)**	**Cassava Starch (%)**
1	0	0	0	0	0	0	0	0	0
4	3.22	1.98	2.25	3.22	1.85	2.17	3.22	1.08	1.19
8	6.26	4.04	4.62	6.26	3.54	3.77	6.26	2.94	3.27
12	8.45	5.96	6.26	8.45	4.24	4.50	8.45	3.25	3.83
16	13.64^{a}	7.29^{b}	7.69^{b}	13.64^{a}	5.51^{c}	5.56^{c}	13.64^{a}	4.06^{d}	4.57^{d}

3.4 Percent Weight Loss of Avocado Fruits at Three Levels of Cassava-starch Coating

The mean percent weight losses of Avocado fruits at three different thicknesses of Cassava-starch coating for 16 days (measured at 4-day interval) are also shown in Table 2. The percent weight loss of uncoated fruits ranged from 3.22% to 13.64%. The percent weight loss of coated ones ranged from 1.19% to 4.57% for 2.88 mm thick coat, 2.17% to 5.56% for 1.92 mm thick coat, and 2.25% to 7.67% for 0.96 mm thick coat. This shows that coating Avocado fruits with Cassava-starch prevented the fruits from losing more weight.

Table 3: Descriptive statistics of the effect of types and thickness of coating

Dependent Variable:		**MANGO**		**AVOCADO**		
Type	thickness	Mean	Std. Deviation	Mean	Std. Deviation	N
Control	0.96mm	12.0300	0.93003	13.6400	0.67746	5
	1.92mm	12.0300	0.93003	13.6400	0.67746	5
	2.88mm	12.0300	0.58919	13.6400	0.67746	5
beeswax	0.96mm	6.5720	0.28446	7.2900	0.20785	5
	1.92mm	4.8840	0.29280	5.5100	0.58703	5
	2.88mm	3.7900	0.18097	4.0600	0.13172	5
cassava starch	0.96mm	7.0900	0.08860	7.6940	0.27465	5
	1.92mm	5.3000	0.21794	5.5600	0.30529	5
	2.88mm	4.2000	0.23495	4.5700	0.35107	5

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3.5 Effect of Type and Thickness of Coating on Weight Loss of Stored Mango Fruits

The descriptive statistical analysis of experimental results of the effect of Beeswax and Cassava-starch coatings and their thicknesses on weight loss of Mango fruits kept for 16 days is shown Table 3. The minimum mean percentage weight loss of uncoated Mango fruits (Control) was 12.03 ± 0.59%; and 3.29 ± 0.18% for Mango fruits coated with Beeswax, and 4.20 ± 0.23% for fruits coated with Cassava-starch (the minimum values occurred at 2.88 mm coating thickness). The analysis of variance (ANOVA) of the results for Mango fruits (Table 4) shows that both Cassava-starch and Beeswax coatings and thicknesses (0.96, 1.92, 2.88 mm) have significant interaction effect ($p < 0.05$) on weight loss of stored Mango fruits at 95%. confidence level.

Table 4: ANOVA table for Mango fruits

Source	Type III Sum of Squares	df	Mean Square	F	P-value
Corrected Model	494.547[a]	8	61.818	233.081	.000
Intercept	2563.301	1	2563.301	9664.729	.000
Type	453.627	2	226.814	855.183	.000
thickness	27.268	2	13.634	51.405	.000
type * thickness	13.652	4	3.413	12.869	.000
Error	9.548	36	.265		
Total	3067.396	45			
Corrected Total	504.095	44			

3.6 Effect of Type and Thickness of Coating on Weight Loss of Stored Avocado Fruits

The descriptive statistical analysis of results of the effect of Beeswax and Cassava-starch coatings and their thicknesses on weight loss of stored Avocado fruits is also shown in Table 3. The minimum mean percentage weight loss was 13.64 ± 0.68% for uncoated Avocado fruits; 4.06 ± 0.13% for Avocado fruits coated with Beeswax; and 4.57 ± 0.35% for fruits coated with Cassava-starch. The ANOVA for Avocado fruits (Table 5) shows also that both the Beeswax and Cassava-starch coatings and their thicknesses had significant effect ($p = 0.000<0.05<0.001$) on weight loss of Avocado fruits stored for 16 days.

Table 5: ANOVA table for Avocado fruits

Source	Type III Sum of Squares	df	Mean Square	F	P-value
Corrected Model	670.128[a]	8	83.766	363.518	.000
Intercept	3175.536	1	3175.536	13780.848	.000
Type	618.466	2	309.233	1341.975	.000
thickness	34.248	2	17.124	74.313	.000
type * thickness	17.414	4	4.354	18.893	.000
Error	8.296	36	.230		
Total	3853.959	45			
Corrected Total	678.423	44			

3.7 Comparative Effect of Beeswax and Cassava-starch on Weight Loss of Mango and Avocado Fruits

The means of the effect of Beeswax and Cassava-starch coatings on weight loss of Mango and Avocado fruits are separated in the Duncan multiple range test results shown in Table 6. It could be observed that no significant (p = 1 > 0.05) difference exist between the mean effect of Beeswax and Cassava-starch on weight loss of Mango and Avocado fruits for each coating thickness. However, there is significant difference between and among the mean effect of coating thickness of Beeswax and Cassava-starch on the weight losses (Duncan separates significant different means in different columns).

Table 6: Duncan table for Mango and Avocado fruits

Thickness	N	Subset (Mango) α = 0.05			Subset (Avocado) α = 0.05		
		1	2	3	1	2	3
2.88mm	15	6.6733			7.4233		
1.92mm	15		7.4047			8.2367	
0.96mm	15			8.5640			9.5413
Sig.		1.000	1.000	1.000	1.000	1.000	1.000

4. CONCLUSION

Having tested the two coating materials (Beeswax and Cassava-starch) at three coating thicknesses on Mango and Avocado fruits, it was observed that performance of the two coating materials were significantly different from control but not significantly different from each other. The application of the two coating materials investigated shows that the choice of the coating material to be used should be based on cost and availability and not performance and efficiency since the two materials have almost equal effectiveness. The coating thickness, however, has significant effect with the 2.88 mm thickness giving best protection against weight losses.

5. ACKNOWLEDGEMENT

The authors wish to acknowledge Mr. Ugwu, Samson Offorma of the Department of Statistics, University of Nigeria, Nsukka for his immense statistical input to this work.

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Chemical Composition of Millet-Based Infant Formula Supplemented with Treated Bambara Nut Flour.

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ABSTRACT

Fermentation and sprouting have been shown to increase nutrient bioavailability and modify the functional properties of foods. Application of these methods in the preparation of infant foods and complementing cereals with legumes will address nutrient density and viscosity problems associated with infant foods. Infant foods were formulated from blends of treated bambaranut and pearl millet and chemical composition of the samples were studied. Millet and bambaranut were soaked separately in water and allowed to ferment for 48 hr at room temperature. While for sprouting, millet and bambaranut were soaked for 12 and 24 hr, respectively, at room temperature, and soaked seeds were separately sprouted for 48 hr. After fermentation and sprouting, the seeds were oven-dried and then milled into a flour of 0.6 mm size. The flours were formulated to six (A, B, C, D, E, and F) complementary diets. The results show that blending treated bambaranut with pearl millet significantly increased the protein, fibre, fat and ash content from 14.46, 0.68, 6.21 and 3.32% to 19.35, 1.21, 8.01 and 5.35% respectively; while, the moisture and carbohydrate contents were significantly reduced. In the same vain, blending treated bambaranut with pearl millet significantly increased all the amino acids composition of the blends. However, blending treated bambaranut with pearl millet increased the trypsin, hydrogen cyanide, oxalate and phytate contents; though, the values fall within the safe consumption limit. Hence, this study revealed that, blending treated bambaranut with pearl millet is beneficial in increasing the nutrient density of infant food.

Keywords: Millet, bambaranut, fermentation, sprouting, infant, chemical properties, Nigeria.

1. INTRODUCTION

Infant formula or complementary foods are foods other than breast milk usually in liquid, semisolid or solid form introduced to infants to provide appropriate nutrients. In

Nigeria and most especially West African countries, the common first weaning food is pap, locally called *akamu* in the south-east Nigeria, *ogi* in the south-west Nigeria or *koko* in northern Nigeria. It is made from cereals such as maize, millet or sorghum. These traditional weaning foods are starchy and characterized to be low in nutritive value (low protein and low energy density), high bulk density and high viscosity.

Traditional food processing methods such as sprouting and fermentation have been reported to increase bioavailability of nutrients, predigest macro molecules, reduce antinutrients and reduce gruel viscosity (James *et al.*, 2018). In essence, these processes make the foods simpler to digest and the nutrients easier to assimilate. Since heat is not required in the two processes, there is considerable retention of enzymes, vitamins and other nutrients that are usually destroyed by high temperature processing. Therefore, there is the need to augment the protein content with cheap and local protein source (bambaranut) and to assess the positive benefits of sprouting and fermentation on the chemical quality of the infant formula.

2. MATERIALS AND METHODS

2.1 Sources of raw material

Bambara nut and pearl millet were purchased from Kure Ultra-Modern Market, Niger State, Nigeria.

2.2 Material preparation

2.2.1 Fermentation of pearl millet and bambaranut

Bambara nut and millet were fermented as described by James *et al*. (2018) with slight modification. The two raw materials were cleaned manually, washed in clean water after which they were soaked separately in cold water in a ratio of 1:3 weight by volume (w/v) and allowed to ferment for 48 hr at room temperature (28 ± 2°C). Fermented millet and bambara nut were thoroughly washed in clean water and oven-dried separately at 60°C for 12 and 24 hr, respectively, and then hammer milled into a fine flour of 0.6 mm size. The flours were packaged differently in coded high-density polythene bags for further analysis.

2.2.2 Preparation of sprouted pearl millet and bambaranut

Methods described by Okafor *et al*. (2014) and James *et al*. (2018) were used to sprout millet and bambara nut with slight modifications. Millet and bambara nut were sorted, washed, and soaked in clean water for 12 and 24 hr, respectively, at room temperature (28 ± 2°C) with change in soaking water at 4 hr interval to prevent fermentation. Soaked seeds were separately spread on jute bag and covered with the same and allowed to sprout for 48 hr with sprinkling of water at 3 hr intervals. After sprouting period, the seeds were evenly spread on oven trays and dried at 60°C for 12 and 20 hr, respectively, and then hammer milled into a flour of 0.6 mm size and packaged differently in high-density polyethylene for further analysis.

2.3 Product formulation

The samples for this study were formulated, thus 100% sprouted millet flour, 100% fermented millet flour, 95% sprouted millet flour and 5% sprouted bambara nut flour, 95% fermented millet flour and 5% fermented bambara nut flour, 95% sprouted millet flour and 5% fermented bambara nut flour, and 95% fermented millet flour and 5% sprouted bambara nut flour, representing samples A, B, C, D, E, and F, respectively.

Amino acid profile, antinutrients and proximate composition were determined using standard methods.

3. RESULTS AND DISCUSSION

The results of this study show that samples A (100% spouted millet) and B (100% fermented millet) had significantly high moisture contents, 9.93 and 9.91%, respectively; while, different blends showed significantly low moisture content. Blending treated bambaranut flour with millet significantly increased the protein content from 14.46% to 19.35%. Sample F (95% fermented millet and 5% sprouted bambaranut flour) had significantly ($p<0.05$) high fibre (1.21%), fat (8.01%) and ash (5.35%) contents; while, sample A (100% sprouted millet) had the lowest values: 0.68%, 6.21% and 3.32% respectively. This implies that blending treated millet and bambaranut flours at different ratios used in this study enhanced the fibre, fat and ash contents. Samples A (100% spouted millet) and B (100% fermented millet) had significantly high carbohydrate contents, 65.43 and 63.58% respectively. However, blending significantly reduced the carbohydrate content with sample F (53.29%) having the lowest value. Samples E (95% sprouted millet and 5% fermented bambara nut) and F (95% fermented millet and 5% sprouted bambara nut) had significantly ($p<0.05$) high histidine, isoleucine, leucine, lysine, methionine, phenyl alanine, threonine, tryptophan and valine. This implies, blending and treatment significantly increased the amino acid contents of samples. However, samples A and B showed significantly low values. In antinutrients, samples A (100% sprouted millet) and B (100% fermented millet) had significantly ($p<0.05$) low trypsin, hydrogen cyanide, oxalate and phytate contents; while, samples E and F showed significantly high values. This implies that addition of treated bambaranut flour to millet increased the antinutrients content of blended samples. In tannin content, samples A and B had significantly ($p<0.05$) high values 0.74 and 0.71% respectively; while blended samples showed significantly low values.

4. CONCLUSION

Sprouting, fermentation and blending ratios used in this study significantly increased the nutritional quality of the formula and these would improve digestibility and bioavailability of nutrients. Inclusion of treated Bambara nut flour in the blend increased a number of antinutrients content, however, the values fall within the tolerable limits by humans.

5. ACKNOWLEGMENT

The authors are grateful to Federal University of Technology, Minna, Nigeria; Michael Okpara University of Agriculture Umudike, Nigeria and Adamawa State University Mubi, Nigeria for their support.

Table 1. Chemical composition of the formulated infant formula

Parameter (%)	A	B	C	D	E	F
Moisture	$9.93^{a} \pm 0.01$	$9.91^{a} \pm 0.01$	$9.86^{b} \pm 0.01$	$9.80^{c} \pm 0.00$	$9.79^{c} \pm 0.01$	$9.78^{c} \pm 0.01$
Protein	$14.46^{f} \pm 0.01$	$15.12^{e} \pm 0.00$	$16.44^{d} \pm 0.00$	$17.20^{c} \pm 0.00$	$18.42^{b} \pm 0.00$	$19.35^{a} \pm 0.01$
Fibre	$0.\ 68^{f} \pm 0.01$	$0.75^{e} \pm 0.01$	$0.84^{d} \pm 0.01$	$0.94^{c} \pm 0.00$	$1.00^{b} \pm 0.00$	$1.21^{a} \pm 0.00$
Fat	$6.21^{f} \pm 0.00$	$7.11^{e} \pm 0.00$	$7.45^{d} \pm 0.00$	$7.81^{c} \pm 0.01$	$7.91^{b} \pm 0.01$	$8.01^{a} \pm 0.01$
Ash	$3.32^{f} \pm 0.06$	$3.51^{e} \pm 0.01$	$3.86^{d} \pm 0.00$	$4.22^{c} \pm 0.00$	$5.04^{b} \pm 0.01$	$5.35^{a} \pm 0.01$
Carbohydrate	$65.43^{a} \pm 0.05$	$63.58^{b} \pm 0.04$	$61.53^{c} \pm 0.03$	$59.35^{d} \pm 0.01$	$57.84^{e} \pm 0.03$	$53.29^{f} \pm 0.04$
Histidine	$1.12^{f} \pm 0.00$	$1.63^{e} \pm 0.00$	$1.85^{d} \pm 0.00$	$1.89^{c} \pm 0.00$	$2.04^{b} \pm 0.00$	$2.11^{a} \pm 0.00$
Isoleucine	$1.76^{f} \pm 0.00$	1.81e ± 0.01	$2.06^{d} \pm 0.01$	$2.51^{c} \pm 0.00$	$2.77^{b} \pm 0.00$	$2.84^{a} \pm 0.01$
Leucine	$5.11^{e} \pm 0.01$	5.34d ± 0.00	$5.52^{cd} \pm 0.00$	$5.62^{bc} \pm 0.00$	$5.84^{a} \pm 0.00$	$5.74^{ab} \pm 0.14$
Lysine	$2.72^{f} \pm 0.00$	$2.94^{e} \pm 0.00$	$3.23^{d} \pm 0.01$	$3.46^{c} \pm 0.01$	$3.82^{b} \pm 0.00$	$3.94^{a} \pm 0.00$
Methionine	$1.24^{f} \pm 0.00$	$1.56^{e} \pm 0.00$	$1.81^{d} \pm 0.01$	$1.94^{c} \pm 0.01$	$1.98^{b} \pm 0.00$	$2.42^{a} \pm 0.00$
Phenyl alanine	$2.45^{f} \pm 0.05$	$2.51^{e} \pm 0.00$	$2.78^{d} \pm 0.00$	$2.83^{c} \pm 0.00$	$2.94^{b} \pm 0.01$	$3.01^{a} \pm 0.00$
Threonine	$1.84^{f} \pm 0.00$	$1.92^{e} \pm 0.00$	$2.28^{d} \pm 0.01$	$2.47^{c} \pm 0.00$	$2.61^{b} \pm 0.00$	$2.84^{a} \pm 0.00$
Tryptophan	$4.71^{f} \pm 0.00$	$4.87^{e} \pm 0.00$	$5.05^{d} \pm 0.01$	$5.33^{c} \pm 0.01$	$5.63^{b} \pm 0.01$	$5.74^{a} \pm 0.01$
Valine	$1.72^{f} \pm 0.00$	$1.94^{e} \pm 0.01$	$2.27^{d} \pm 0.01$	$2.64^{c} \pm 0.00$	$2.75^{b} \pm 0.00$	$2.84^{a} \pm 0.00$
Trypsin	$0.28^{f} \pm 0.00$	$0.33^{e} \pm 0.01$	$0.39^{d} \pm 0.01$	$0.52^{c} \pm 0.01$	$0.62^{b} \pm 0.01$	$0.73^{a} \pm 0.00$
Tannins	$0.74^{a} \pm 0.01$	$0.71^{a} \pm 0.00$	$0.66^{b} \pm 0.00$	$0.54^{d} \pm 0.01$	$0.50^{e} \pm 0.00$	$0.59^{c} \pm 0.01$
Hydrogen cyanide	$0.29^{f} \pm 0.01$	$0.36^{e} \pm 0.01$	$0.43^{d} \pm 0.01$	$0.56^{c} \pm 0.00$	$0.62^{b} \pm 0.01$	$0.74^{a} \pm 0.01$
Oxalate	$0.14^{f} \pm 0.00$	$0.22^{e} \pm 0.00$	$0.30^{d} \pm 0.00$	$0.38^{c} \pm 0.00$	$0.47^{b} \pm 0.00$	$0.53^{a} \pm 0.01$
Phytate	$0.97^{f} \pm 0.01$	$1.22^{e} \pm 0.01$	$1.88^{d} \pm 0.00$	$2.11^{c} \pm 0.00$	$2.74^{b} \pm 0.01$	$3.04^{a} \pm 0.00$

Mean ± *SD* of triple determinations. Values followed by different subscript on a row are significantly different from each other ($p < .05$). A = 100% sprouted millet; B = 100% fermented millet; C = 95% sprouted millet and 5% sprouted bambara nut; D = 95% fermented millet and 5% fermented bambara nut; E = 95% sprouted millet and 5% fermented bambara nut; F = 95% fermented millet and 5% sprouted bambara nut.

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Estimating Crop Evapotranspiration and Growth of Tomato in a Greenhouse Using Blaney-Criddle, Cropwat 8.0 and Evaporation Pan

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ABSTRACT

Many empirical methods for predicting reference evapotranspiration rates are available but accurate prediction under different environmental condition is not certain. Greater uncertainty exists under a greenhouse (control environment) condition. In this study, Blaney-Criddle (temperature based method), Class 'A' Evaporation pan and CROPWAT 8.0 (FA0-56 Penman- Monteith) methods were used to estimate the evapotranspiration of tomato (Rio Grande and Roma VF varieties) over a period of 93 days in a low technology greenhouse. An automatic thermos-hygrometer was installed to measure the atmospheric conditions and class A evaporation pan to measure the rate of evapotranspiration inside the greenhouse. The mean crop evapotranspiration of tomato using Blaney-Criddle for the months of April, May, June and July were 6.60, 6.21, 6.64 and 6.33 mm/day, respectively while the mean crop evapotranspiration using Evaporation pan were 3.78, 3.65, 3.62 and 3.28 mm/day and for CROPWAT 8.0 were 5.61, 5.00, 4.38 and 3.81. Diameter of the biggest of tomato fruit was 13.1 cm with a length of 4.45 cm while the smallest fruit has diameter of 7 cm with a length of 2.4 cm. Class A Evaporation pan gave consistent values of evapotranspiration from April to July than Blaney-Criddle that gave higher evapotranspiration because it depends only on temperature and daily sunlight.

Keywords: Blaney-Criddle, Class A Evaporation pan, Controlled environment, crop coefficient, crop evapotranspiration

1. INTRODUCTION

The crop water need mainly depends on the climate, the crop type and growth stage of the crop. According to Allen *et al.* (1998), the water need of a crop consists of transpiration and evaporation which occur simultaneously as evapotranspiration. The water required by the crop is usually expressed in mm/day, mm/month or mm/season. Reference evapotranspiration (ET_o) expresses the evaporative demand of the atmosphere at a specific location and time of the year but it does not depend on the crop and soil factors (Raghunath, 2007 and Michael, 2008). The only factors affecting ET_o are climatic parameters which can be computed from weather data according to (Schwab *et al*., 1993 and Michael, 2008). Allen *et al*. (1998) defined reference evapotranspiration as a the evapotranspiration from a hypothetical reference crop with an assumed height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23. The reference surface closely resembles an extensive area of actively growing grass of uniform height completely shading the ground and with sufficient soil moisture. Albedo is the fraction of solar radiation which is reflected by the earth's surface but the value depends on the type of surface, angle of incidence of sun's ray and the slope of the ground surface (Michael, 2008).

The amount of water that is required for evapotranspiration and water needed for metabolic activities (processes) is called consumptive use but also referred to as evapotranspiration. Consumptive use is higher than the evapotranspiration by the quantity of water needed for photosynthesis, transport of minerals and photosynthates, plant growth and structural support of the plant. The actual water that is used for the metabolic processes is less than 1% of evapotranspiration, therefore, consumptive use of crop is assumed to be equal to evapotranspiration (Michael, 2008). A proper irrigation scheduling (when to irrigate and quantity of water apply during irrigation) is one of the main factors in achieving high yields and avoiding loss of quality in greenhouse tomato. To do this, it is fundamental to know the crop water requirements or the actual evapotranspiration which depends on specific interactions among soil, crop and atmospheric conditions. The crop coefficient (k_c) values represent the crop type and the development of the crop. There are several k_c values for a single crop depending on the crop's stages of growth.

Ufoegbune *et al*. (2012) stated that tomato plant exhibits four stages of growth with specific crop coefficient (k_c) for each growth, the stages of the growth are initial growth stage (1 -35 days with k_c of 0.45), development stage (35 -75 days with k_c of 0.75), flowering growth stage (75 -125 days with k_c of 1.15) and ripening stage (125 -150 days with k_c of 0.80). Hanson (2010) also produced a graph showing the relationship between the canopy growth of tomato and its coefficients which varied from 0.2 (initial growth stage) to 1.1 (flowering growth stage) but 1.05 at 80% canopy growth. Evapotranspiration can be estimated by direct or indirect method. Accurate estimation of the crop water requirement is needed to avoid excess or water deficit application which could have negative effect on nutrients availability for plants growth (Blanco and Folegatti, 2004). This can be done by using appropriate method to determine the crop evapotranspiration (ET_c). Plants like tomato always respond to its environment and this often affects the yield of tomato. This optimum condition is not easily determined, thus, there is need to quantify the water requirement of the crop based on the climatic factors using empirical formula for optimum tomato production. This experiment is better done in greenhouse farming. The objectives of this study were to determine the tomato yield and evapotranspiration of tomato using Blaney-Criddle, CROPWAT 8.0 (FAO-56 Penman- Monteith) and Class A Evaporation pan methods in a greenhouse.

2. MATERIALS AND METHODS

Location of the Study and Characteristics of the Greenhouse

The site of the experiment is located at the Department of Agricultural and Bio-Environmental Engineering Technology, Institute of Technology (IOT), Kwara State Polytechnic, Ilorin, Kwara State, Nigeria. The experimental site in Ilorin lies on the latitude 8°30¹N and longitude 4°35¹E at an elevation of about 340 m above mean sea level (Ejieji and Adeniran, 2009). Ilorin is in the Southern Guinea Savannah Ecological zone of Nigeria with annual rainfall of about 1,300 mm. The wet season begins towards the end of March and ends in October while the dry season starts in November and ends in March (Ogunlela, 2001).

The greenhouse is 6 m long, 3 m wide and 2.5 m in height constructed using wood. It is covered with transparent polythene nylon and screen net to prevent entrance of insects and pests. One humidifier was put in the greenhouse to keep the humidity between 65 t0 85% and one thermo-hygrometer was also put in the greenhouse for reading the temperature and humidity. The soil used in this study was sandy loamy. A total of 12 buckets were used and of the bucket has a diameter of 18 cm and 25 cm deep. A 5 kg of the soil was put in the each bucket and 0.5 kg of cow dung to increase the fertility of the soil for normal growth of the tomato. Two varieties of tomato were planted in the buckets on 28th April 2017 and terminated on 30th July 2017. A 1 litre of water was applied to each tomato plant in the bucket at 2 days interval. The varieties of the tomato were Rio Grande and Roma VF tomatoes. The chemical properties of the soil are shown in Table 1.

Table 1 Chemical properties of the soil before mixing with the cow dung

Nutrient	Value
Nitrogen, %	0.53
Phosphorus, mg/Kg	3.23
Potassium, Cmol/Kg	3.77
Calcium, Cmol/Kg	0.91
Magnesium Cmol/Kg	0.34
Sodium Cmol/Kg	0.91
Organic matter, %	1.40
Organic carbon %	0.81
pH	5.57

Measurement of crop physiological Growth

The tomato Plant heights were measured from the soil surface to the terminal bud of the main shoot using thread and then measured on a ruler in cm. The number of branches per plant and the leaves on each plant was counted and recorded on weekly basis. The stem diameter was measured and recorded using a digital vennier caliper. The leaf area of each leaf from each bucket was calculated using a 1 cm grid. Each leaf was placed on the 1 cm grid and their outline was traced. The amount of grid (squares) between the leaf outline on the grid was counted and the area was calculated using 1 square centimeter (1 cm^2). The Leaf Area Index (LAI) was also estimated using Equation (1) given by Breuer *et al.*, (2003).

$$LAI = \frac{A_L}{A_G} \tag{1}$$

where: A_L area of the leaf (m^2) and A_G is the ground surface area (m^2).

Data Collection and evapotranspiration measurement in the greenhouse

Experimental data were collected for one growing season for climatic condition inside the greenhouse. An automatic thermo-hygrometer was installed in the greenhouse which automatically stores data for the temperature and humidity within the greenhouse. A humidifier was also used to maintain relative humidity range 67 to 80.

Class A Evaporation pan was used to measured the rate of evaporation inside the greenhouse on a daily basis. The mean value of minimum and maximum temperatures obtained inside the greenhouse with the values of daylight hour was used to compute reference evapotranspiration using Blaney-Criddle method given in Equation (2) as stated by Schwab *et al.* (1993). Equation (3) was used to determine crop evapotranspiration of tomato. The mean monthly values of temperatures, relative humidity, percentage daylight hour (P) and crop coefficient (k_c) used in this study for the computation crop evapotranspiration of tomato were shown in Table 2. The peak value of crop coefficient of 1.05 which normally occurs at mid-stage or flowering stage (at 80% canopy growth) as given by Hanson (2010) was used in this study to compute the water requirement of tomato in order to avoid water stress (water deficit) because water deficit at any growth stage could affect the crop yield but it adversely affects the yield at flowering stage.

According to Kashyap and Panda (2011), the different methods for computing evapotranspiration are available for the users based on different data availability and the levels of accuracy required in a particular area. According to Takakura *et al.* (2005), Blaney-Criddle equation is a method for estimating reference crop evapotranspiration when only air temperature is available for the site and Blaney-Criddle formula is given in Equation (2).

$$ET_O = P(0.46T_{mean} + 8) \quad (2)$$

$$ET_c = k_c \times ET_O \quad (3)$$

where ET_o is the reference evapotranspiration (mm/day), P is the mean percentage daylight hours (fraction), T_{mean} is the average or mean value of maximum and minimum temperature (°C), ET_c is the crop evapotranspiration of tomato or any crop (mm/day) and k_c is the crop coefficient.

Table 2 Mean values of weather data from the greenhouse during study

Month in 2017	Mean temperature (°C)	Relative humidity (%)	Annual daylight hours	Crop coefficient
April	28.2	80.3	0.3	1.05
May	25.4	67.5	0.3	1.05
June	28.4	68.5	0.3	1.05
July	26.3	71.8	0.3	1.05

Determination of reference evapotranspiration using CROPWAT 8.0

CROPWAT means crop water requirement that is determined from reference evapotranspiration. Crop water requirement is the product of crop coefficient and reference evapotranspiration (k_c x ET_o). CEOPWAT 8.0 is based on FAO-56 Penman-Monteith (FAO-56 PM) equation which involves all the factors affecting evapotranspiration. FAO-56 PM given in Equation (4) is regarded as the best empirical formula for computing ET_o, it gives reliable and accurate values of evapotranspiration (Michael, 2008). As given in Equation (4) The reference evapotranspiration (ET_o) was determined using CROPWAT 8.0 (FAO-56 PM) so that the results of ET_o and ET_c using Blaney-Criddle and Class A evaporation pan could be compared with that of CROPWAT 8.0. A 20 years weather data from 1998 – 2017 for Ilorin was used for computing the ET_o and ET_c that occurred outside the greenhouse for the Blaney-Criddle and FAO-56 PM methods. The mean values of the weather data are shown in Table 3.

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.3U_2)} \qquad (4)$$

where ET_o is the reference evapotranspiration (mm/day), R_n is the net radiation at the crop surface (MJ/m^{2}day), G is the soil heat flux density (MJ/m^{2}day), T is the mean daily temperature at 2 m height (^{o}C), U_2 is the wind speed at 2 m above the ground surface (m/s), Δ is the slope of vapour pressure (kPa/^{o}C), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa) and $e_s - e_a$ is the saturation vapour pressure deficit (kPa).

Table 3 Mean values of 20 years weather data for Ilorin for outside the greenhouse

Month	Min Temp (°C)	Min Temp (°C)	Mean Temp (°C)	Humidity (%)	Wind Speed (km/day)	Sun light (hours)	Radiation (MJ/m^2/day)
April	23.1	34.2	28.65	69	216	6.7	19.9
May	22.5	32.6	27.55	76	207	6.7	19.4
June	21.6	30.9	26,25	81	190	6.2	18.1
July	21.3	29.2	25.25	82	199	4.5	15.9

Determination of reference and crop evapotranspiration using Class 'A' evaporation pan

Two methods were used to determine the evaporation that occurred from the evaporation in 24 hours (a day). The first method was done by measuring the difference between the initial depth of water and final depth of water (mm) in the evaporation pan using a meter rule. The second method was done dividing the volume of water used to refill the evaporation pan (Epan) to its initial depth of the point arrow by the area of evaporation pan as given in Equation (5). The metallic characteristic of the evaporation pan which is hotter than the temperature of water normally increase the rate of evaporation but evaporation pan coefficient (k_p) of 0.75 was used in this study. Raghunath (2006) stated that k_p varied from 0.67 to 0.82 and the mean value is 0.75 that was used. The area of the evaporation pan, evaporation through the pan, ET_O and ET_c were computed using Equations (5), (6), (7) and (8), respectively as given by Yusuf *et al*. (2015).

$$A_{pan} = \frac{\pi d^2}{4} \tag{5}$$

$$Epan = \frac{V_{wL}}{A_{pan}} \tag{6}$$

$$ET_O = k_p \times Epan \tag{7}$$

$$ET_C = k_c \times ET_O \tag{8}$$

where: A_{pan} is the area of Class A evaporation pan (m^2), d is the internal diameter of the evaporation pan (m), Epan is the evaporation that occurs from pan (mm/day), V_{wL} is the volume of water that is used to refill the evaporation pan to its initial depth (litre), k_p is the evaporation pan coefficient while ET_O (mm/day), ET_C (mm/day) and kc had been defined in Equations (2) and (3).

3. RESULTS AND DISCUSSION

Reference and crop evapotranspiration in and outside the greenhouse

The mean values of evaporation from Class A Evaporation pan, the reference evapotranspiration, the crop evapotranspiration of tomato using Blaney-Criddle, CROPWAT 8.0 and Class A Evaporation pan that occurred inside the greenhouse were shown in Table 3 while the results for the outside the greenhouse were shown in Table 4. The values of reference evapotranspiration and crop evapotranspiration of tomato were all higher for Blaney-Criddle than the values from Class A Evaporation pan and even higher than results from CROPWAT 8.0 (FAO-56 PM). Blaney-Criddle method mainly depends on temperature and this could be the factor for given higher values of evapotranspiration when the temperatures were high even when other factors influencing evapotranspiration are low. The values of ET_o and ET_c were higher for both

Blaney-Criddle and Class A Evaporation pan inside the greenhouse than the outside greenhouse because the temperature inside the greenhouse was higher by 1 to 2 °C compared to outside the greenhouse. The values ET_o and ET_c using Class A Evapotranspiration obtained in this study were within the range obtained by Yusuf *et al*. (2015) which varied from 2.84 to 4.96 mm/day inside a greenhouse. The ET_o and ET_c from FAO-56 PM for outside the greenhouse were higher than the results of ET_o and ET_c from Class A Evaporation pan for outside the greenhouse but the results of ET_o and ET_c from Class A Evaporation pan gave the actual evapotranspiration that occurred in the study area which were affected by factors influencing evapotranspiration prevailing in the study area at that particular time of the study. Michael (2008) stated that Class A Evaporation pan could be used for computing crop evapotranspiration for irrigated farm.

Table 3 Mean evaporation, reference and crop evapotranspirations of tomato using Blaney-Criddle, Class A evaporation pan in the greenhouse and CROPWAT 8.0 (FAO-56 PM) for outside greenhouse

Parameter	Blaney-Criddle				CROPWAT 8.0 (FA-56 PM)				Class A Evaporation pan			
	April	May	June	July	April	May	June	July	April	May	June	July
Epan (mm/day)	-	-	-	-	-	-	-	-	4.80	4.64	4.60	4.16
ET_o (mm/day)	6.29	5.91	6.32	6.03	5.34	4.76	4.16	3.63	3.60	3.48	3.45	3.12
ET_c (mm/day)	6.60	6.21	6.64	6.33	5.61	5.00	4.37	3.81	3.78	3.65	3.62	3.28

Table 4 Mean evaporation, reference and crop evapotranspirations of tomato using Blaney-Criddle, CROPWAT 8.0 (FAO-56 PM) and Class A evaporation pan outside for the greenhouse

Parameter	Blaney-Criddle				CROPWAT 8.0 (FA-56 PM)				Class A Evaporation pan			
	April	May	June	July	April	May	June	July	April	May	June	July
Epan (mm/day)	-	-	-	-	-	-	-	-	3.40	3.38	5.25	3.28
ET_o (mm/day)	6.29	5.91	6.32	6.03	5.34	4.76	4.16	3.63	2.38	2.54	3.94	2.46
ET_c (mm/day)	6.60	6.21	6.64	6.33	5.61	5.00	4.37	3.81	2.50	2.67	4.14	2.58

Vegetative growth of tomato during the study

The mean monthly growth, number of leaf and branches, stem thickness and leaf area of the Rio Grande and Roma VF tomato varieties were shown in Table 5. The Roma VF grew faster and had higher growth height than the Rio Grande tomato when the same quantity of water and cow dung was applied. The stem thickness, leaf area, number of leaf and number of branches of Roma VF tomato were higher than the results from Rio Grande tomato as shown in Table 5.

Table 5 Mean monthly growth, number of leave, number of branches, stem thickness and leaf area of tomato plant in the greenhouse

Month	Tomato variety	Mean height (cm)	Number of leaves	Number of branches	Stem thickness (mm)	Leaf area (cm^2)
May	Rio Grande	77	10	3	2.20	31.16
	Roma VF	100	13	3	3.80	33.31
June	Rio Grande	226	27	5	4.60	50.46
	Roma VF	253	29	7	5.75	53.46
July	Rio Grande	402	47	11	5.70	64.01
	Roma VF	394	41	16	6.70	67.06

4. CONCLUSION

The values ET_o and ET_c using Class A Evapotranspiration obtained in this study range from 2.84 to 4.96 mm/day inside the greenhouse. This gave the actual evapotranspiration that occurred in the study area. The values of reference evapotranspiration and crop evapotranspiration of tomato were all higher for Blaney-Criddle compare to values from Class A Evaporation pan and CROPWAT 8.0 (FAO-56 PM). The ET_o and ET_c from FAO-56 PM outside the greenhouse were higher than the results of ET_o and ET_c from Class A Evaporation pan outside the greenhouse. The tomato plant Roma VF had higher growth height than the Rio Grande tomato when the same quantity of water and cow dung was applied. The stem thickness, leaf area, number of leaf and number of branches of Roma VF tomato were higher than the results from Rio Grande tomato.

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Some Engineering Properties of Breadfruit Seed Varieties Relevant to Handling

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ABSTRACT

Determination of some engineering properties of two varieties of breadfruit seeds (Var. Africana and Var. Inversa) was carried out. The initial moisture content was 6.85% and later adjusted by rewetting to 14.85%, 21.85% and 28.85%(wb). The following engineering properties, true density, bulk density, percentage porosity, specific heat capacity, terminal velocity and drag coefficient were determined. Thermal property (specific heat capacity) of the seed was determined using the calorimeter method. The aerodynamic properties (terminal velocity and drag coefficient) were also determined by using an air column made of a vertical wind tunnel in conjunction with a voltage regulator to vary the wind speed and a digital anemometer to determine the air speed. Data obtained were statistically analyzed using Minitab statistical software. The following results were obtained. The true density of Var. Africana decreased from 1033.68 kg/m^3 to 842.81 kg/m^3 which amounted to 18.5% decrease, while for var. Inversa it decreased from 948.38 kg/m^3 to 911.89 kg/m^3 amounting to 3.85% decrease as the moisture content increased from 6.85 to 28.85%. The bulk density was observed to increase linearly as the moisture content increased. It increased from 361.239 to 408.723 kg/m^3 for Var. Africana and 317.55 to 387.638 kg/m^3 for Var. Inversa. The porosity of Var. Africana ranges from 65.06% to 51.6% while for Var. Inversa it ranges from 66.5% to 57.2%. The terminal velocity increased from 5.5 to 8.0 m/s for Var. Africana and 3.89 to 6.8 m/s for Var. Inversa respectively as the moisture content increased from 6.85 to 28.85 %.

KEYWORDS: Breadfruit seed, terminal velocity, drag coefficient, percentage porosity

1. INTRODUCTION

The breadfruit seed is the mature ovule of *Treculia Africana*, it is light brown in colour, roughly oval and spherical in shape. The seeds are contained in a pulp mass inside the fruit. When the fruits are harvested they are stored to ferment for 3-4 days, then mashed and the seeds freed by washing the solubilized pulp off the seeds in a basket with running water, and later sun dried. The dried seeds are available in the market in the undehulled state (Omobuwajo *et al*., 1999).

When dehulled the seeds may be cooked and eaten as the main dish like rice or roasted and eaten as a snack in the same way as peanut. It could also be cooked with fresh corn into porridge. The seed is used in these food forms in several parts of West Africa and especially Southeastern Nigeria (Akande, 1998). It is used in preparing pudding, as a thickener in traditional soups and in manufacture of food products such as flour for bread, beverages and weaning food for children (Onyekwelu and Fayose, 2007).

Engineering properties of breadfruit seed are essential for the design of equipment for handling, separation, conveying, drying, storing, aeration and processing. Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Rajabipour *et al.* (2006) reported that drag coefficient and terminal velocity of material are important parameters in aerodynamic and hydrodynamic behaviour which depends on acceleration due to gravity and fluid flow. These properties help in the design of equipment for separation and handling. Knowledge of specific heat capacity is important in engineering design calculations involving thermal processing of agricultural products (Mortaza *et al*., 2008). Temperature and moisture content greatly influence the specific heat capacity of agricultural materials due to the relatively high specific heat of water.

The aim of this research work was to investigate some engineering properties of two varieties of breadfruit seed *Var. Africana* and *Var. Inversa* relevant to bulk handling. These properties include densities, porosity, aerodynamic and thermal properties as influenced by moisture content. Regression models were also generated with respect to moisture content.

2. MATERIALS AND METHODS

2.1 Moisture content determination and adjustment

Standard procedures stated for ungrounded grain and seed in the ASAE S352.2 (2003) was adopted in order to obtain the different moisture content. Electric oven (Gallenkamp oven 300 plus series), carrying cans, and electronic weighing balance (WENSAR PGB Series) with accuracy of 0.01 g were used to determine moisture content of the two varieties of breadfruit seed. The moisture content was calculated using equation 1(Abodenyi, *et al.*,2015)

$$M.C_{(w.b)} = \frac{M_{b-}M_a}{M_{b-}M_c} \times 100\% \quad (1)$$

Where; $MC_{(wb)}$= moisture content (wet basis)

M_b = the weight of moisture can plus sample weight before oven-drying (gm)

M_a = the weight of moisture can plus sample weight after oven-drying (gm)

M_c = weight of moisture can (gm)

The desired moisture content were obtained by determining the required amount of water, M, as calculated from equation 2 (Davies and Zibokere, 2011) ,

$$M = W_s\left(\frac{M_{2-}M_1}{100-M_2}\right) \quad (2)$$

Where, W_s = weight of sample (kg)

M = weight of distilled water that was added (kg)

M_1 = initial moisture content (%) of breadfruit seed

M_2 = desired moisture content (%) of breadfruit seed

The samples were adjusted from 6.85% to 14.85%, 21.85% and 28.85% w.b.

2.2 Determination of true density of breadfruit seeds

The seed volume and true density ρ_T as a function of moisture content was determined by water displacement method (Adejumo *et al.*, 2007, Davies and Zibokere, 2011). One hundred seeds of known average weight were dropped into a container filled with water. The net volumetric water displacement by the seed were noted and recorded. The experiment was repeated five times. The true density of breadfruit seed was then evaluated using the expression as given by equation 3;

$$\rho_T = \frac{m}{v} \quad (3)$$

Where, ρ_T = true density (kg/m^3)

m = mass of the sample (kg) and V = volume (m^3)

2.3 Determination of bulk density and percentage porosity

The bulk density (ρ_B) in kg/m^3 is the ratio of the mass sample of thes breadfruit seeds to its volume. Equation 4 was used to determine the bulk density using a container of 300 mm height and 200 mm diameter. The container was filled with the sample from a height of about 150 mm, (Karababa, 2006). The electronic balance was used to weigh the samples:

$$\rho_B = \frac{M_{\rho 2} - M_{\rho 1}}{V} \qquad (4)$$

Where, $M_{\rho 2}$ = mass of cylinder plus seeds (g)
$M_{\rho 1}$ = mass of empty cylinder (g)
V = volume of the cylinder (cm^3)

The porosity (ε) of the bulk seed was computed from the values of the true density (ρ_T) and bulk density (ρ_B) of the seeds by using equation 5;

$$\varepsilon = \frac{\rho_T - \rho_B}{\rho_T} \times 100 \qquad (5)$$

3.1 Determination of Aerodynamic Properties

3.1.1 Determination of terminal velocity

The terminal velocity of the breadfruit seed was determined by using an air column as used by Adedeji (2012). It is made of vertical wind tunnel of diameter 44.28 mm and height of 600 mm. A voltage regulator and a digital anemometer (model AM- 4812) were used to determine the air speed. Each sample of the two varieties at the required moisture of 6.85, 14.85, 21.85 and 28.85% were dropped into the air stream from the top of the air column and the air velocity adjusted until the seed, is suspended in the air stream. The respective velocity (m/s) near the location of the seed suspension was measured with the help of the digital anemometer having accuracy of ± 0.1 m/s. The experiment was replicated five times and the readings recorded.

3.1.2 Determination of drag coefficient

The drag coefficient was calculated from equation 6 (Mohsenin, 1986)

$$CD = \frac{2Mg}{A_\rho \ \rho_A V_t} \qquad (6)$$

Where, CD = the drag coefficient
M = weight of the seed at terminal velocity (g)
g = acceleration due to gravity (m/s^2)
A_ρ = area of the particle (m^2)
ρ_A = density of air (kg/m^3)
V_t = terminal velocity of the particle (m/s)

3.2 Determination of Specific Heat Capacity

The specific heat capacities of the two varieties of the seed were determined by the method of mixture as described by Oje and Ugbor (1991) and Ogunjimi *et al.*, (2001). Hot water of known weight and temperature was poured into an adiabatic drop calorimeter containing twenty- five seeds of each variety at a time. The initial temperature of the seeds was taken. The mixture was stirred with a copper stirrer until equilibrium was reached; the final temperature of the mixture was recorded. Specific heat capacity was computed from equation 7. The experiment was replicated five times for each of the variety at the required moisture content.

$$C_{S=} \quad \frac{[C_W\ M_W\,(T_{wi-}T_{wf})]}{M_s\,(T_{si-}T_{wf})} \qquad (7)$$

Where, C_{s} = specific heat capacity of the seed (J/kg/°C)

C_W = specific heat capacity of water (J/kg/°C)

M_W = Mass of water (g)

M_S = Mass of the seed (g)

T_{WI} = Initial water temperature (°C)

T_{WF} = Final water temperature (°C)

T_{SI} = Initial temperature of seed (°C).

3.3 Experimental Design and Statistical Analysis

The experimental design was a 2×4 RCBD (Randomized Complete Block Design) with replications. Two varieties of breadfruit seed (*Var. Africana* and *Var. Inversa)* were used at four different moisture content levels of 6.85, 14.85, 21.85 and 28.85 % and each parameter determined was replicated five times.

4. RESULTS AND DISCUSSION

4.1.1 True and bulk densities

The result of the effect of moisture variation on true density is presented in Table 1. The true density of *Var. Africana* decreased from 1033.68 kg/m^3 to 842.81 kg/m^3 which amounted to 18.5% decrease, while for *var. Inverse* it decreased from 948.38 kg/m^3 to 911.89 kg/m^3 amounting to 3.85% decrease as the moisture content increased from 6.85 to 28.88%.

The regression equations, 8 and 9 indicates a negative linear correlation which is to say that as the moisture content increased the true density decreased. Taheri *et al*., (2012) observed the same result for hemp seed, and Bagherpour *et al* (2010) also found true density to decrease with increase in moisture content from 1330 to 1194 kg/m^3 and moisture content from 8 to 20% wb.

$$\rho_{TA} = -10.25MC + 1140 \qquad R^2 = 0.856 \qquad (8)$$

$$\rho_{TIN} = -2.055MC + 979.8 \qquad R^2 = 0.812 \qquad (9)$$

This result revealed that the relative increase in the weight of breadfruit seed due to moisture absorption is lower than the corresponding volumetric increase. This finding agrees with Tunde-Akintunde and Akintunde (2007) for beniseed and Davies and Zibokere (2011) for three varieties of Cowpea, and Solanki *et al* (2011) for neem fruit and seed. The ANOVA (Table 2) result indicated that the moisture content had significant effect on true density at $P \leq 0.05$ probability. Also, the interaction effect between moisture content and variety was significant.

The bulk density was observed to increase linearly as the moisture content increased. It increased from 361.239 to 408.723 kg/m^3 for *Var. Africana* and 317.55 to 387.638 kg/m^3 for *Var. Inversa*. The increase in bulk density for neem seed indicated increase in mass owing to moisture in the seed. This result agrees with the result of Solanki *et al.* (2011) on neem fruit and seed, Adedeji (2012) on neem seed and kernel and Dursun and Dursun (2005) caper seed. The ANOVA of the effect of moisture content on bulk density of breadfruit varieties indicates that the effect was significant at $P \leq 0.05$ probability and also significant for the interactive effect of moisture content and variety. The coefficient of determination R^2 obtained from the regression models gave values of 0.983 for *Var. Africana* and 0.996 for *Var. Inversa* on the effect of moisture content on bulk density of the two breadfruit seed varieties.

$$\beta\, \rho_{A} = 2.122MC + 349.0 \qquad R^2 = 0.983 \qquad (10)$$

$$\beta\, \rho_{IN} = 3.196MC + 293.9 \qquad R^2 = 0.996 \qquad (11)$$

Asoegwu *et al,* (2011) found the R^2 value for African breadfruit seed to be 0.984. The mean separation between the varieties and moisture content is presented in Table 1. There is a significant difference between all the moisture content levels for both varieties which tallies with the ANOVA result in Table 2. Bulk density and true density are useful in the design of hoppers and storage facilities.

4.1.2 Porosity of breadfruit varieties

Figure 3 shows the effect of moisture content on percentage porosity of *Var. Africana* and *Var. Inversa*. Increase in moisture content decreased the porosity of the seeds. The porosity of *Var. Africana* ranges from 65.06% to 51.6% while for *Var. Inversa* it ranges from 66.5% to 57.2%. This shows that a pack of *Var. Inversa* is more porous than *Var. Africana*. This property is required in the aeration process in agricultural material handling; from this result *Var. Inversa* might dry faster than *Var. Africana* during air drying process. This result agrees with Aydin *et al*. (2002), for Turkish Marhleb, Irtwange and Igbeka (2002b) for two African yam bean accessions TSs 137 and TSs 138 and Alonge and Adegbalugbe (2005) for groundnut. The result in Table 1 and the ANOVA (Table 2) indicate that there is a significant difference between all the moisture content levels for both varieties at $P \leq 0.05$ alpha level. Regression equations 12 and 13 shows that the coefficient of determination are significant for the two varieties at $p \leq 0.05$.

$$\varepsilon_A = -0.676MC + 70.74 \qquad R^2 = 0.912 \qquad (12)$$

$$\varepsilon_{IN} = -0.418MC + 70.14 \qquad R^2 = 0.945 \qquad (13)$$

The coefficient of determination (R^2) tended towards unity (1) indicates that the interaction of the independent variable has a very strong effect on the dependent variable.

4.2 Effect of Moisture Content on Thermal Properties of Breadfruit Seed Varieties

4.2.1 Specific heat capacity of breadfruit seed varieties

The influence of moisture variation on specific heat capacity of *Var. Africana* and *Var. Inversa* is presented in Figure 4. Increase in moisture content resulted to increase in specific heat capacity of the two varieties. *Var. Africana* increased from 2869.70 J/kg/^{O}C to 3909.63 J/kg/^{O}C while, *Var. Inversa* increased from 2811.35 to 3777.30 J/kg/^{O}C as the moisture increased from 6.85 to 28.85%. The mean effect of moisture content on breadfruit varieties is shown in Table 1. Regression analysis from equations 14 and 15 showed that there is a linear relationship between *Var. Inversa* and the moisture content while *Var. Africana* had a polynomial relationship as evident in Figure 4.

$$C_A = -2.663MC^2 + 141.9MC + 2026 \qquad R^2 = 0.999 \qquad (14)$$

$$C_{IN} = 47.67MC + 2500 \qquad R^2 = 0.929 \qquad (15)$$

The R^2 value for *Var. Africana* is higher than that for *Var. Inversa*, so the model for the *Var. Africana* is recommended.

The increase in specific heat capacity of breadfruit varieties is in agreement with findings of some previous researchers. The specific heat of hard red spring wheat was found to increase linearly from 1054 to 2521 J/kg/^{O}C with moisture content in the range of 10 to 23 % db by Muir and Viranvanichai (1992) and Mirzaee *et al*. (2008) for Apricot fruit.

The specific heat of shea nut kernel as a function of moisture content was determined by Aviara and Haque (2001). They found that the specific heat increase linearly from 1792 to 3172 J//kg/^{O}C as moisture was increased from 3.32% to 20.7% (db). This property can be used to determine the amount of heat required in the processing of the seed. It can also be used to design equipment and facilities for drying, preservation and processing of breadfruit seed, for making industrial products such as beverages, snacks pastas, flours, and cosmetics and in the pharmaceuticals, the knowledge of the specific heat capacity is important. The ANOVA (Table 2) showed that moisture content has a significant effect on the specific heat capacity of breadfruit seed. But there was no significant effect on the interaction between moisture and variety at 0.05 probability level.

4.3 Effect of Moisture Content on the Aerodynamic properties of Breadfruit Seed Varieties

4.3.1 Terminal Velocity of Breadfruit Seed Varieties

The mean effect of moisture content on terminal velocity is shown in Table 1. As moisture content increased from 6.85 to 28.85% (wb) the terminal velocity also increased from 5.5 to 8.0 m/s for *Var. Africana* and 3.89 to 6.8 m/s for *Var. Inversa* respectively. The result is in agreement with the report of Simonyan *et al.* (2008), Gursoy and Guzel (2010) and Adedeji (2012). The increase in terminal velocity with increase in moisture content can be attributed to the increase in the weight of an individual breadfruit seed per unit frontal area presented to the air stream. The regression equations and correlation between the moisture content and terminal velocity are shown in equations 16 and 17 and Figure 5.

$$V_{tA} = 0.120MC + 4.668 \qquad R^2 = 0.970 \qquad (16)$$

$$V_{tIN} = 0.132MC + 2.989 \qquad R^2 = 0.999 \qquad (17)$$

The terminal velocity for *Var. Africana* was found to be higher than that of *Var. Inversa*. This is a good parameter for effective separation. The ANOVA indicates that the effect of moisture content on the breadfruit variety is significant at 0.05 level of probability, but not significant for interaction effect of variety and moisture content. This result indicates that in the design of a cleaning chamber for breadfruit seed decorticator the terminal velocity should not be more than 8.0 m/s but higher than 3.89 m/s. Terminal velocity has practical application in calculating volume of air stream for seed and chaff separation, such as fan and sieve arrangement of the thresher.

4.3.2 Drag coefficient of breadfruit seed varieties

From Table 1 it was observed that as the moisture content increased the drag coefficient for *Var. Africana* reduced from 0.01 to 0.0029, for *Var. Inversa* it reduced from 0.005 to 0.0018. Drag coefficient is resistance of a seed in a flow environment. This property is required in the design of cleaning and sorting machine. The result obtained agrees with McCormick (1989) findings that less drag coefficient of an object the higher the moisture content.

The ANOVA shows that there is no significant effect at $p \leq 0.05$ for the two varieties. The regression analysis indicates a polynomial correlation as shown in Figure 6 and equations 18 and 19

$CD_A = 0.005MC^2 - 0.003MC + 0.014 \qquad R^2 = 0.999 \qquad (18)$

$CD_{IN} = 0.006MC^2 - 0.002MC + 0.007 \qquad R^2 = 0.981 \qquad (19)$

5. CONCLUSION

1. The bulk density increased from 361.239 kg/m^3 to 408.723 kg/m^3 as the moisture content increased from 6.85% to 28.85 % wb for *Var. Africana*, and from and 317.55 to 387.64 kg/m^3 for *Var. Inversa*.
2. The following properties for *Var. Africana* decreased with increase in moisture; true density and porosity; ranging from 1033.68 kg/m^3 to 842.81 kg/m^3 and 65.06 to 51.58% respectively. While for *Var. Inversa* the decrease ranged from 948.38 to 911.89 kg/m^3 for true density and 66.51% to 54.24 % for porosity.
3. The specific heat capacity was found to increase from 2869.70 to 3909.63 J/kg/^{o}C for *Var. Africana* while for *Var. Inversa* it increased from 2811.35 to 3777.30 J /kg/ ^{o}C as the moisture content increased from 6.85 to 28 85%.
4. The terminal velocity for *Var. Africana* and *Var. Inversa* increased from 5.50 to 8.0 m/s and 3.89 to 6.8 m/s, respectively as moisture content increased from 6.85 to 28.85%.
5. The drag coefficient was observed to decrease with increase in moisture content for *Var. Africana* from 0.010 to 0.0029, while for *Var. Inversa* it deceased from 0.005 to 0.0018 for moisture range of 6.85 to 28.85 %.

Table 1: Mean Separation for Some Engineering Properties of Breadfruit Seed Varieties Using LSD at 0.05

Variety	MC (%)	True Density (kg/m^3)	Bulk density (kg/m^3)	Porosity (%)	Terminal velocity (m/s)	Drag coefficient	Specific heat capacity(J/Kg/^{o}C)
Africana	6.85	1033.68^a	361.24^a	65.06^a	5.50^a	0.010^a	2869.70^a
	14.85	1047.71^b	383.9^b	63.31^b	6.30^b	0.0059^a	3560.13^b
	21.85	863.38^c	395.82^c	54.06^c	7.75^c	0.0038^a	3842.32^c
	28.85	842.81^d	408.72^d	51.58^d	8.01^d	0.0029^a	3909.63^c
LSD $_{0.05}$		**13.554**	**2.1673**	**0.6009**	**0.2192**	**0.0582**	**348.08**
Inversa	6.85	948.38^a	317.55^a	66.51^a	3.89^a	0.005^a	2811.35^a
	14.85	962.13^b	339.30^b	64.80^b	4.96^b	0.0035^a	3142.60^b
	21.85	948.34^c	362.85^c	61.82^c	5.90^c	0.0020^a	3720.74^c
	28.85	911.89^d	387.64^d	54.24^d	6.80^d	0.0018^a	3777.30^c
LSD $_{0.05}$		**13.554**	**2.1673**	**0.6009**	**0.2192**	**0.0582**	**348.08**

Means having the same letter in the same column are not Means having the same letter in the same column are not statistically different from each other at $p \leq 0.05$.

Table 2: Summary of ANOVA Results for Some Engineering Properties of Two Breadfruit Seed Varieties

Parameters	Sources of Variations	DF	F	P
True density	Variety	1	1.18	0.286^{ns}
	M.C	3	90.75	0.000*
	Interaction	3	51.54	0.000*
Bulk Density	Variety	1	1137.14	0.000*
	M.C	3	544.64	0.000*
	Interaction	3	32.20	0.000*
Porosity	Variety	1	186.45	0.000*
	M.C	3	320.08	0.000*
	Interaction	3	24.91	0.000*
Terminal vel.	Variety	1	180.65	0.000*
	M.C	3	127.51	0.000*
	Interaction	3	1.13	0.354^{ns}
Drag coefficient	Variety	1	160.42	0.068^{ns}
	M.C	3	119.26	0.070^{ns}
	Interaction	3	3.14	0.069^{ns}

Specific heat capacity	Variety	1	1.15	0.292 ns
	M.C	3	7.45	0.001*
	Interaction	3	0.22	0.880 ns

*= significant at $p \leq 0.05$, ns = not significant at $p \leq 0.05$

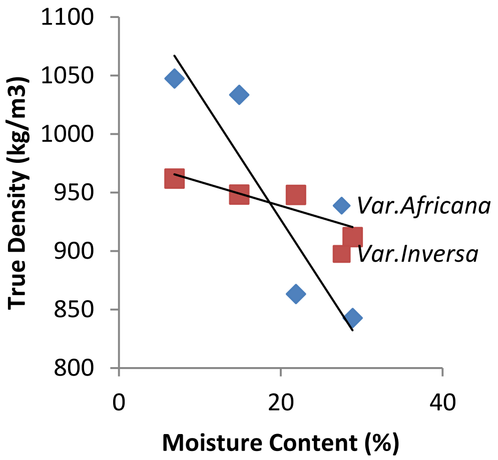

Figure 1: Effect of Moisture Content on True Density of *Var.Africana* and *Var. Inversa*

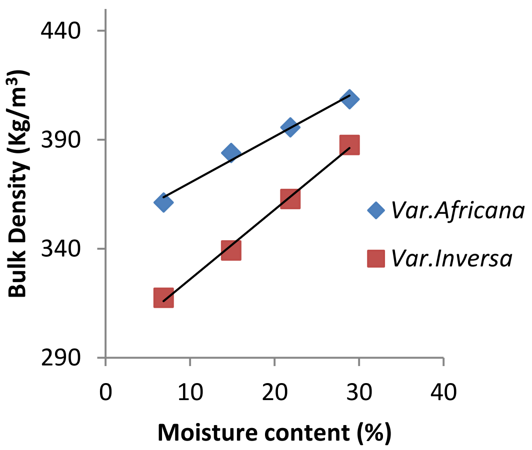

Figure 2: Effect of Moisture Content on Bulk Density of Breadfruit Seed Varieties

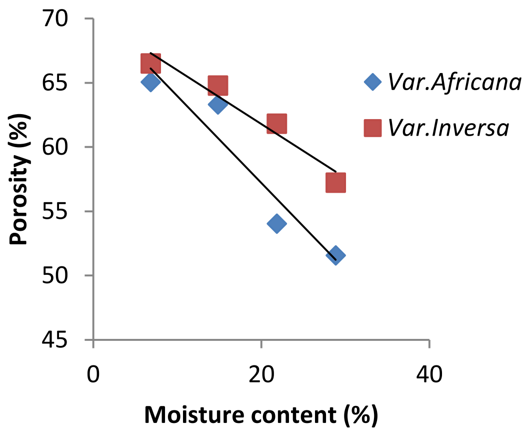

Figure 3: Effect of Moisture Content on Porosity of Breadfruit Seed Varieties

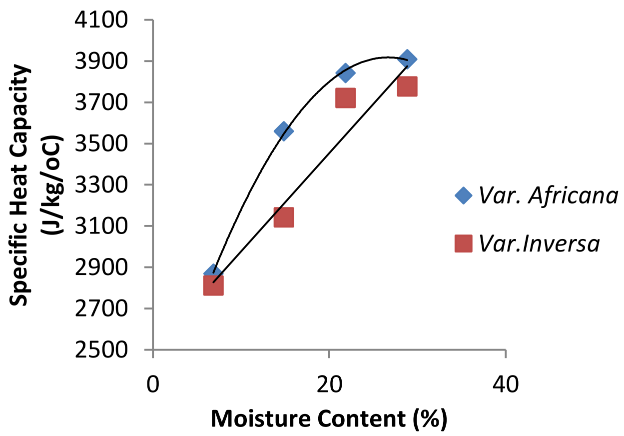

Figure 4: Effect of Moisture Content on Specific Heat Capacity of Breadfruit Seed Varieties

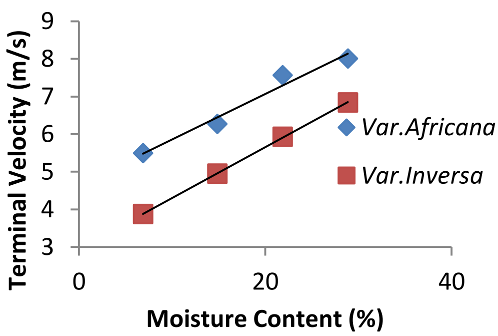

Figure 5: Effect of Moisture Content on Terminal Velocity of Breadfruit Seed Varieties

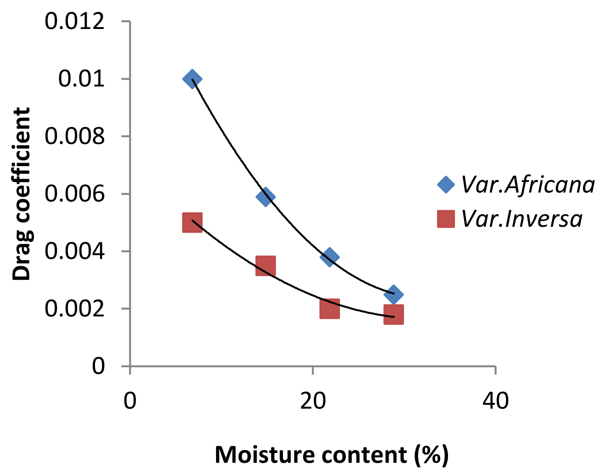

Figure 6: Effect of Moisture Content on Drag Coefficient of *Var. Africana* and *Var. Inversa*

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Development of a Hand Push-Type Cassava Harvester

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ABSTRACT

Cassava harvesting especially on large scale involves first, cutting the stem at a predetermined height above the ground and preserving it for the next planting season, after which a preferred method of uprooting the tubers is employed. It is categorized as the most difficult and challenging aspect in its production process. Most practiced world over, especially in Africa and Nigeria in particular, is the manual system of uprooting by hand which is tedious and mostly characterized with defects on farmers over time. Some of these defects include; blistered/callus palms, arched spinal cord and waist pain, amongst others. Root tuber damage, land mass and the farmers financial status are major considerations in the choice and adoption of a method of harvesting, (manual, semi-mechanized or mechanized) with respect to the end use of the harvested produce and availability/accessibility of resources. These and more led to the development of a hand push-type cassava harvester, incorporated with a cabin to protect the operator from unfavourable weather conditions and driven manually on two wheels. The mechanism of a simple machine such as the lever was employed in driving and powering the machine and its major components, adopting the first and second-class lever principle in the design. The machine, comprising of three main mechanisms to carry out the following operations; stem cutting, soil loosening and tuber harvesting was successfully designed, fabricated and tested.

Keywords: Development, Hand Push-Type, Cassava Harvester, Nigeria.

1. INTRODUCTION

Cassava, *Manihot esculanta* is a tropical, herbaceous crop, with a tuberous starchy root of the family Euphorbiaceae (Akinwonmi and Andoh, 2013). It is an essential source of food and income and classified as one of the three world's most important food crops, amongst rice and maize (IFAD *et al.*, 2008). Cassava is ranked as the fourth supplier of dietary energy in the tropics (after rice, sugar and maize) and the ninth globally. Its cultivation and processing provide household food security, income and employment opportunities for hundreds of millions of people across the globe, mostly in Africa, Asia and the America. Worldwide, cassava provides the livelihood for millions of farmers and traders (FAO and IFAD, 2001). It is a basic staple food for millions of people in the tropical and subtropical regions, as well as being a major source of raw material as flour and starch for numerous industrial applications and animal feed (Anderson *et al.*, 2004; FAO and IFAD, 2001).

Cassava is known to be exceptionally tolerant to high soil acidity and low levels of some basic soil nutrients (Phosphorus). It is also known to be a very drought-tolerant and water-efficient crop. Thus, cassava can compete with other more valuable crops such as maize, soybean and vegetables mainly in areas of acidic and low-fertility soils, and those with low or unpredictable rainfall (Howeler, 2012). The Federal Government of Nigeria recent directive on the substitution of 10% of wheat flour with cassava flour by flour millers, has further led to the surge in demand of cassava produce from between 200,000 and 300,000 tonnes to the tune of 600,000 tonnes per day (Olukunle, 2005). All these facts points to opportunities that abound in the area of cassava production, but, these opportunities cannot be fully exploited using the traditional harvesting and processing methods currently in use in the country which is generally adjudged as arduous, labour intensive, time consuming and unsuitable for large scale production (Adetan *et al.*, 2003; Quaye *et al.*, 2009; Agbetoye, 2005).

Lack of access to mechanised and improved farming systems to support production and processing of cassava is impeding the development of the cassava market in Nigeria. This technological gap has left farmers with little or no option but to produce cassava on a low scale, mainly for subsistence and local markets which is archaic, arduous, mundane and highly labour intensive. Although the continent and Nigeria in particular is ranked the highest producer of cassava in the world, in terms of classification of its yield, it is ranked below the fiftieth (50^{th}) position, leaving much to be desired beyond its production status (Nweke *et al.*, 2002). These therefore, buttresses the objective of this work; to review the efforts made, and currently being made towards an efficient and less cost effective mechanised system of cassava harvesting.

Cassava is basically harvested firstly by cutting off the stalks 20 – 30 cm above the ground, which is done manually using a machete with the remaining stump left to enable pulling the roots (tubers) off the ground. Where the soil is too hard, the roots can be lifted out of the ground using a pointed metal bar or metal fork attached to a wooden stick used as a lever. There are basically three methods generally employed in harvesting cassava. They are traditional or manual method, semi-mechanised system and mechanised harvesting. The traditional system employs uprooting tubers with bare hands and sometimes with the aid of a hoe or cutlass. Where the soil is hard, especially during peak dry season, the roots are lifted out of the ground manually using a pointed metal bar or metal fork attached to a wooden stick used as a lever. A major challenge with this method is the defects it poses to farmers, tedium, drudgery, and tuber damage associated with this harvesting method (Bobobee, 2014). The present situation in the country whereby limited quantities of cassava-based product are exported is largely due to the inability of these products to meet basic local demands, let alone international demands and standards for healthy foods (Adetunji and Quadri, 2011). Therefore, buttressing the need for a review of the efforts made towards an efficient and less cost effective semi-mechanised combined system of cassava harvesting.

2. METHODOLOGY

2.1 Machine Description and Components

The machine consists of three mechanisms for soil loosening, stem cutting and tuber harvesting (Figure 1). All three mechanisms where fastened to the frame by means of temporal fasteners (Bolts and nuts). This was necessary for ease of transport and maintenance. The mechanism of a simple machine as the lever was employed in driving and powering all mechanisms of the machine. In the design of the cassava harvester, just the first and second class lever principles were applied. The first class principle of levers having the fulcrum in between the load and the effort was applied in the design and fabrication of the uprooting mechanism, the scraper and secateurs. While the second class lever principle was adopted in driving the machine, with the load in between the effort and the fulcrum. The major components of the harvester are; the machine frame, the wheels, pruning shears (secateurs), lever controls, griping jaw, soil loosening component (scraper) and the harvester cab (Figure 2).

2.1.1 Machine Frame

The machine frame is a skeletal structure on which all other components are assembled. The frame with dimensions of 120 cm length and 80 cm width was designed to accommodate the loads, vibrations and stresses from the various machine elements without failure, and also to allow for easy uprooting of tubers with root spreads of over 60 cm. Selection of material for the frame was on the basis of its strength, rigidity, cost and availability.

2.1.2 The Wheels

The machine was designed to be driven on two-wheels, situated at the front adopting a second class lever principle, transmitting power obtained from human push effort. A wheel diameter of 400 m was used in order to give significant ground clearance between the ridge top and the machine frame. Rigid stands with circular base at the rear were incorporated to keep the machine balanced during idle time and during harvesting.

2.1.3 Pruning Shears (Secateurs)

They consist of two blades, pivotally connected at a point on the machine frame for cutting cassava stem before harvesting. Interacting edges of both blades were sharped to ease cutting, with one shearing blade firmly fixed to the frame. This mechanism was employed to convert and transmit the force produced from the vertical motion of the lever arm to horizontal motion/force to the cutting blade. Maximum allowable opening position of 60^o between blades and 10 cm apart was given to accommodate stems larger than 50 mm in diameter.

2.1.4 Griping jaw

The griping jaw with a serrated groove/single or jagged edge, was designed to accommodate a wide variety of stem girts between 20 – 70 mm, with little or no slip. This component is tasked with the responsibility of uprooting the tubers off the ground by gripping the stem at its base, close to ground surface, displacing the tubers from the soil at an increasing angle from applied force transmitted from the uprooting lever.

2.1.5 Soil loosening Component (Scraper)

The soil loosening component was built in form of a digger, with twin prongs of length 15 cm, firmly fastened on a carbon steel metal bar frame of length 50 cm, made from high carbon steel sheets, for ease of penetrating the soil without deformation. They are used to loosen hard compact soils, to a depth of about 10 cm below the soil surface, to ease uprooting and to minimize root breakage in hard soils during uprooting.

2.1.6 Harvester Cab

This component is designed to provide shelter for the operator from harsh weather conditions, like intense sunlight and rain. The cabin frame was made from mild steel angle irons and its cover/roof from tarpaulin.

2.2 Mode of Operation

The machine was taken to the field and tested on completion of fabrication. Testing of the machine was achieved for each mechanism systematically from cutting, to soil loosening and then harvesting. This was done by conveying the machine to the field, randomly selected matured cassava stands with varying stem diameters, positioned each stalk to be cut in between the cutting blades, then clutch down the cutting lever intermittently until the stem was cut. Next, the soil loosening diggers were engaged to break up the soil to a required depth so as to ease uprooting, where uprooting seemed more difficult. Thereafter, the uprooting mechanism was engaged by positioning the griping jaw at the base of the already coppiced stem, so as to grip the stem properly at the node closest to ground to prevent slip, after which a downward force was applied to the uprooting lever with a good mechanical advantage to uproot the cassava tuber from the ground.

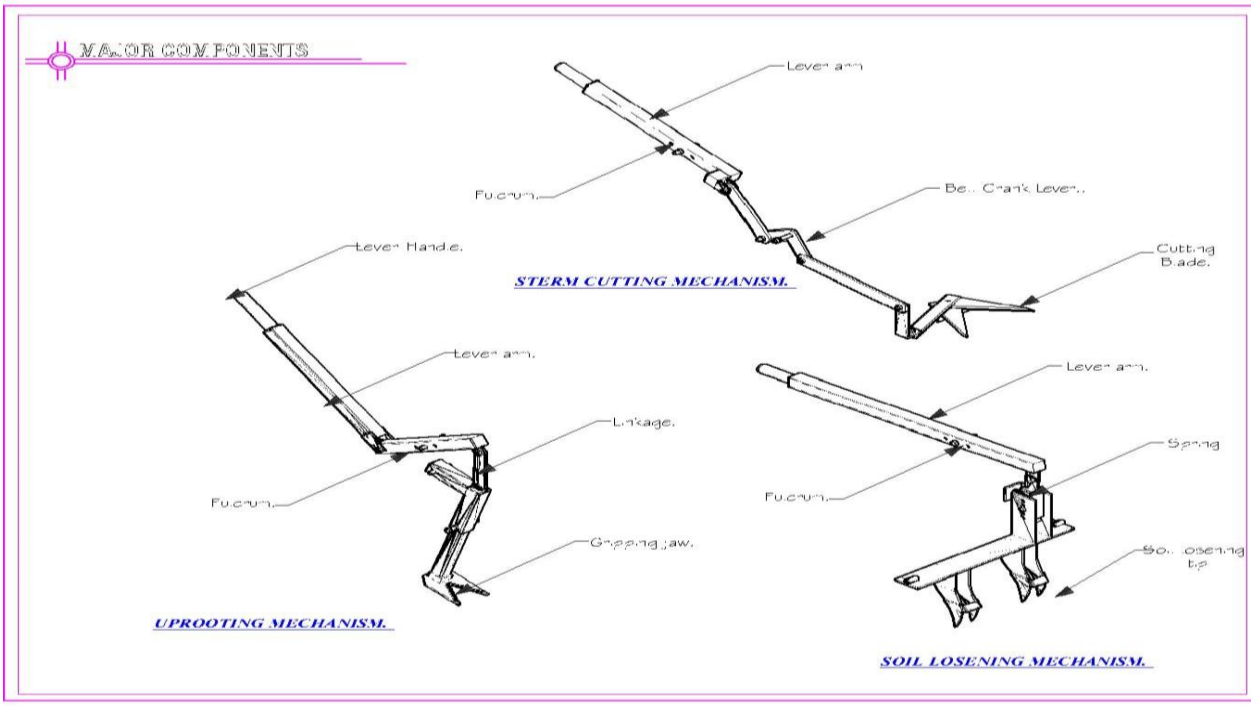

Figure 1: Mechanisms of the Push-Type Cassava Harvester

2.3 Preliminary Investigations

The following Preliminary investigation was conducted on relevant physical properties of the soil, cassava stem and tuber, essential in the design of the component parts of the harvester (Tables 1 and 2):

2.3.1 Moisture Content

Moisture content was determined for both the soil and the cassava stem. The soils moisture content was investigated in order to design an experiment to evaluate the machines performance for soil loosening and tuber uprooting, on varying moisture levels and recommend the soils moisture content in which the machine will perform optimally during harvesting. The soils moisture content was determined and classified by randomly collecting nine (9) different soil samples from the cassava field (Table 1). The classification was based on three treatments; Class A – Ten litres of water applied to the soil, Class B – Application of five litres of water and Class C – Control system (No water added). In order to minimise the possibility of errors, three replicates of soil sample were randomly collected for all three treatments at depths of 0 – 10, 10 – 20 and 20 – 30 cm (Smith *et al.*, 1994). Collected soil samples were oven dried at a temperature of 150^0 for 8 hours, after which were re-weighed and recorded. The soil moisture content was determined for all three treatments using equation 1 (Smith *et al.*, 1994). Moisture content in the stem was determined as a variable to investigate the effects of varying moisture levels in the stem to its cutting efficiency. Moisture content in the stem was determined by randomly collecting stem samples of length 15 cm from fifty (50) cassava stands from the demonstration farm. Each stalk sample was numbered and weighed on a Ohaus precision digital lab scale before oven dried at a temperature of 150^o for 18 hrs. Dry stalk samples were then carefully collected, re-weighed and recorded and the moisture determined. Equation 2 was used to determine the moisture content in the stem. On successful determination of the moisture content in the stems, samples were then classified into three moisture content categories of 40 – 55% (stalks affected by fire from indiscriminate bush burning), 55 – 70% and 70 – 85%.

$$MC_{(d.b)}\ \% = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \tag{1}$$

$$MC_{(d.b)}\ \% = \frac{W_w - W_d}{W_w} \times 100 \tag{2}$$

Where,

$MC_{(d.b)}$ % = Percentage Moisture content in dry basis

W_1 = weight of sampling bag

W_2 = weight of sampling bag and soil

W_3 = weight of sampling bag and oven dried soil

W_w= weight of wet stalk

W_d= weight of oven dried stalk

2.3.2 Stem Girth/Diameter:

This was determined from Fifty (50) randomly selected stem samples from the field, by measuring and recording diameters of each sample, using a Vernier calliper. The mean stem diameter was also calculated and recorded (Table 2).

1. **Root Yield per Plant:**

The root yield is achieved by individually quantifying the mass of each harvested cassava tuber, using a conventional weighing scale

2. **Root Spread (cm)**

This is the horizontal distance between the ends of the tubers along the horizontal, from one end to the other, determined with the aid of a measuring tape.

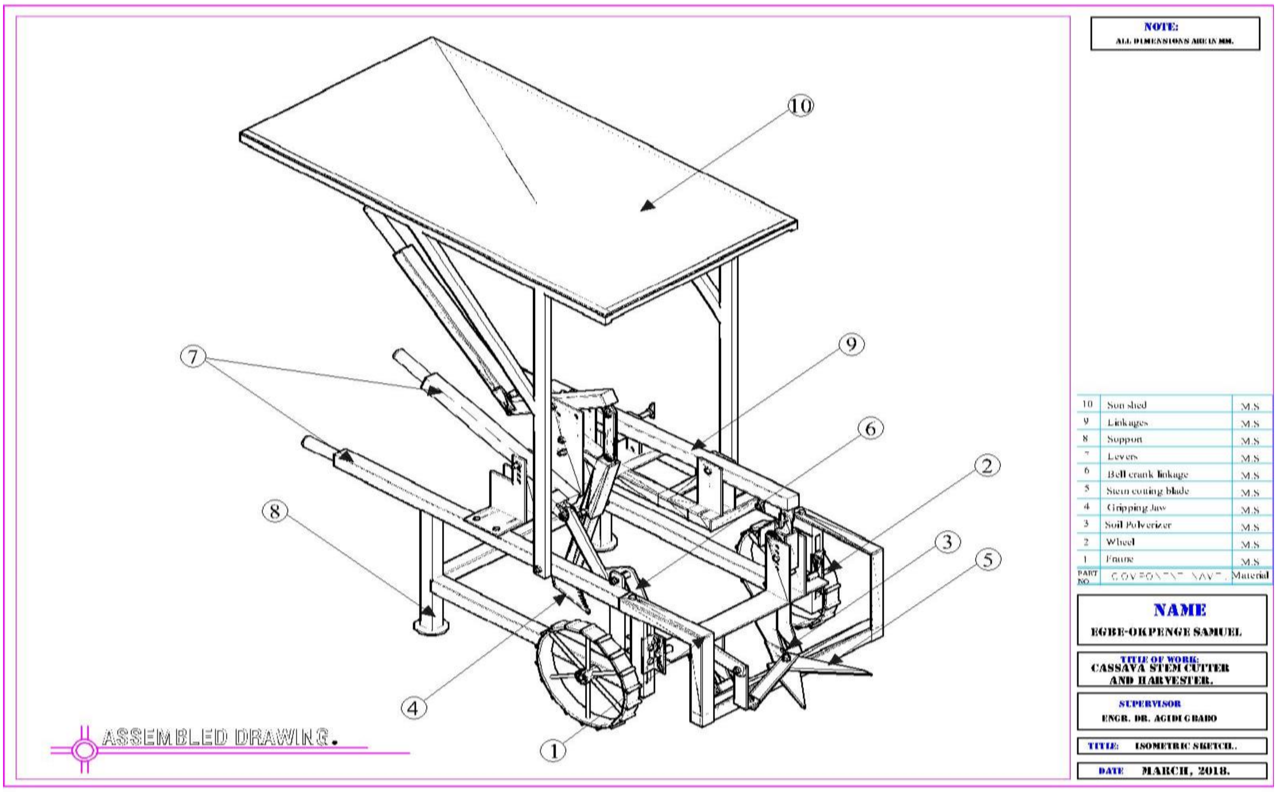

Figure 2: Assembly Drawing of the Developed Push-Type Cassava Harvester

Table 1. Summary of Results for Soil Moisture Content

Class	Replication			Mean
	Sample 1(%)	Sample 2 (%)	Sample 3 (%)	
A	16.9	18.4	19.2	18.17
B	10.5	11.8	10.1	10.80
C	1.5	1.87	2.45	1.94

3. DESIGN CONSIDERATIONS

3.1 General Design Considerations

The following design considerations were adopted in the design and fabrication of the machine;

1. Material selection for fabrication was from readily available sources, such as to minimize production cost, so as to ease replacement of parts.
2. Effort and energy requirement to drive the machine and increase mechanical advantage.

3. Adaptability of the harvester to varying planting systems (on mounds or flat surfaces) and to common recommended varieties, made possible by inclusion of adjustable mechanisms on both the harvester mechanism, the soil loosening mechanism and the cutting mechanism.
4. The machine was designed to achieve an appreciable reduction in overall purchasing/rental cost (affordable to local farmers) of similar imported devices and decrease in root losses.
5. Dimensions of the machine frame were chosen, such that can conveniently allow for inter-row movement within the farm and to ergonomically fit at least 90% of its intended users.
6. Temporal fasteners (bolts and nuts) were used in assembling the machine. This is to ease maintenance, replacement of parts, export purposes and also, to facilitate safe conveyance of the machine from one location to another.
7. The harvester and soil loosening component levers were built to operate on a first class lever principle (with the fulcrum between the load and the force), while the machine frame was made to run on a Second class principle on two front wheels (with the load situated between the force and the fulcrum). This is to ease movement, turning and manoeuvring the machine on the farm.

3.2 Anthropometric and Ergonomic Considerations

Anthropometry is the science which deals with the size and shape of people within a population (Fernandez and Marley, 1998). The application of anthropometry, in this design is to incorporate the relevant human dimensions, with an aim to accommodate at least 90% of potential users, taking into account both static (height) and dynamic factors (body movements, reach distances and movement patterns. Ergonomics was considered in the design of the structural composition of the machine (ease of reach and operation of control mechanisms), taking into consideration proposed operators physiological and biomechanical capabilities in order to optimize the efficiency and productivity of the harvester, in assuring the safety, health, and wellbeing of the operators (Kaankuka *et al.,* 2016).

3.3 Functional Design Considerations

I. Soil factors:

a) Soil moisture content (db): This was considered in the design because, higher soil moistures, requires less force to overcome in uprooting and vice-versa. At harvest, soil moisture was found to range between 1.5 – 20% on Sandy-loam and clay-loam which are the most recommended soils for cassava cultivation (Agbetoye *et al.,* 2000).

b) Forces of cohesion existing in the soil affects the ease of uprooting and determines the use of the soil loosening component to break the forces. These forces ranged between 9.6 – 15.5 N/mm^2 (Smith *et al.,* 1994).

c) Angle of shearing resistance determining the lift angle of the tubers. Implying that uprooting is best achieved overcoming the soil forces at angles ranging from 45^{o} above (Smith *et al.*, 1994).

Crop factors:

a) Root tuber yield per plant which is relevant in the choice and selection of durable materials for fabrication and further guides in dimensions of the machine. Root tuber yield was found between 5.84 – 14.7 kg (Amponsah *et al.*, 2017; Udensi *et al.*, 2011). And also measured with a weighing scale and was found to range from 3 – 12.78 kg.

b) Root depth: applicable in the design for the cutting depth of the soil-loosening component and the force requirement to completely uproot a tuber. This was with respect to planting orientation, nature of soil and variety (Udensi *et al.*, 2011).

c) Stem girt was considered in the design of cutting mechanism, thickness of blade, cutting angle, shearing force required and maximum opening distance between blades. It also aided in the determination of the groove angle and length of the griping jaw.

d) Root spread/diameter per stand: regarded as the distance between the tips of the farthest tubers from the stem. A determinant factor in the choice of the machine frame width, to avoid obstructions in uprooting the tubers completely above the ground surface.

III. Machine factors:

a) Available power: designed to be derived from human push force. Energy requirement to drive the harvester was determined from the principle of moments. Where the entire weight of the machine is 45 kg, the energy required to drive was found as 126 N, at a mechanical advantage of 3.5

b) Uprooting Force Requirement: this aided the design for the length of lever arms (mechanical advantage) required to overcome the maximum required uprooting force under varied soil types and conditions, depths and Planting Orientations as asserted by Agbetoye *et al.*, (2014) and Amponsah *et al.*, (2017).

c) Lifting Angle: A lifting angle of 45^0 was adopted as opined by Agbetoye *et al.*, (2000) and Ogunjirin *et al.*, (2016) that, uprooting at increasing angles from the horizontal, reduces the likelihood of tuber breakage in the soil. This determined the angle of inclination of the griping jaw arm from the fulcrum.

Table 2: Results for Preliminary Investigation of Cassava Physical Properties

Properties	Sample Size	Minimum	Maximum	Mean
Stem Diameter (mm)	50	2.08	4.31	2.82
Moisture Content (%)	50	45.84	81.02	68.97
Tuber Depth (cm)	50	10.82	29.48	16.59
Yield per Plant (kg)	50	2.19	8.93	4.86
Root Spread (cm)	50	21.38	69.55	44.83

4. CONCLUSION

A simple semi-mechanized hand push-type cassava harvester was designed and fabricated to cut cassava stems, loosen the soil were uprooting seems difficult, so as to minimize tuber damage during uprooting tubers. The machine basically works on a principle of levers, to operate and maneuver all mechanisms. Relevant properties of the soil (moisture content), crop (stem girth, tuber spread/diameter and yield per plant) and machine factors (available power to operate the machine, uprooting force and lifting angle) were taken into consideration with anthropometry, aiding the design and selection of materials for fabrication of the machine to perform efficiently.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Modelling of Moisture Loss and Oil Uptake during Deep-Fat Frying of Plantain (*Dodo*)

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ABSTRACT

In this study, model was developed to predict moisture loss and oil uptake during deep-fat frying of plantain (*dodo*). Plantain samples were sliced and fried at different frying temperatures (150, 160, 170, 180 and 190 °C) in a deep fryer for periods varying from 2 to 4 min. Moisture and fat analyses were determined based on the AOAC standard method. Mathematical model was developed from fundamental law of mass diffusion with the aim of predicting moisture loss and oil uptake rate during DFF of *dodo*. The model was solved numerically using explicit Finite Difference Technique (FDT). Computer codes were written in MATLAB environment for moisture loss and oil uptake in the slices at different frying conditions. The predicted results were compared with experimental data and good agreement was obtained. The correlation coefficients between the predicted and experimental values of moisture and oil transfer models ranged from 0.988 to 0.994 and 0.958 to 0.978, respectively. The results show that the model is consistent and it may be used to predict moisture loss and oil uptake during deep-fat fried of *dodo*.

Keywords: Frying, moisture loss, oil uptake, modeling, plantain, Nigeria

1. INTRODUCTION

Plantain (*Musa paradisiacal* AAB) belongs to the *Musacace* family and is cultivated in many tropical and subtropical countries of the world. Nigeria and Cameroon are the two major plantain producing, consuming and exporting countries in Africa and are ranked among the twenty most important plantain producing countries worldwide (FAO, 2013). It ranks third after yam and cassava for sustainability in Nigeria (Akomolafe and Aborisade, 2007). Plantain production in Nigeria was estimated at 2,722,000 metric tons in 2011, with an average consumption level of 190 kg/person/year (FAO, 2012).

Plantain is rich in carbohydrates, antioxidants like dopamine and minerals like potassium and calcium and caters for the calorific needs of people in many developing countries (Kanazawa and Sakakibara, 2000; Mohapatra *et al.*, 2010). It is commonly consumed in fried form in Nigeria. Ripe plantain can be eaten raw on account of its content of vitamin C and other essential minerals. It is one of the green vegetables with the richest iron and other nutrient contents (Aremu and Udoessien, 1990). However, they are highly perishable and susceptible to fast deterioration, as a result of the high moisture content and high metabolic activity, which persists after harvest (Demirel and Turhan, 2003). Over the years, many value-addition processing had been applied to plantain to form many food products like fully ripe fried plantain (*dodo)*, boiled plantain, plantain flour, plantain chips (*ipekere*), beverage and others in order to curb deterioration and also add value to the product.

Deep-Fat Frying (DFF) can be considered as a high temperature and a short time process which involves both mass transfer, mainly represented by water loss and oil uptake, and heat transfer (Vitrac *et al.*, 2002). It is one of the major value addition processes for plantain of various ripening stages. DFF as a method of food processing combines high processing speed with good product appearance, although lower yield and higher fat content of fried products was also reported for the method (Ziaiifar *et al.*, 2008).The primary reason for the popularity of DFF foods may be desirable characteristics like soft, juicy interior as well as thick and crispy outer crust (Garcia *et al.*, 2002).

Fried plantain products remain popular in spite of all the health issues associated with high intake of dietary fibre. This is attributed to the unique textural and quality characteristics imparted by DFF. Consumers' knowledge of health implications of high calorie has necessitated the resolve by food manufacturers to seek means to optimise the process for minimal fat absorption while the desired qualities are preserved. Many previous studies on DFF of plantain have been limited to the parameter estimation of the solid-liquid phase contacting systems (Diaz *et al*., 1996) and effect of ripening stages on DFF qualities of plantain chips (Mba *et al*., 2013). The understanding of mass transfer phenomena, especially moisture loss and fat uptake, and how they relate to processing conditions namely; frying temperature and time would help in designing an optimal process for DFF of plantain. Therefore, the study is aimed at modelling the moisture loss and oil uptake during DFF of *dodo*.

2. MATERIALS AND METHODS

2.1 Preparation of Sample

Plantain (*Musa paradisiacal* AAB) fruits were purchased from a local farm in Ogbomoso. Fresh, matured plantains were kept at 30 ± 2 °C and allowed to ripen slowly until they reached the desired yellow stage of ripeness using colour index chart according to Aurore *et al*. (2009). The fruits were peeled and sliced with stainless steel knife. The pulps were sliced to slice thickness of 5 mm using an electric slicing machine (Berkel, model EAS65).

2.2 Frying conditions

Ten slices per sample time were deep fried in 2.5 liters of hot oil contained in an electrical fryer (Beckers, Model F1-C, Italy) at each of the frying temperatures tested: 150, 160, 170, 180 and 190 °C, with three replicates at each temperature. Plantain-to-oil weight ratio was maintained at 1:20 in order to keep the temperature of frying constant (±1°C). Slices were fried at different temperature and time intervals. For each selected sampling time, the fried slices were drained over a wire screen for 5 minutes and allowed to cool to room temperature before oil and water content analysis were done. The oil was preheated for 1 hr prior to frying, and discarded after 6 hr of use (Blumenthal, 1991).

2.3 Moisture and oil content Determination

Moisture content of plantain sample was measured by drying the samples in a convection oven at 105 °C until constant weight. Five gram (5 g) of sample was weighed into a pre-weighed moisture dish. The dish plus sample taken was transferred into the oven pre-set at 105 °C to dry to a constant weight for 24 hours overnight. At the end of the 24 hours, the dish plus sample was removed from the oven and transferred to desiccator, cooled for 30 min and weighed (AOAC, 2005). The oil content was determined following the AOAC (2005) method. Fried plantain samples were ground using a grinder. Five gram of sample was weighed into thimbles for fat extraction in a solvent extractor (SER 148, VelpScientifica, Usmate, Italy) using petroleum ether. Oil content was determined as the ratio of the mass of extracted fat and dry matter of the sample.

2.4 Mathematical Model

Mathematical model for moisture and oil transfer during the process is developed from mass diffusion into and out of the slice. The following assumptions were made: homogeneous tissue is assumed and two - dimensional diffusion occurs, the sample is considered to be almost a slab, the initial moisture and fat concentration is uniform, external resistance to mass transfer is negligible and diffusing mass enters through plane faces and negligible amount through the edge, moisture transfer to and from the plantain is due to concentration gradient and the amount of moisture loss in the plantain during frying was negligible. Therefore, moisture and fat transfer can be described by Fick's first law (Crank, 1975).

Rate of mass transfer = Influx of mass into the slice – Out flux of mass from the slice

Time rate of change of water in the slice: $= \frac{\partial (m) Ax}{\partial t}$ (1)

Influx of water into the slice = j (2)

Out flux of Water from the slice = $j + \frac{\partial_j}{\partial_x}$ (3)

Substitute equation 1, 2, 3 into statement of species conservation and gives:

$$\frac{\partial (m) Ax}{\partial t} = j - \left(j + \frac{\partial_j}{\partial_x} Ax \right) \quad (4)$$

$$\frac{\partial (m) Ax}{\partial t} = - \left(+ \frac{\partial_j}{\partial_x} Ax \right) \quad (5)$$

Divide equation (5) by Ax and it becomes:

$$\frac{\partial m}{\partial t} = - \frac{\partial j}{\partial x} \quad (6)$$

Recall, Fick's first law of diffusion:

$$j = -D_{eff} \frac{\partial c}{\partial x} \quad (7)$$

$D_{eff} = e$Effective diffusion coefficient

M = moisture concentration of species in a mixture, mol (or mass)/m^3.

x = plantain thickness (m)

j = flux of the mass relative to the chip (number of species crossing unit plane per unit time)

Now, combine equation 6 and 7 and obtain:

$$\frac{\partial m}{\partial t} = \frac{\partial m}{\partial t} \varepsilon . D \frac{\partial m}{\partial t} \quad (8)$$

Where $\frac{\partial m}{\partial t}$ = left hand side (LHS), $\frac{\partial m}{\partial t}\varepsilon. D\frac{\partial m}{\partial t}$ =right hand side (RHS)

Equation 8 is an appropriate equation for the prediction of mass transfer rate during plantain chip frying.

The following initial and boundary conditions were used:

Initial condition: $M(t = 0, x) = M_0$ (9)

Boundary condition**:** $M(t = 0, x) = M_e$ (10)

$M(x = L, t) = M$ (11)

2.5 Numerical Solution Technique

The equation was solved using explicit finite difference solution method. It was transformed into different equation by dividing the domain of solution to a grid of points in the form of mesh and the derivatives are expressed along each mesh point referred to as a node. Knowing the dependent variable at each node initially and it is approximated for the next time step until the final step. The numerical grid of the solution domain consists of two perpendicular lines representing the x- direction and t-direction. Thus, the finite difference representation of the mesh points is shown as follows:

$Xi = i\delta x \; for \; i = 0, 1, 2 \ldots \ldots \ldots m$ (12)

$Yi = j\delta t \; for \; i = 0, 1, 2 \ldots \ldots \ldots n$ (13)

Where δx and δt represent grid sizes in the *x* and *t* directions respectively and

subscripts denote the location of the dependent variable under consideration.

The finite difference representations of various derivatives that appear in the governing equation are derived from Taylor's series expansion. Applying Taylor's series expansion in *t* (time) direction but keeping *x* (space) constant and truncate second term of the series for the left hand of the governing equation, therefore, Finite Difference Equation (FDE) of LHS of equation 8 was obtained:

$\frac{\partial c}{\partial t} = \frac{M_{i.j+1} - M_{i,j}}{\delta t}$ (14)

Similarly, Taylor's series expansion in the x (space) direction, keeping t constant; and again, Taylor's series expansion in the x direction (backward difference), keeping t constant. Therefore, FDE of RHS of the equation 8 was obtained:

$$\frac{\partial^2 c}{\partial^2 x} = \frac{M_{i.-1} - 2M_{i,j+} M_{i+1,j}}{(\delta x)^2} \quad (15)$$

Governing equation was derived by equating equation (14) and (15)

$$\frac{M_{i.j+1} - M_{i,j}}{\delta t} = \frac{M_{i.-1} - 2M_{i,j+} M_{i+1,j}}{(\delta x)^2} \quad (16)$$

$$M_{i.j+1} - M_{i,j} = \frac{\delta t}{(\delta x)^2} M_{i.-1} - 2M_{i,j+} M_{i+1,j}$$

$$M_{i.j+1} = M_{i,j} + r\left[M_{i.-1} - 2M_{i,j+} M_{i+1,j}\right] \quad (17)$$

Where: $r = \frac{D_{eff\delta t}}{(\delta x)^2}$

At $x = 0, then, i = 0, M_{0.j+1} = M_{0,j} + r\left[M_{-1,j} - 2M_{0,j} + M_{+1,j}\right]$ (18)

Then, $M_{-1,j}$ (pseudo moisture concentration at external mesh point is assumed) in equation 18 is calculated:

To represent $\frac{\partial M}{\partial x}$ more accurately at $x = 0$ by central difference formula, it is necessary to introduce the pseudo concentration $M_{-1,j}$ at the external mesh point by imagining the sheet of the tissue is extended very slightly. Therefore, finite difference approximation at boundary $x = 0$ in terms of central difference representation:

$$\frac{M_{1,j-} M_{-1,j}}{2\delta x} = M_{0,j} \quad (19)$$

From equation 19, external mesh point becomes:

$$M_{-1,j} = M_{1,j} - 2\delta x M_{0,j} \quad (20)$$

Substitute equation 20 into equation 18 and it gives:

$$M_{0.j+1} = M_{0,j} + 2r\left[M_{1,j} - M_{0,j}(1 + \delta x)\right] \quad (21)$$

Equation 21 is the discretized equation of mass transfer equation for every node, and this algebraic relationship was used to obtain the transient moisture and oil content at each node.

2.6 Computer simulation

Codes were developed in MATLAB to implement solution and analysis of FDE at different frying conditions. Therefore, resulting equation from the FDT was implemented in MATLAB by developing codes in its command window so as to predict the moisture distribution during frying process. The criterion ($\frac{D\delta t}{\delta x} \leq \frac{1}{2}$, $\frac{D\delta t}{\delta y} \leq \frac{1}{2}$) for stability and convergence of the solution was satisfied during the simulation process in MATLAB environment. Then, correlation coefficient for simulated results with experimental data was performed, in MATLAB environment, for the determination of degree of model predictability. The agreement between predicted and experimental results was further evaluated using the following statistical parameters: Mean square error (MSE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and Mean Absolute Deviation (MAD). (Hemmati and Kharrat, 2007). The above statistical parameters can be calculated as follows:

$$MSE = \frac{\sum_{t=1}^{n}(A_t - F_t)}{n} \tag{22}$$

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(A_t - F_t)^2}{n}} \tag{23}$$

$$MAPE = \frac{\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|}{n} \times 100 \tag{24}$$

$$MAD = \frac{\sum_{n}^{t=1}|A_t - F_t|}{n} \tag{25}$$

3. RESULTS AND DISCUSSION

3.1 Predicted and experimental results for moisture loss from *dodo*

Figure 1 show curves of experimental and predicted moisture loss rate during frying of *dodo* at different temperatures (150, 160 170, 180 and 190 °C). It was noticed that the predicted result curves follow the exponential pattern as observed in experimental results. The predicted results for moisture loss during the frying process provide satisfactory prediction of experimental data. There was an insignificant error between predicted and experimental data at different frying temperature was observed from 2 - 4 minutes as indicated in Figure 1. This occurrence might be as a result of start-up operation mechanism of frying process. However, there was perfect match in the prediction of moisture removal during frying at this temperature little or no underestimation and overestimation was noticed between simulated and actual results at different frying temperature. The exponential nature of moisture loss curves revealed that moisture content decrease in *dodo* as frying time increases.

The statistical analysis (i.e. R^2, MSE, RMSE, MAD and MAPE calculated for frying of *dodo* ranged from 0.988 to 0.994, 0.0025 to 0.0093, 0.0238 to 0.0836, 0.0023 to 0.0095 and 0.7349 to 1.3480, respectively (Table 1). The model had the highest R^2 and MAPE values while the lowest values of MSE, RMSE and MAD was used as a basis for good predictability of the model. According to Azoubel and Murr (2002), value of MAD and MAPE less than or equal to 10% indicates good prediction of experimental data and the lower the percentage the better the model for predictive purpose. This indicates that the model, with the aid of FDM, for moisture transfer rate during the process predicts satisfactory. The closer the value to 1 the better the prediction and it was noticed that all the prediction produced in this work is very close to 1. The trend reported in this work is similar to earlier work on the kinetics of plantain frying process (Mba *et al*., 2013; Manjunatha *et al*., 2014).

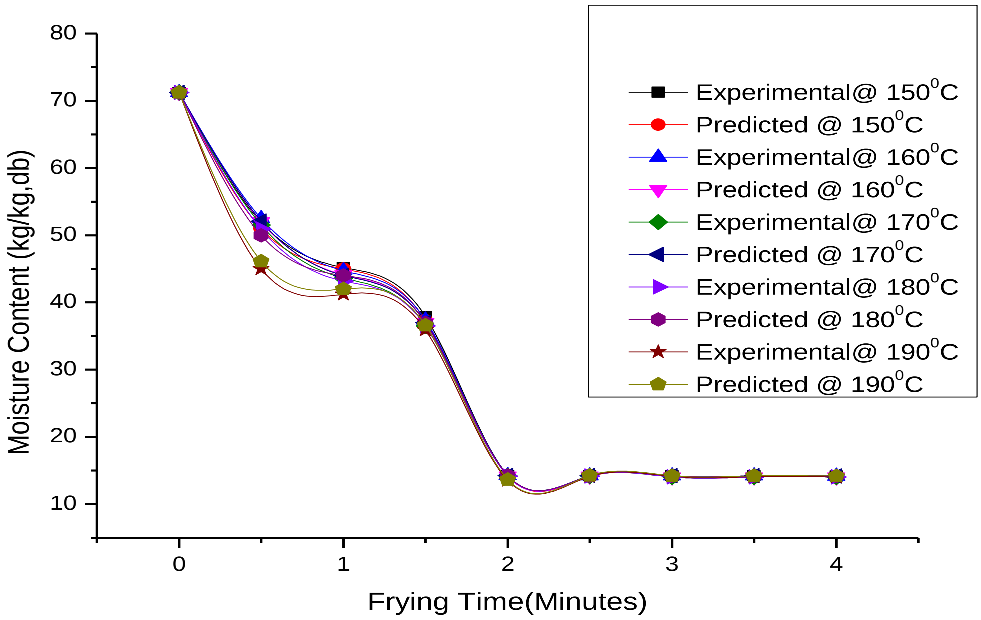

Figure 1: Predicted and experimental moisture loss in *dodo* during deep-fat frying

3.2 Predicted and experimental results for oil uptake from *dodo*

Figure 2 presents the comparison between predicted and experimental oil uptake results of *dodo* deep fried at 150, 160 170, 180 and 190 °C temperature. The predicted results of oil uptake during the frying process provide satisfactory prediction of experimental data (Fig. 2). It was observed that the predicted result curves follow the parabolic pattern as observed in experimental results. Statistical parameters such as R^2, MSE, RMSE, MAD and MAPE calculated at different frying temperature were varied from 0.958 to 0.978, 0.0006 to 0.0202, 0.0078 to 0.1420, 0.0069 to 0.0194 and 0.5716 to 1.3214, respectively, as displayed in Table 2.

It could be seen that the prediction showed good representation of experimental data with the value of R^2, MSE, RMSE, MAD and MAPE obtained between experimental and predicted results. The correlation coefficients are near one which indicates positive correlation. The deviation between predicted and experimental value in this work might be due to the error in the experimental measurement and the assumptions made in the present analysis as indicated earlier. The parabolic nature of oil uptake curves revealed that oil content increased in *dodo* as frying time increased. The trend reported in this work is similar to an earlier work on potato slices (Troncoso and Pedreschi, 2009; Duong, 2016).

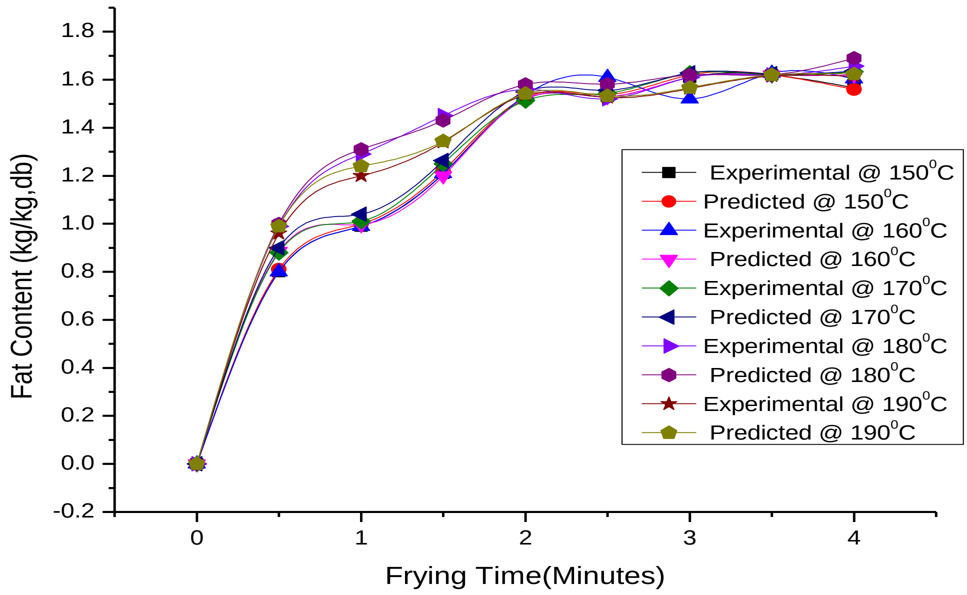

Figure 2: Predicted and experimental oil uptake in *dodo* during deep-fat frying

Table 1: Statistical index of predicted and experimental results of moisture content

Temperature (°C)	R^2	MSE	RMSE	MAD	MAPE
150	0.992	0.0078	0.0253	0.0023	0.7340
160	0.994	0.0025	0.0536	0.0095	0.9731
170	0.989	0.0093	0.0312	0.0036	1.2530
180	0.988	0.0083	0.0836	0.0025	1.3480
190	0.992	0.0032	0.0238	0.0032	1.1452

Table 2: Statistical index of predicted and experimental results of oil content

Temperature (°C)	R^2	MSE	RMSE	MAD	MAPE
150	0.978	0.0006	0.0078	0.0069	0.5716

160	0.973	0.0024	0.0499	0.0346	1.0648
170	0.969	0.0003	0.0182	0.0135	1.1233
180	0.968	0.0201	0.1420	0.0194	1.3214
190	0.958	0.0003	0.0173	0.0114	0.9589

3.3 Prediction of moisture content distribution at different positions

The simulated moisture profile at different axial positions of plantain samples from top to the centre at 170 °C are presented in Figure 3. It was observed that moisture rate removal was proportional to axial distance from the centre of plantain sample. It was further noticed from the curve that the distance of X_5 = 0.005 m is far from the centre of the plantain and highest moisture removal was achieved as depicted in Figure 3. On the contrary, at the beginning of the moisture removal distribution during the frying process it was observed that maximum residual moisture content was found at X_1 = 0.025 m location and the centre of *dodo* witnessed a slower moisture removal rate (Fig. 3). High rate of moisture removal was observed at the plantain surface relative to inner surfaces. This could be explained in terms of the moisture transfer resulting from direct interaction with the frying medium (Kassama and Ngadi, 2005).

The predicted results from this study show that axial positions, within the plantain sample, have effect on the moisture removal rate during frying process. As revealed in Figure 3, moisture removal equilibrium (no net moisture transfer from plantain slices) was reached between 100 - 120 seconds period of time. Moisture content distribution during *dodo* frying in this work predicted equilibrium moisture removal point. The predicted results obtained from this work are similar to previous works reported in the literature (Garayo and Moreira, 2002; Kassama and Ngadi, 2005). This suggests that the moisture transfer model could predict shut down and startup operations of plantain frying process and this will be useful for industrial application of the process.

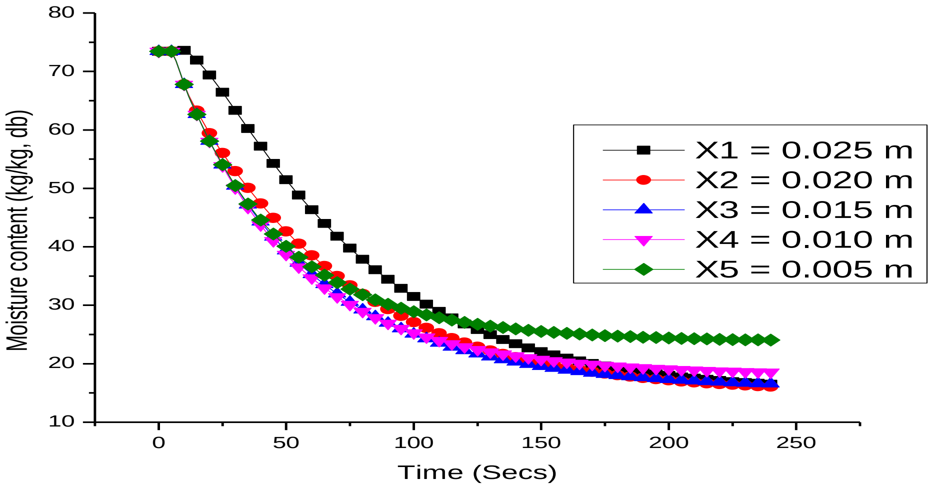

Figure 3: Predicted moisture loss distribution during DFF of *dodo* at different positions

3.4 Prediction of oil uptake distribution at different positions

The simulated oil uptake profile at different axial positions of plantain samples during frying process of *dodo* at 170 °C are shown in Figure 4. It was observed that the rate of oil absorption was proportional to axial distance from the centre of plantain sample. It was further noticed from the curve that distance of X_5 = 0.005 m is far from the centre of the plantain and least oil uptake was achieved as depicted in Figure 4. There was a slower moisture removal rate at the centre of *dodo* (Fig. 4). In contrast, high rate of oil uptake was observed at the plantain surface relative to inner surfaces. This could be explained in terms of the oil transfer resulting from direct interaction with the frying medium (Moyano and Pedreschi, 2006). The predicted results from this study show that axial positions, within the plantain sample have effect on the oil uptake rate during frying process. Oil uptake distribution during plantain frying in this work predicted equilibrium point. Figure 4 revealed that oil uptake equilibrium was reached between 120 - 220 seconds period of time. The predicted results obtained from this work are similar to previous works reported in the literature (Krokida *et al.*, 2000).

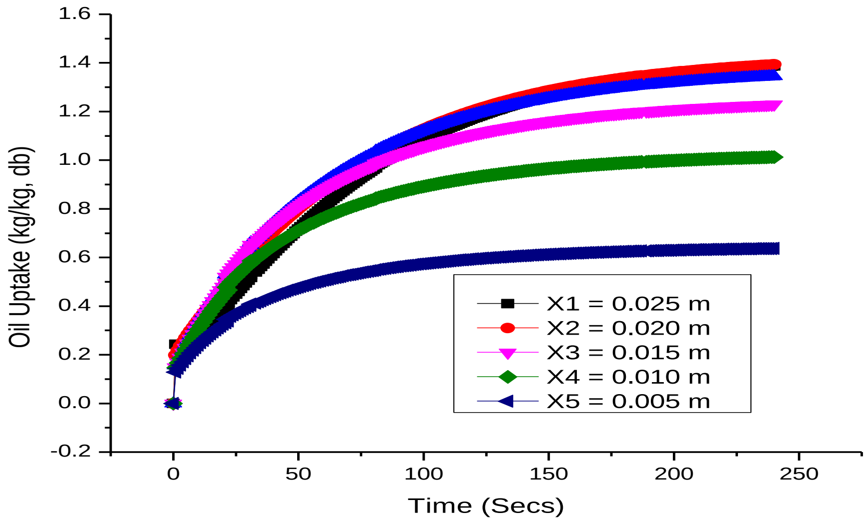

Figure 4: Predicted oil uptake distribution during DFF of *dodo* at different positions

4. CONCLUSION

In the present study, the moisture loss and oil uptake during deep-fat frying of *dodo* is modeled. It was established that FDM solution technique is a better tool for solving partial differential equation related to moisture and oil transfer. There is a close agreement between the experimental and predicted result for this study. The correlation coefficients between the predicted and experimental values of moisture and oil transfer models ranged from 0.988 to 0.994 and 0.958 to 0.978, respectively. The results show that the model is consistent and it may be used to predict moisture and oil transfer during DFF of *dodo*.

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Effects of Moisture Content, Operation and Design Parameters on Separation Efficiency of Moringa Seed Shelling Machine: Optimization Approach

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ABSTRACT

Cleaning operation such as separation of kernel from shell enhances the quality of agricultural produce. Optimization of separation efficiency of moringa seed shelling machine was carried out based on moisture content and relevant operation and design parameters. Separation efficiency as affected by moisture content, cylinder speed, clearance, feed rate and cylinder bar inclination was examined. The separation efficiency was not significantly affected by the moisture content and feed rate. Separation efficiency increased with increase in the clearance while it decreased with increase in the cylinder speed and cylinder bar inclination. Optimum values of 11.79%, 7.98 mm, 249.21 rpm, 30.0 kg/h and 40^o were obtained for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination respectively while the separation efficiency had an optimum value of 70.9%.

Keywords: Moringa seed, shell, kernel, separation efficiency and optimization.

1. INTRODUCTION

Moringa oleifera is a shrub which belongs to *Moringacae* family. It is a non-toxic natural organic polymer having 14 species (Ramachandran *et al.*, 1980; Bichi, 2013; Vieira *et al*., 2010). The plant produces pods having the shape of a drumstick which contains the seeds. Moringa seed is triangular in shape with papery wings along its ridges. Moringa kernel has white to creamy colour and nearly spherical in shape (Price, 2007; Hasanah and Abdulkarim, 2011; Aviara *et al*., 2013). It is a very important plant in the northern part of Nigeria. This drought resistant plant ranges in height from 5 to 12 m, with drooping branches and trunk about 30cm wide. Price (2007) reported that moringa leaf is an excellent source of vitamin A, vitamin C and vitamin B as well as calcium, phosphorous and iron. The mature seed of moringa is a good source of edible oil; the mature seed contains between 33 - 40% oil. It has been reported that moringa oil is of excellent quality (i.e. having 73% oleic acid which is similar to olive oil) for cooking. This makes the oil of moringa seed to burn without smoke and does not become rancid and sticky (Rashid *et al.*, 2008; Adejumo and Abayomi, 2012; Aviara *et al*., 2013).

Pod yield in India has been reported to be 19 kg pods/tree/year. This is the equivalent of 31,000 kg/ha per year at 2.5 m × 2.5 m spacing (Radovich and Paul, 2008). In Nigeria Ndubuaku *et al*. (2014) reported mean annual seed production of 16.74 tonnes/ha/yr and mean annual pod production of about 37.69 tonnes/ha/yr in three major ecological zones. The production capacity of moringa plant in Nigerian ecological zone was reported to be greater than that of India. This indicates the adaptability of the plant to the prevalent weather condition of Nigeria.

It has been discovered that separation of shells from seed tends to reduce the wax content of oil during oil extraction thus lowering the turbidity of such oil (Figueiredo *et al.*, 2013). Moreover, shelling also enhances reduction in further refinement of oil after extraction and thus making it available for immediate use. These research findings highlighted the importance of separation in moringa seed processing. Therefore, this study focused on optimization and effect of moisture content, operation and design parameters on separation efficiency of moringa seed shelling machine using response surface method.

2. Materials and Methods

2.1. Determination of Separation Efficiency

The separation efficiency, also known as the screening efficiency is a measure of the overall efficiency of the separator in separating the kernels from the shells (Akubuo and Eje, 2002). The separation efficiency of the moringa seed shelling machine in Plate 1 was computed using Equation 1 as done by Akubuo and Eje (2002).

$$SE = 100\left[\frac{a}{a+b} \times \frac{c}{c+d}\right] \quad (1)$$

Where SE is separation efficiency (%)

a is Mass of kernel in the product tray (g)
b is Mass of kernels mixed with the shells in reject tray (g)
c is Mass of the separated shells (g)
d is Mass of shells with the separated kernels in product tray (g)

Plate 1: Moringa seeds shelling machine

2.2. Optimization

The process optimization of the separation efficiency was carried out by using Response Surface Methodology (RSM). The experimental plan was generated using Design-Expert 10 by applying Central Composite Rotatable Design (CCRD) with three replications for each run. The separation efficiency of the moringa seed shelling machine and the independent parameters were analyzed using two factor interaction and quadratic models. The Analysis of Variance (ANOVA) was carried out to determine the adequacy of the models developed. One hundred grams of moringa seeds was used for each test (CIGR, 1999; Fadele and Aremu, 2018). The experimental design for the separation process is presented in Table 1. Three major parameters were considered, namely seed condition (moisture content), operation parameters (viz. cylinder-concave clearance, cylinder speed and feed rate) and design parameter (viz. cylinder bar inclination). According to literature all these independent factors have been found to relatively affect seed shelling process (Fadele, 2018; Pradhan *et. al*., 2010; Ogunsina *et al*., 2010, Srivastava *et al*., 2006 and Pinson *et al*., 1991). The dependent factor considered was separation efficiency. The experimental design adopted was five factors, five levels Central Composite Rotatable Design (CCRD) as shown in Table 1.

Central Composite Rotatable Design comprises three major design points which include axial, central and factorial points. Half fraction CCRD was adopted for the experimental design (Montgomery and Runger, 2003). The total number of experimental runs is given as $N = (2^k)\frac{1}{2} + 2k + c$ where *'k'* is the number of independent parameters and *'c'* is the centre point. The experimental design plan comprises 16 factorial points, 10 axial points and 6 replications at the centre point. In the optimization process, 32 runs were generated in all as shown in Table 2. Some samples of moringa seed were adjusted to moisture levels of 10.75, 11.75, 12.75, 13.75 and 14.75%. The test was also carried out at five cylinder-bar inclination levels (30°, 40°, 50°, 60° and 70°); five cylinder speed levels (200, 240, 280, 320 and 360 rpm); five cylinder-concave clearance levels (5, 6, 7, 8 and 9 mm); five feed rate levels (12, 18, 24, 30 and 36 kg/h). Each factor level was replicated concurrently with other factors three times for each run.

Table 1: Experimental Design for Moringa Seed Separation

Factors			**Levels**		
	1	**2**	**3**	**4**	**5**
Moisture Content (%)	10.75	11.75	12.75	13.75	14.75
Clearance (mm)	5.0	6.0	7.0	8.0	9.0
Cylinder Speed (rpm)	200	240	280	320	360
Feed Rate (kg/h)	12	18	24	30	36
Cylinder Bar Inclination (°)	30	40	50	60	70

Table 2: Plans of Experimental Design for Moringa Seed Separation

Runs	**FR (kg/h)**	**CS (rpm)**	**MC (%)**	**CBI (°)**	***C* (mm)**	**SE (%)**

1	18	240	11.75	60	6	61.69
2	24	280	12.75	40	5	59.63
3	24	360	12.75	50	7	54.75
4	30	240	11.75	50	8	69.8
5	24	280	12.75	50	7	67.54
6	24	280	12.75	40	7	61.24
7	24	280	12.75	40	7	69.74
8	24	280	12.75	50	7	70.08
9	24	200	12.75	40	7	80.4
10	24	280	14.75	30	7	53.2
11	18	240	13.75	50	6	70.91
12	24	280	12.75	50	7	71.38
13	18	320	11.75	60	6	45.83
14	30	320	11.75	50	6	54.62
15	30	240	11.75	40	6	68.67
16	18	240	13.75	50	8	76.62
17	30	320	13.75	40	6	58.95
18	30	320	11.75	60	8	59.11
19	24	280	10.75	50	7	61.71
20	18	320	11.75	60	8	59.07
21	12	280	12.75	60	7	60.28
22	18	320	13.75	50	8	63.14
23	18	320	13.75	50	6	56.82
24	24	280	12.75	60	7	60.63
25	24	280	12.75	40	9	74.71
26	30	240	13.75	50	8	80.36
27	18	240	11.75	70	8	65.72
28	36	280	12.75	50	7	72.8
29	30	320	13.75	60	8	51.46
30	24	280	12.75	40	7	73.02
31	24	280	12.75	60	7	66.68
32	30	240	13.75	50	6	69.74

Where FR is feed rate, CS is cylinder speed, MC is moisture content, CBI is cylinder bar inclination, *C* is clearance, SE is separation efficiency.

3. RESULTS AND DISCUSSION

3.1. Effect of seed, operation and design parameters on separation efficiency

The relationship between separation efficiency and the independent parameters (clearance, cylinder speed and cylinder bar inclination) at $p< 0.05$ significance level are as shown in Figures 1 – 3. The separation efficiency was not significantly affected by the moisture content and feed rate. Separation efficiency increased with increase in the cylinder/screen clearance as shown in Figure 1; however, it decreased with increase in the cylinder speed and cylinder bar inclination as shown in Figures 2 and 3. The increase of separation efficiency with cylinder/concave clearance could be due to reduction in interference generated by air with that of the blower as the cylinder/concave clearance increased. The decrease in separation efficiency with increase cylinder speed and cylinder bar inclination was as a result of increment in interference between the air being generated by the cylinder and blower, which adversely affected the separation of kernel from the shell.

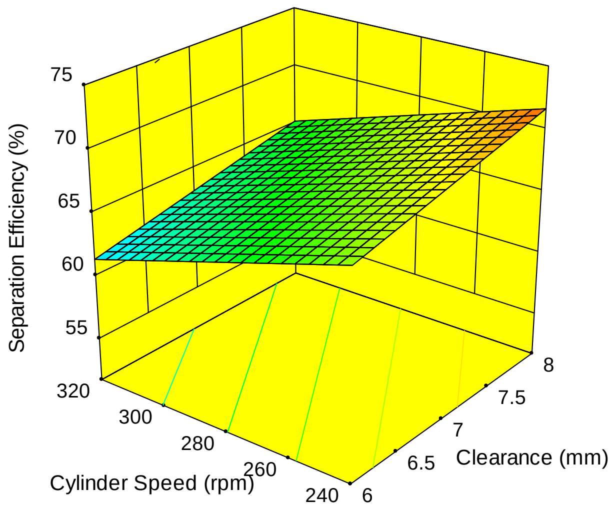

Figure 1: Separation efficiency against cylinder speed and clearance

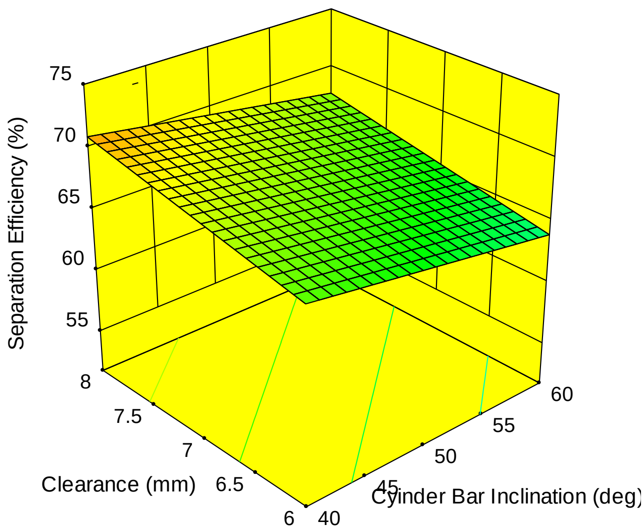

Figure 2: Separation efficiency against cylinder bar inclination and clearance

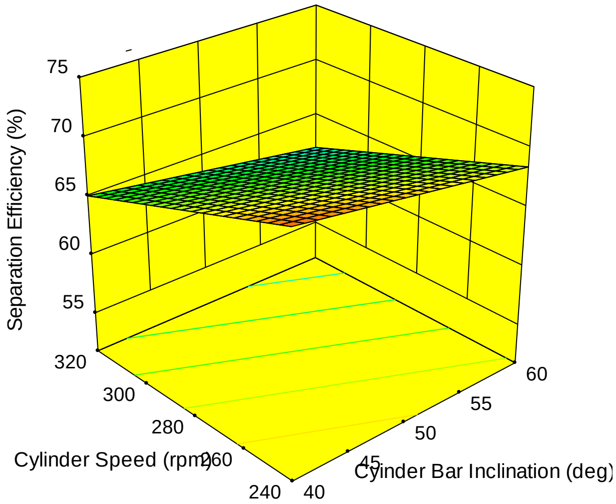

Figure 3: Separation efficiency against cylinder speed and cylinder bar inclination

3.2. Modeling and optimization of separation efficiency

The optimization of the moringa seed shelling process showed the optimum values of 11.79%, 7.98mm, 249.21rpm, 30.0kg/h and 40°for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination respectively while the separation efficiency which is the response has an optimum value of 70.9% and desirability of 0.76. Akubuo and Eje (2002) reported a separation efficiency of 82.1% for palm kernel separator. Oriaku *et al*. (2014) obtained 68.1% as separation efficiency for corn decobbing and separating machine while Tarabi *et al*. (2016) obtained 95% for separation efficiency of calotropis bast fibre decorticator. Lim *et al*. (2016) also reported the separation efficiency of jatropha seed shelling machine to be 56.5%. The optimum separation efficiency obtained agreed with values reported by other researchers; it falls within the range of values obtainable from the literature. The ANOVA results which established the statistical significance of the regression model relating the separation efficiency to the moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination at 95% confidence level ($p < 0.05$) is as shown in Table 3. The model F-value of 9.93 implied that the model established was significant. There is only a 0.01% chance that an F-value as large as this could occur due to noise. The model developed was significant as depicted by F-value; this implies that at least one of the independent variables contributed to the response observed in separation efficiency. The F-values and the corresponding p-values obtained for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination were 0.17, 10.16, 29.51, 0.057 and 5.11; 0.68, 0.0037, 0.0001, 0.81 and 0.032 respectively.

Table 3: ANOVA of Regression Model for Separation Efficiency

Source	**Sum of Squares**	**DF**	**Mean Square**	**F-Value**	**Significance Level**
Model	403.00	5	80.60	9.93	< 0.0001
Moisture Content	*1.38*	*1*	*1.38*	*0.17*	*0.6839*
Clearance	*82.45*	*1*	*82.45*	*10.16*	*0.0037*
Cylinder Speed	*239.48*	*1*	*239.48*	*29.51*	*< 0.0001*
Feed Rate	*0.47*	*1*	*0.47*	*0.057*	*0.8126*
Cylinder Bar Inclination	*41.50*	*1*	*41.50*	*5.11*	*0.0323*
Residual	210.96	26	8.11		
Lack of Fit	*170.38*	*21*	*8.11*	*1.00*	*0.5583*
Pure Error	*40.58*	*5*	*8.12*		
Correlation Total	613.96	31			

Furthermore, the coefficient of determination (R^2) obtained was found to be 0.66 as indicated in Equation 2. This showed that the variation in the independent variables accounts for 66% of the total variability in the separation efficiency of the moringa seed shelling machine. The predicted R^2 and adjusted R^2 values were found to be 0.46 and 0.59 respectively. The predicted R^2 is in reasonable agreement with the adjusted R^2 values since the difference between them is less than 0.2.The adequate precision (signal to noise ratio) of 12.17 was obtained, which is greater than 4; this showed that the model has a signal which is strong enough for optimization and can be used to navigate the design space. The regression model was reduced with respect to the significance level of the independent parameters for its improvement as expressed in Equation 2.

$$SE = 78.00 + 1.909C - 0.0798CS - 0.155CBI \qquad 2$$

($R^2 = 0.66$, Adj.$R^2 = 0.59$, Pred.$R^2 = 0.46$, Adeq. Precision = 12.17)

Where

SE is the separation efficiency

C is the clearance

CS is the cylinder speed

CBI is the cylinder bar inclination

4. CONCLUSION

The optimization of the separation of moringa kernel from shell was carried out using a moringa seed shelling machine. The separation efficiency was significantly affected by variation in cylinder speed, cylinder-concave clearance and cylinder bar inclination at $p<0.05$ while moisture content and feed rate had minimal effect on the separation efficiency. Separation efficiency increased with increase in the cylinder/screen clearance while it decreased with increase in the cylinder speed and cylinder bar inclination. The optimum values for the independent parameters were 11.79%, 7.98mm, 249.21rpm, 30kg/h and 40.0^o for moisture content, clearance, cylinder speed, feed rate and cylinder bar inclination while the separation efficiency has an optimum value of 71.0%. The desirability values established for the optimization process for the separation process indicated the nearness of the response values to the predicted values and adequacy of models developed in describing the obtained data. It is recommended that shelling chamber should be offset from the separation unit in order minimize air interference during separation process.

5. ACKNOWLEDGEMENTS

The authors wish to thank Forestry Research Institute of Nigeria for their support towards this research. The provision of facilities from the Department of Agricultural and Environmental Engineering, University of Ibadan Nigeria is appreciated. The contribution of researchers in Federal College of Forestry Mechanization Afaka Kaduna, Nigeria is also appreciated.

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Moisture Sorption Characteristics of Dehydrated In-shell African Walnut (*Tetracarpidium conophorum*)

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ABSTRACT

Moisture sorption isotherms are useful thermodynamic tools for determining water interactions within food systems and providing information that can assist in optimizing food processing operations such as drying, mixing, packaging and storage, as well as to maximize retention of quality parameters such as colour, aroma, texture, and nutrient. Moisture sorption isotherm characteristics of African walnut were evaluated at three different temperatures (28, 33 and 38°C) and relative humidity range of 11.20 - 97.00 % using gravimetric method; five mathematical models (GAB, BET, Peleg, Smith and Ferro Fontan) were fitted into the experimental data. Sorption isotherms of the dehydrated walnut gave type II (S-shaped) isotherms according to BET classification. Temperature had significant effect on the equilibrium moisture content (EMC). A nonlinear regression analysis method was used to evaluate the constants of sorption models. The models were evaluated statistically by calculating coefficient of determination (R^2), the mean relative percentage error (P) and the reduced chi-square (λ^2). The BET model gave the best fit for the obtained data among the tested models with R^2 value of 0.9892. Calculated monolayer moisture (M_o) content from BET ranged from 5.018 to 7.922% db for adsorption and 9.842 to 10.143% db for desorption respectively.

Keywords: African walnut, drying, sorption isotherm, sorption models, equilibrium moisture content, nonlinear regression.

1. INTRODUCTION

African walnuts (*Tretracarpidium conophorum*) can be described as rounded, stone fruits of the walnut tree with single seed. The fruit of the walnut is enclosed in a hull which is green, leathery, and fleshy. After harvest, this hull is usually removed to reveal the wrinkly walnut shell that encloses the kernel, and the shell is then removed to obtain the kernel (Atungulu *et al.*, 2013). Primarily, walnut plant is cultivated in Nigeria for the nuts, which is traditionally eaten after boiling (Akpuaka and Nwankwor, 2000; Ndie *et al*., 2010).

Biochemically, walnut is composed of polyunsaturated fatty acids, especially linoleic and oleic acid, it is also high in protein content (Savage *et al*., 2001), which makes it of significant economic value and medicinal importance for human health; due to these facts, there has been an increasing interest in its consumption and utilisation. Some of the other beneficial components it contains include plant protein (for example, arginine, leucine), carbohydrates (for example, dietary fibre), vitamins (for example, vitamin A and E), pectic substances, minerals (magnesium, potassium, phosphorus, sulphur, copper and iron), plant sterols and phytochemicals (Savage *et al*., 2001; Colaric *et al*., 2006; Ogunmoyole *et al.*, 2011).

Although African walnuts have high socio-economic potentials, the product is still under-utilised in Nigeria, especially at industrial level. This can mainly be attributed to the fact that there is lack of storage facilities for the walnut market which has been hampering the production on a full scale and exploration of its inherent potentials (Ekwe and Ihemeje, 2013). Thus, in order to overcome the challenge of spoilage and inconsistent seasonal availability, there is need for development and provision of appropriate storage facilities for the African walnut (Babalola, 2011) as well as appropriate preservation methods.

Deterioration of food occurs during handling or due to mechanical, physical, chemical or microbial damage (Rahman, 1999; Mujumdar, 2004); microbial growth depends on the storage conditions and the moisture level in the product. Among the commonly employed methods for preserving food such as freezing, vacuum packing, canning, preserving in syrup, food irradiation, addition of preservatives, the most popular is dehydration (Jangam *et al.*, 2010).

1.1 Research Justification

Dehydration which removes water from food materials will result in its stability and as well reduce storage and transportation cost. To a great extent, most dried foods quality depends upon their physical, chemical and microbiological stability, which is mainly a consequence of the relationship between the equilibrium moisture content (EMC) of the food material, and its correspondence water activity (a_w) or relative humidity at a given temperature (Guilan *et al*., 2007).

Moisture sorption isotherms (MSI) is the terminology usually used to express the relationship between equilibrium moisture content and equilibrium relative humidity (ERH) or water activity of materials being studied. It is worthy of note to know that this relationship is complex and unique for each product due to different interactions which may be colligative, capillary or surface effects between the water and the solid components of the product at different moisture contents. According to Al-Mahasneh *et al*., 2011, MSI are useful thermodynamic tools for determining water interactions within food systems and providing information that can assist in optimizing food processing operations such as drying, mixing, packaging and storage, as well as to maximize retention of quality parameters such as colour, aroma, texture, and nutrient. Several authors (Johnson and Brennan, 2000; Chowdhury *et al*., 2005; Akanbi *et al*., 2006; Samapundo *et al*., 2007; Oyelade *et al*.,2008) have reported some of the importance of knowing the sorption characteristics of products as being essential in respect to storage stability and food product acceptability, drying process modelling, design and optimization of drying equipment, aeration, calculation of moisture changes which may occur during storage and for selecting appropriate packaging materials for dehydrated products. Isosteric heat of sorption, often referred to as differential heat of sorption, is used as an indicator of the state of water adsorbed by the solid particles (Fasina *et al*., 1997; Togrul and Arslan, 2007).

Water sorption properties of foods can be predicted using water sorption isotherm equations. Guilan *et al*., 2007 noted that many empirical and semi-empirical equations describing the sorption characteristics of foods have been proposed in the literature; these equations are suitable for some food products only, or for selected ranges of a_w, and part of these equations clearly show the effect of temperature on sorption isotherms. According to Togrul and Arslan (2007), among the models which were reviewed, 23 common equations for fitting sorption isotherms to different food materials were reported, some of the models took into consideration the effect of temperature; these include modified Chung-Pfost (Chung and Pfost, 1967), modified Henderson (Henderson, 1952), modified Halsey (Halsey, 1948) and modified Oswin (Oswin, 1946) models. Brunauer– Emmett–Teller (BET) and Guggenheim–Anderson–de Boer (GAB) equations were reported to be the most popular food isotherm equations (Cadden, 1988; Togrul and Arslan, 2007).

While the sorption characteristics of other exotic walnut of the Juglandaceae family (*Juglans regia*, *microcarpa*, *hindsii* cultivars) have been studied extensively, there is dearth of information on the sorption characteristics of African walnut (*Tetracarpidium conophorum*) specie available in Nigeria and other neighbouring African countries. The study of sorption isotherm properties of African walnut will provide information that can be used directly to know the storability, solve process design problems (e.g. dryer design and operations), predict energy requirements and determine its proper storage conditions (Ekwe and Ihemeje, 2013).

1.3 Objectives

This study therefore experimentally determined the sorption characteristics of dehydrated in-shell African walnut kernels at three different temperatures of 28, 33, and 38 °C, evaluated the suitability of five moisture isotherm model equations and investigated the nature of the moisture sorption hysteresis.

2. MATERIALS AND METHODS

2.1 Materials

Raw unshelled walnuts were obtained from Ogbese market, Ondo State, Nigeria. All other reagents used were of analytical grade.

2.1.1 Sample Treatment

The bulk quantity of walnuts was cleaned and divided into two portions. One portion of the walnuts used for adsorption isotherm was dried in an air-draught oven at 120 °C for 10 hours to obtain a moisture content of about of 4 % (dry basis). The other portion used for desorption process was first dampened by placing in known amount of water so as to allow them pick up moisture for 4 days This enabled the moisture content to be raised to a stable and uniform level.

2.2 Methods

2.2.1. Experimental Sorption Isotherm

Water sorption isotherms (adsorption and desorption) were determined by gravimetric method which involved exposure of samples to different salts (LiCl, CH_3COOK, $MgCl_2.6H_2O$, K_2CO_3, Mg $(NO_3)_2.6H_2O$, NaBr, $SrCl_2.6H_2O$, NaCl, $(NH_4)_2SO_4$, $BaCl_2.2H_2O$) at a_w of 0.112 to 0.970 as shown in Table 1. The salts were employed as saturated solutions to give constant water activity environment. The samples were placed on perforated lid in different desiccators containing the salts. After which the desiccators were placed in a temperature-controlled chamber at different temperatures of 28, 33 and 38°C covering the main range of possible storage condition (to investigate the effect of different temperatures).

Samples were weighed consistently daily until a constant weight was achieved. Moisture content was determined by AOAC vacuum oven method (AOAC, 1990) at 60°C. An analytical balance (model) with a sensitivity of 0.1mg was used to measure water uptake. This procedure was performed in triplicate.

Table 1: Amount of water and salt used to prepare the different saturated salts and expected water activity

No.	Name	Salt (g)	Distilled water (g)	a_w (30°C)
1.	LiCl	112	63	0.112
2.	CH_3COOK	126	79	0.226
3.	$MgCl_2.6H_2O$	300	100	0.327
4.	K_2CO_3	300	135	0.431
5.	$Mg(NO_3)_2.6H_2O$	225	34	0.528
6.	NaBr	300	120	0.577
7.	$SrCl_2.6H_2O$	300	75	0.708
8.	NaCl	300	90	0.752
9.	$(NH_4)_2SO_4$	300	120	0.800
10.	$BaCl_2.2H_2O$	375	105	0.903
11.	K_2SO_4	20	100	0.970

2.2.2 Determination of moisture content

Moisture content was determined by gravimetric method (AOAC, 2000). Five gram (5g) of the sample was pre-weighed (W_1) in a petri dish and placed in an oven at 105 °C for 3 hour. The sample was removed from the oven, cooled in a desiccator, and re-weighed. It was taken back to oven for another 1 hour, cooled and weighed, this was repeated until a constant weight was achieved and recorded as (W_2). All analyses were carried out in triplicates. Moisture percentage was calculated as shown in Equation 1:

$$moisture\ (\%) = \frac{(W_1 - W_2)}{W_1} \times 100 \text{…………..} \quad \text{(Eq.1)}$$

2.2.3 Data Analysis: Mathematical Modelling of Moisture Sorption Isotherm

Five mathematical equations namely; GAB, BET, Peleg, Smith and Ferro Fontan were used for describing desorption and adsorption isotherms of in-shell walnut in the range of temperature 28, 33 and 38^{0}C. The expressions and the parameters of the five models used to fit the data are presented in Table 2.

The goodness of fit of the data to the equations was evaluated by the criteria of correlation coefficient (R^2), the mean relative percentage error (P) and the reduced chi-square (X^2) presented as in equations 2, 3 and 4 respectively. The higher the R^2 value and the lower the X^2 and P values, the better is the goodness of the fit.

3 $$R^2 = \frac{\sum_{i=1}^{n}\left(M_{\exp,i} - M_{pre,i}\right)\sum_{i=1}^{n}\left(M_{pre,i} - M_{\exp,i}\right)}{\sqrt{\left[\sum_{i=1}^{n}\left(M_{\exp,i} - M_{pre,i}\right)\right]^2\left[\sum_{i=1}^{n}\left(M_{pre,i} - M_{\exp,i}\right)^2\right]}} \quad \text{……………. Eq. (2)}$$

$$P = \frac{100}{N}\sum_{i=1}^{N}\frac{M_{\exp,i} - M_{pre,i}}{M_{\exp,i}} \quad \text{…………….. Eq. (3)}$$

$$X^2 = \frac{\sum_{i=1}^{N}(M_{exp,i} - M_{pre,i})^2}{N-n} \quad \text{………………Eq. (4)}$$

where, $M_{exp,I}$ = ith experimentally observed equilibrium moisture content, $M_{pre,I}$ = ith predicted equilibrium moisture content, N = number of observations and n = number of constants (Kaya and Kahyaoglu, 2007). Where A, B, C and D are parameters of the equations, T is temperature (^{o}C), X_e is equilibrium moisture content (kg/kg d.b.), and a_w is the water activity (Kaya and Kahyaoglu, 2007).

Table 2: Mathematical models used to describe moisture adsorption and desorption isotherm behaviours of the dehydrated African walnut

Model name	Equilibrium Moisture Content Model equation
Smith	$X_e = A - B\ln(1 - a_w)$
GAB	$X_e = \frac{CABa_w}{(1 - Ba_w)(1 - Ba_w + ABa_w)}$
Ferro-Fontan	$X_e = \left\{1 \Big/ \left[\frac{1}{\alpha}\ln\left(\frac{\gamma}{a_w}\right)\right]^{\frac{1}{r}}\right\}$
Peleg	$X_e = Aa_w{}^B + Ca_w{}^D$
BET	$X_e = \frac{ABa_w}{(1 - a_w)(1 + (A-1)a_w)}$

3. RESULTS AND DISCUSSIONS

3.1 Moisture Sorption Isotherms of Dehydrated Walnut: Effect of Temperature on Sorption Isotherms

The isotherms shown in figures 1 and 2 were obtained by plotting the corresponding mean EMC of three replicates against a_w at each temperature for adsorption and desorption processes respectively. The effect of temperature on the moisture sorption isotherm reveals that there was an initial increase in the equilibrium moisture content as temperature increased to 33°C and then the equilibrium moisture content decreased as temperature further increased to 38°C at constant a_w (0.226 – 0.800), but there was decrease in the equilibrium moisture content with increasing temperature, at a constant a_w (0.903 – 0.970); the decrease in EMC with increasing temperature signifies that the product became less hygroscopic with increasing temperature which means it can absorb more moisture at lower temperatures than at higher temperatures at constant relative humidity environment (Ariahu et al., 2006). According to Ronald *et al*., (2005), this can be explained by the change in the excess enthalpy of water binding, dissociation of water, or increase in solubility of solute in water as temperature increases. Also, this trend may be due to a reduction in the total number of active sites for water binding as a result of physical and/or chemical changes in the product induced by temperature (Mazza and LeMaguer, 1980; Moreira *et al*., 2008; Saad *et al*., 2014).

The effect of temperature on the sorption isotherm is of great importance (Falade and Awoyele, 2005), this is due to the fact that foods are exposed to a range of temperatures during storage and processing, and also a_w changes with temperature. Temperature affects the mobility of the water molecules and the dynamic equilibrium between the vapour and adsorbed phases (Al-Muhtaseb *et al*., 2004).

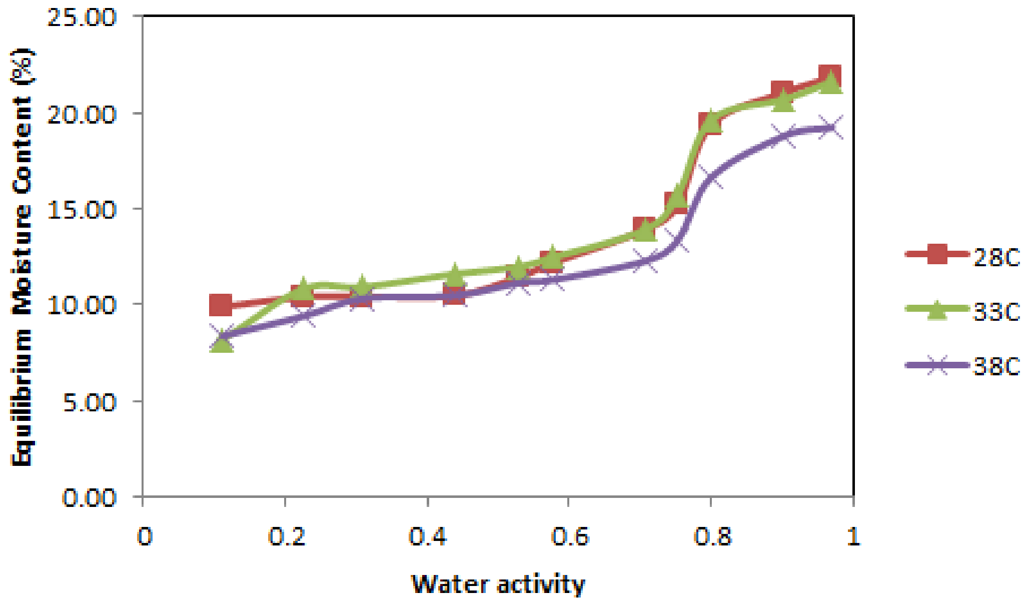

Figure 1: Effect of temperature on the adsorption isotherm of dehydrated African walnut

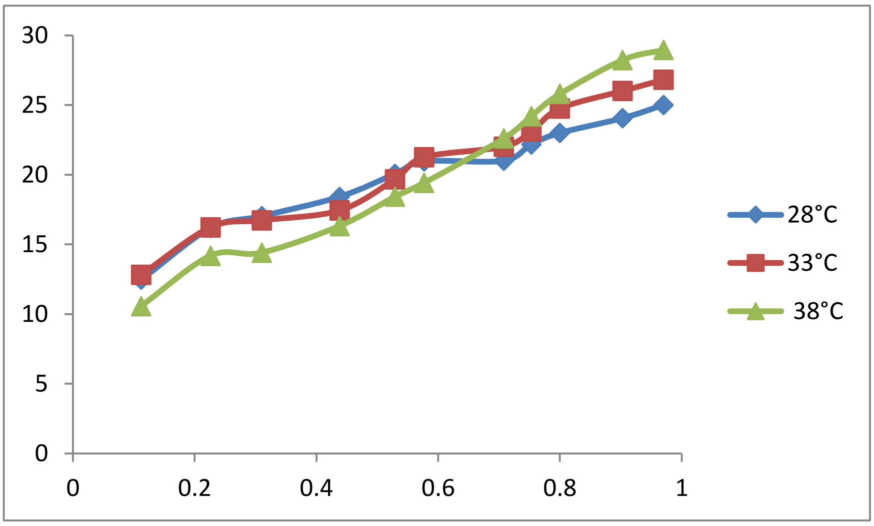

Figure 2: Effect of temperature on the desorption isotherm of dehydrated African walnut

The monolayer moisture content (M_o) for each temperature, calculated using the BET and GAB models, is presented in Table 3. In general, the M_o value calculated using the BET model was lower than that calculated using the GAB equation this is in agreement with the reports of other researchers (Erbas *et al*., 2005; McMinn *et al*., 2007; Lee and Lee, 2008).

For adsorption, M_o decreased as temperature increased while it decreased for desorption isotherm. The behaviour of M_o decreasing with increase in temperature been ascribed to a reduction in the number of active sites due to physical and chemical changes induced by temperature (Moreira *et al*., 2008). The M_o is the minimum moisture content covering hydrophilic sites on the material surface, and it is a necessary data for achieving storage with minimum quality loss for long time. Furthermore, at this condition, the rates of spoilage reactions, except for oxidation of unsaturated fats, are minimal. Therefore, at a given temperature, the safest a_w level is that corresponding to M_o or lower (Moreira *et al*., 2008)

3.2 Modeling of Sorption Isotherms

Table 3 showed the result of the nonlinear regression analysis of adsorption and desorption isotherms of in-shell walnut obtained at 28°C, 33°C, and 38°C. The values of constants of the five models, that is, GAB, BET, Smith, Ferro-Fontan, Peleg, fitted to the desorption and adsorption data along with their standard error (P), the correlation coefficient (R^2), and the reduced chi-square (X^2) for the studied temperatures are given. Examination of the results revealed that some of the models are acceptable for predicting the EMC.

In considering the models with lowest standard error and the highest coefficient of correlation, the BET gave the best fitting for adsorption at 33°C and 38°C and Smith model was best fit at 28°C, while Peleg models gave the best fitting of desorption isotherms at 28°C, BET gave the best fitting at 33°C and Ferro Fontan gave the best fitting at 38°C. The R^2 of the models that fit the isotherms ranged from 0.903 to 0.999. Lomauro *et al*., (1985) pointed out that when percentage average relative deviation is less than 5, the fit is considered to be excellent. It is well-known that the fit becomes better as the coefficient of determination 'R^2' approaches 1. Also, the smaller the standard errors of models the better is the fit. Considering all these three criteria for the isotherms of the walnut at the three temperatures, the sorption data were in good agreement with GAB and other tested models. However, BET model seems to be excellent to represent the experimental sorption data. Comparison of the experimental and predicted isotherms for dehydrated walnut over the range of temperature and a_w commonly encountered in the tropics in food storage structures are shown in figures 3-5 for the adsorption isotherms and figures 6-8 for the desorption isotherms.

Table 3: Estimated parameters and fitting criteria of the models applied to experimental sorption data of dehydrated African walnut

Model names	Const.	Adsorption			Desorption		
		28°C	33°C	38°C	28°C	33°C	38°C
Smith	A	9.3806	9.4023	9.6824	15.1562	14.5851	11.8149
	B	-8.1272	-9.5799	-10.5799	-11.3994	-12.6404	-17.7076
	R^2	0.9992	0.8758	0.8758	0.7906	0.8929	0.9499
	P	0.0000	0.0211	1.164E-10	1.707E-15	0.0000	8.574E-10
	X^2	1.69E-17	1.34E-02	4.00E-19	8.08E-29	0.00E+00	1.25E-17
BET	C	-6.02E+00	-8.93E+00	-9.02E+00	-1.13E+01	-1.12E+01	-1.62E+01
	M_o	5.018	5.856	7.922	10.143	9.913	9.842
	R^2	0.9027	0.9392	0.9892	0.987	0.9771	0.9771
	P	-2.36E-08	0.0008222	0.0001921	0.0027622	1.63E-12	1.63E-12
	X^2	8.79E-14	1.90E-09	8E-05	3E-05	8.13E-14	8.13E-14
GAB	C	-3.79E-07	-2.38E-07	-2.38E-07	-8.35E-07	-1.12E-07	-1.12E-07
	K	0.8219	0.73913	0.73913	0.7688	0.1622	0.1622
	M_o	8.642	9.2241	14.8728	20.3271	17.9138	17.9138
	R^2	0.943	0.869	0.962	0.922	0.9731	0.9731
	P	-8.36E-10	3.59E-08	4.921E-08	1.67E-15	1.13E-15	1.13E-15
	X^2	1.53E-13	0.001	1E-05	8.01E-23	3.03E-23	3.03E-23
Ferro-Fontan	A	4.4426	5.3367	6.0169	11.0965	7.03742	4.1174
	Y	2.5528	2.7230	2.9101	4.8628	5.0022	7.9389
	R	0.216736	0.2451	0.2699	6.05E-02	9.58E-02	9.87E-02
	R^2	0.8375	0.8892	0.8892	0.9856	0.9697	0.9812
	P	3.36E-10	0.05979	1.192E-06	-0.003498	0.0098708	0.0330662
	X^2	1.17E-03	1.07E-01	2.81E-01	3.39E-04	1.83E-03	1.86E-02
Peleg	K_1	3.9892	6.9166	7.6596	8.1121	7.62	6.18
	K_2	10.84	11.89	13.901	12.3797	14.8789	16.1923
	n_1	1.8529	2.50449	2.82829	2.4099	2.2645	2.2917

	n_2	0.00079	0.00085	0.00091	0.00081	0.00099	0.0010
	R^2	0.9003	0.8540	0.8540	0.9895	0.9616	0.9715
	P	-8.36E-05	0.0214	0.0369261	0.0008715	0.0277175	0.0277175
	X^2	0.0000	0.0137	0.0000	0.0000	0.0144	0.0144

3.3 Moisture Sorption Hysteresis of Dehydrated African Walnuts

The experimental adsorption and desorption isotherms (change in EMC with a_w) obtained at 28, 33, and 38°C for African walnut are shown in Figures 9, 10, and 11. The EMC at each a_w represents the mean value of three replications. The temperature chosen is suggestive of average ambient temperature at which most food products are stored in tropics. The results indicated that the adsorption isotherms of the dehydrated walnut exhibit about type II curve. The adsorption isotherms at the temperatures lay below their desorption counterparts and both enclosed hysteresis loop. Hysteresis has been related to the nature and state of the components in a food, reflecting their potential for structural and conformational rearrangements (Yan *et al*. 2008). The sorption isotherms have the sigmoidal-shaped profile according to the BET classification. These curves are typical of plant products as reported by Kouhila et al., (2002), Ait-Mohammed *et al*., (2004) and Idlimam *et al*., (2008). Hysteresis between adsorption and desorption existed over almost the entire range of water activity at 28°C. Similar behaviour of adsorption and desorption isotherms was observed for 33°C and 38°C. The hysteresis effect was more pronounced at lower temperatures in which water content on the desorption isotherm is higher than that on the adsorption side at the same water activity. One of the reasons for difference in moisture content between the two closures.

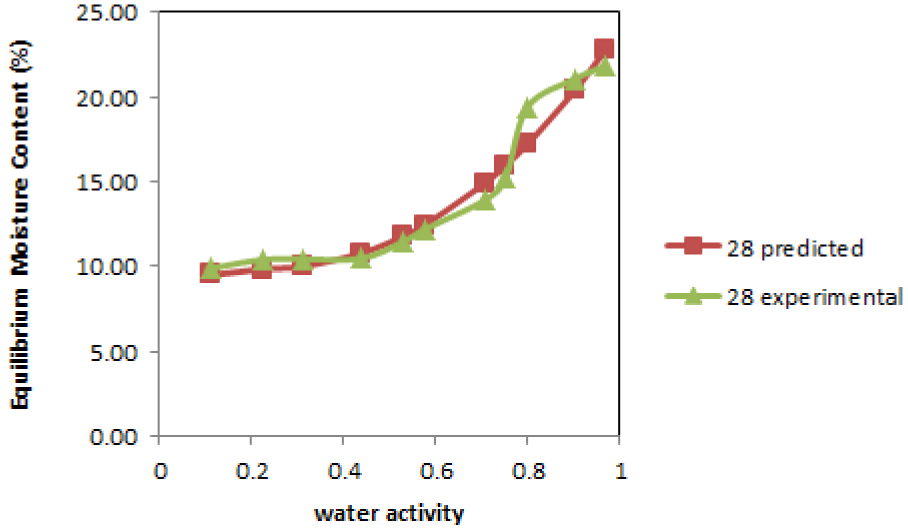

Figure 3: Comparison of experimental and GAB predictive adsorption isotherms of dehydrated African walnut at 28°C

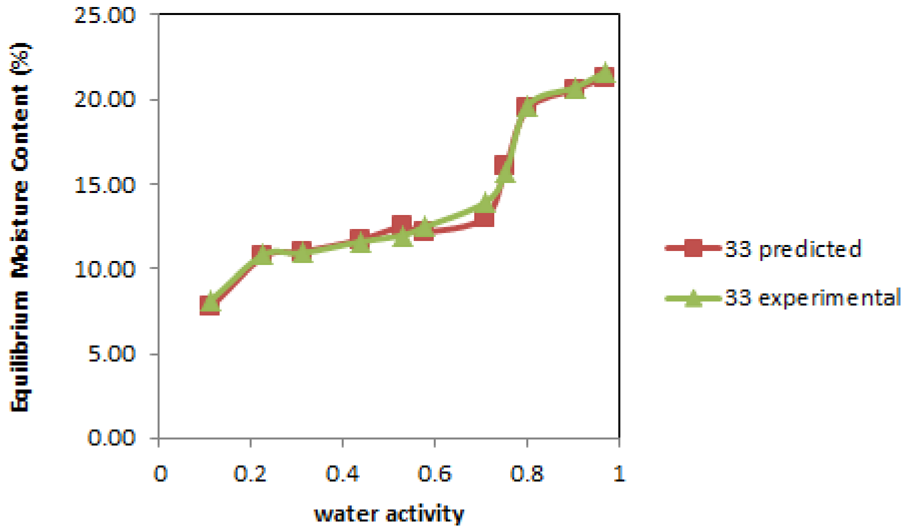

Figure 4: Comparison of experimental and GAB predictive adsorption isotherms of dehydrated African walnut at 33°C

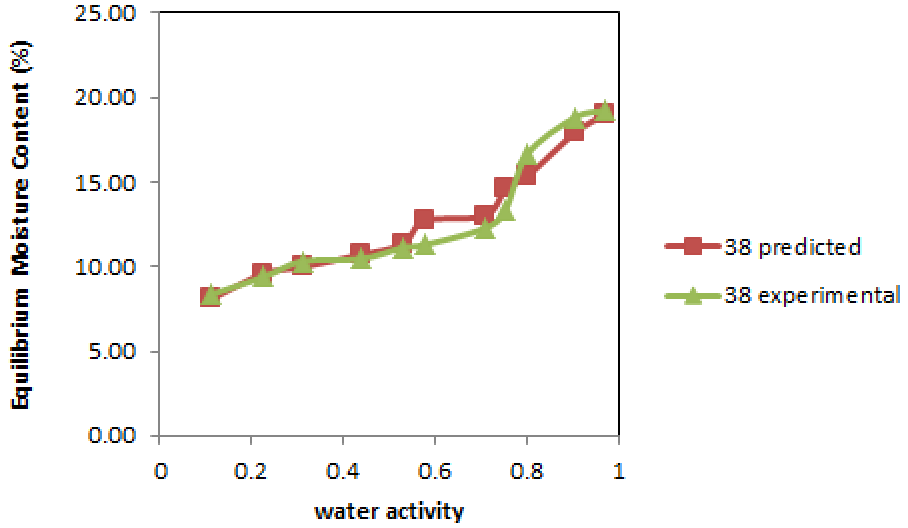

Figure 5: Comparison of experimental and GAB predictive adsorption isotherms of dehydrated African walnut at 38°C

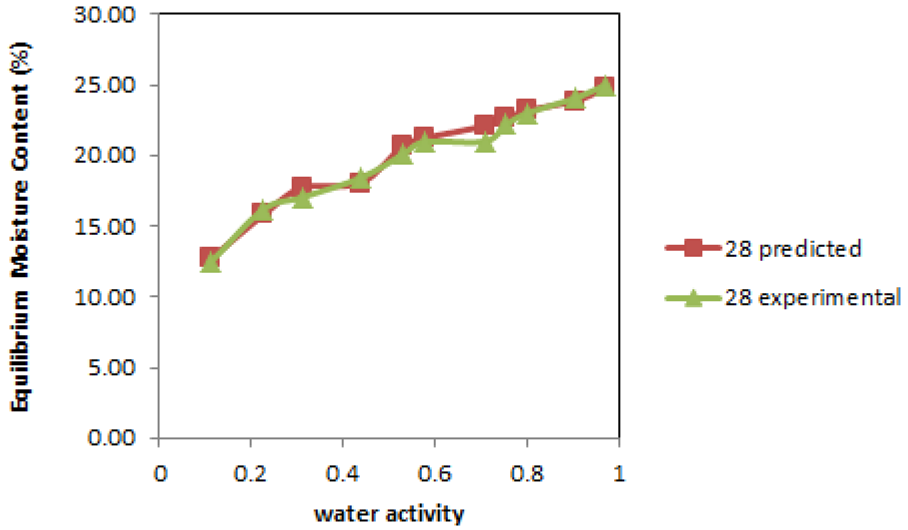

Figure 6: Comparison of experimental and GAB predictive desorption isotherms of dehydrated African walnut at 28°C

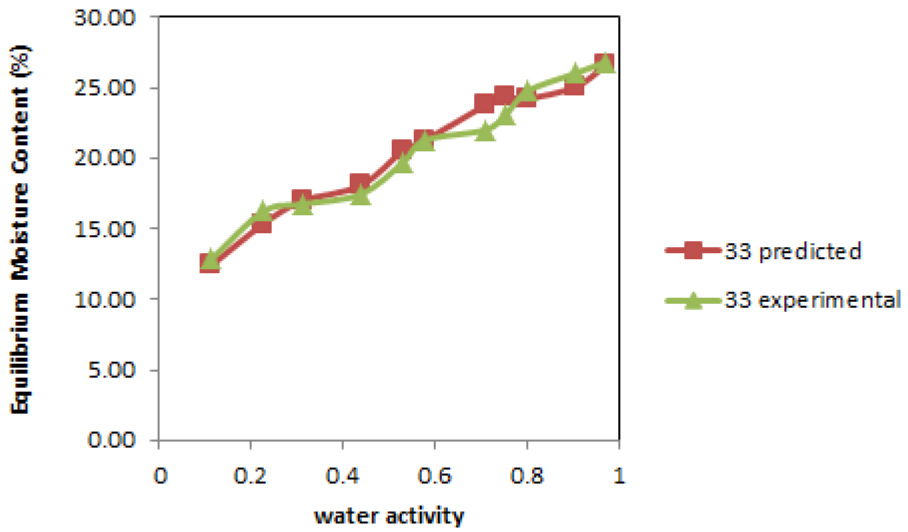

Figure 7: Comparison of experimental and GAB predictive desorption isotherms of dehydrated African walnut at 33°C

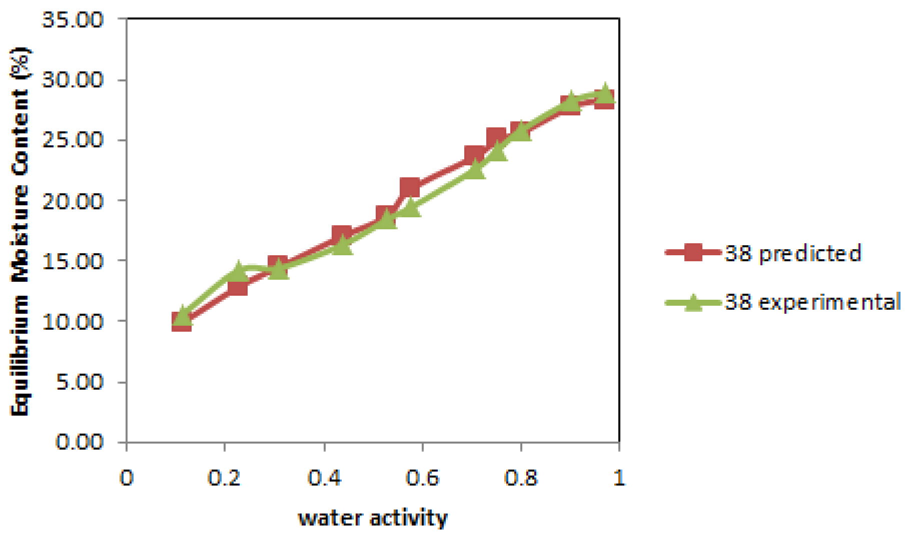

Figure 8: Comparison of experimental and GAB predictive desorption isotherms of dehydrated African walnut at 38°C

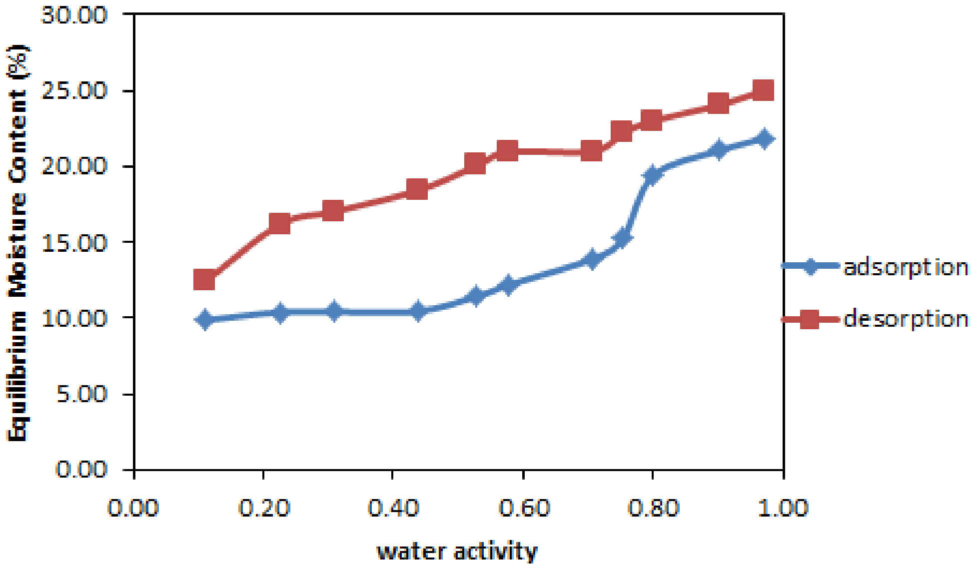

Figure 9: Adsorption and desorption isotherm of dehydrated African walnut at 28^{o}C

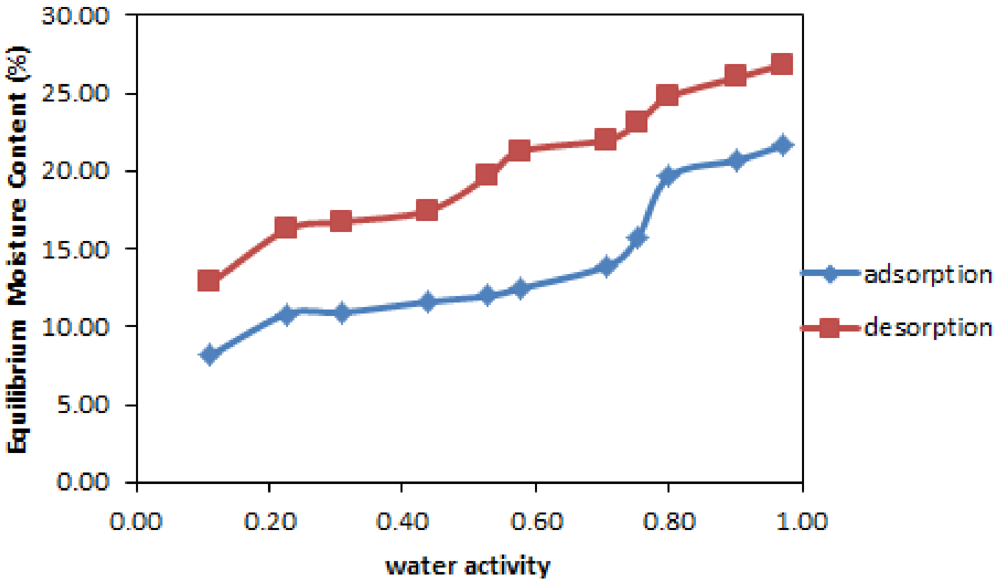

Figure 10: Adsorption and desorption isotherm of dehydrated African walnut at 33^{o}C

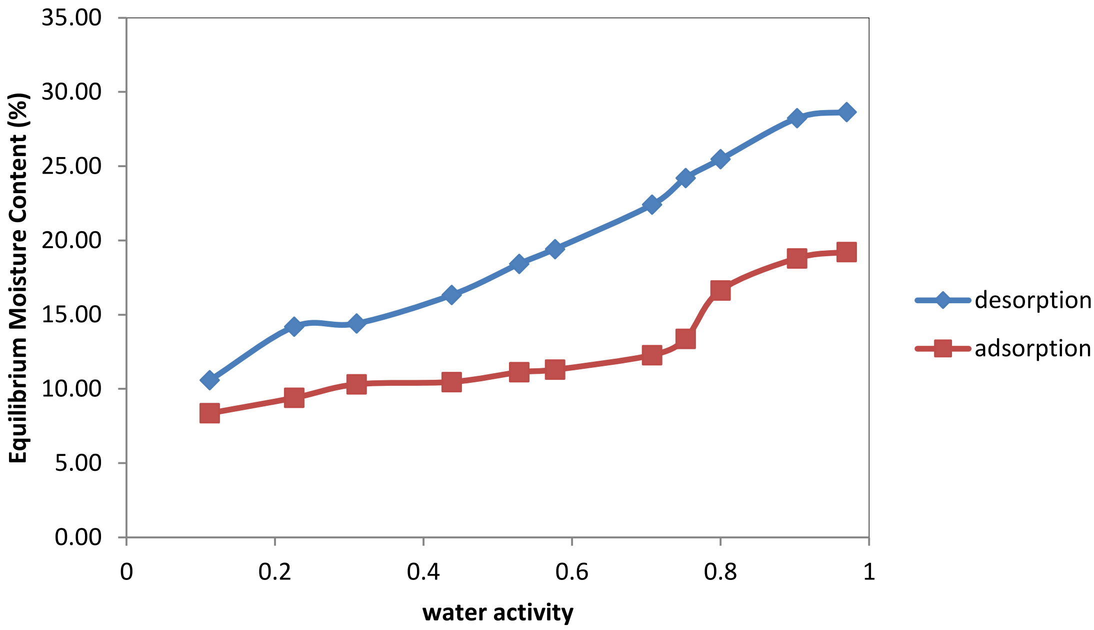

Figure 11: Adsorption and desorption isotherm of dehydrated African walnut at 38°C

points is that, during drying (desorption), some solutes may supersaturate below their crystallization water activity and thus hold more water as a_w is lowered (Barbosa-Carnovas *et al.*, 2007; Saad *et al.*, 2014). The swelling of polymeric materials during moisture adsorption can also lead to hysteresis (Raji and Adeniran, 2011). Iglesias and Chirife (1976) recognized that it is not possible to give a single explanation of the hysteresis phenomena in foods due to food being a complex biological material.

The figures revealed that the equilibrium moisture content increased with water activity at constant temperature. This may be due to the fact that vapor pressure of water present in foods increases with that of surroundings (Shivhare *et al.*, 2004). In the first segment (with low water activity) of the S-shaped sorption isotherm curves, walnut kernels sorbed relatively lower amounts of moisture. However, larger amount of moisture was absorbed at higher a_w. Similar behaviour has been reported by other authors for different foods (Sanni *et al.*, 1997; Lee and Lee, 2008). Two bending regions are noted, one around 0.1 to 0.3 and another at 0.5 to 0.6. The isotherm is therefore divided into three zones. According to Aguilera and Stanley (1999), in zone I (a_w between 0.05 and 0.2) minimal water is contained in the product, and the water molecules present are tightly bound to active sites (e.g., polar groups in molecules) mainly by hydrogen bonding. In zone II (a_w between 0.2 and 0.5) the water is more loosely bound, initially as multilayer above the monolayer; later, as moisture content increases, this water successively fills micro-pores and macro-pores in the system. In this region, chemical and biochemical reactions requiring solvent water start to take place because of the increased mobility of solutes. In zone III (a_w between 0.6 and 0.9), excess water is present in macro-capillaries, exhibiting nearly all the properties of bulk water. Microbial growth becomes a major deteriorative reaction in this region (Saad *et al.*, 2014). According to Vanden Berg and Bruin (1981), a general sigmoid sorption isotherm can be divided into three different parts; ranges I (a_w 0–0.22), II (a_w 0.22–0.73) and III (a_w 0.73–1.0). In ranges II and III, water molecules penetrate newly created pores of the already swollen structure and are mechanically entrapped in the void spaces. Therefore, water uptake particularly at higher a_w would be markedly influenced by the stability of the micro-porous structure.

4. CONCLUSIONS

Moisture sorption isotherms were determined for dehydrated African walnut at three different temperatures of 28, 33 and 38°C. There was a significant effect of temperature on the equilibrium moisture content (EMC) in the range of temperatures studied. The EMCs were found to decrease with increasing temperature at constant a_w; they were also found to increase with increasing a_w at constant temperature. The isotherms obtained are sigmoidal in shape and showed evident effect of hysteresis. In general, BET model provided a better fit to the experimental data than other tested models, thus it was found to be the most appropriate equation for representing the sorption isotherms. M_o increased with temperature for adsorption, while it decreased with increasing temperature for desorption.

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Some Physical Properties of Negro Pepper Seed (*xylopia aethiopica*) Necessary for Post- Harvest Handling

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ABSTRACT

Negro pepper is a spice with high nutritional value and several beneficial phytochemical compounds. Physical attributes of biomaterial are important in many problems associated with the design of machines and the analysis of the behavior of the product during agricultural processing operations such as handling, planting, harvesting, milling, threshing, cleaning, grading, sorting and drying. This study was aimed at determining some physical properties of Negro pepper seed (xylopia aethiopica) including axial dimensions, grain mass, bulk and true densities and porosity. Manual methods of measurements were employed in which the seeds were either measured directly or in bulk. Other parameters were calculated such as arithmetic, geometric mean diameter and sphericity. Seed weight and volumes were measured by using standard measuring equipment. All properties were determined at a fixed moisture content. The result of the study showed that the average length, width and thickness of the negro pepper seed were 5.99 ± 0.42, 3.51 $\pm$ 0.25 and 3.05$\pm$0.14mm respectively. Geometric mean diameter and sphericity of the Negro Pepper Seed were obtained as 3.80 $\pm$0.13mm and 65.53.$\pm$0.11% respectively. The Solid density, Porosity and bulk density for negro pepper seeds were 0.56 $\pm$0.25 g/m^3 49.50 $\pm$ 0.22 % and 1.125 $\pm$0.31 g/m^3 respectively all measurement were obtained at a seed moisture content of 3.75% wet basis

Keywords: negro pepper seed, physical properties, sphericity, true density, bulk density.

1. INTRODUCTION

The size and shape of an agricultural commodity, or of a processed product, not only affect the degree of consumer acceptance but in many cases influence packaging, distribution of stresses when forces are applied, and processing ability. As pointed out by Medalia (1980) "to define the shape of a body fully, one must specify the location of all points on the external surface." This is not only a time-consuming process but also has mathematical difficulties for more irregular shaped commodities. Therefore, qualitative shape description is the most popular with food graders. The shapes of fruits and vegetables have been classified into 13 categories such as round, oblate, oblong, conic, elliptical, truncated, ribbed, etc. (Mohsenin, 1980).

Every parts of the Negro pepper plant such as the bark, seeds, stem, fruit and leaves are of great importance in medicine for therapeutic purposes. Furthermore, some parts of crop can be combined with other plants parts for tackling many ailments and diseases. Researchers revealed that Negro pepper contains anti-oxidizing, calmative, laxative and antimicrobial properties .The seeds can be added whole or crushed before being used to prepare assorted food dishes such as soups, yam porridge, pepper soup**,** stews, sauce, meat and fish etc. It can also be used alone or mixed with garlic or ginger for making herbal tea. Negro pepper can also be used as a preservative Abolaji *et.al*., (2007). Negro pepper seeds can be crushed and mixed with the roots of *Gardenia tennifolia* for preparing herbal tonic for treating coughs, fever, flu and cold. The crushed Negro pepper seeds can also be mixed with other ingredients for the treatments of other ailments such as rheumatism, gastrointestinal problems, respiratory system disease, menstrual problems Abolaji *et al.,* (2007).

The nutritional and health benefits of spices are gaining wide acceptance as they are being sold in various forms in many marketing outlets in Nigeria. Tairu (1999) Negro pepper can be used medicinally as a cough remedy, a post-partum tonic and a lactation aid others are for treatment of stomachache, bronchitis and dysentery. The dried fruits are also used as spices in the preparation of two special local soups named “obeata” and “isi-ewu” taken widely in the Southwest and Southeastern parts of Nigeria respectively *(*Abolaji *et al., 2007*). In the course of exploiting the usefulness of this seed, they are usually subjected to various processing and unit operations which do affect these qualities. Cooking or roasting alters the nature of many spice constituents like starches, proteins and volatiles by changing their physical, chemical and nutritional characteristics.

(a) (b)

Fig 1 (a) Dried Negro pepper fruit pods in clusters (b) Negro Pepper Seeds

Many spices including negro pepper are ground to coarse or fine particles to provide convenience for human consumption. Further, the unit processing from harvesting to milling adds to the cost and hence becomes a process of value addition. The immediate question that arises is the quality of the ground material; a processor always tries to maintain the same quality in the finished product compared to the original sample (whole seed). It is obvious that some portion of input mechanical energy is transformed into thermal energy during grinding (milling). The extent of transformation of mechanical energy depends on several factors including raw material attributes, type and design of the material handling system, and engineering properties of the material and the processing machine. Thus, there is a need to know how these factors affect the quality and characteristics of the finished product. Other issues that may come up is the extent of deterioration of quality which may directly or indirectly affect market value. In the present era of competitive world trade, it is very important that the quality of the product should be of international standards. The last question that arises here is how to maintain or improve the quality of the product. Not much work has been carried out to find the answers to these questions.. But detailed scientific data are still lacking to solve these problems. Negro Pepper seed play a vital role in the socio-economic and health wellbeing of the people. At every stage of harvest, handling and packaging operation care must be taken to avoid injuries thereby reducing quality.

Researchers have reported on physical and engineering properties for different seed types such as sunflower(Helianthus annuus L.) (Gupta and Das, 1997), sesame (Tunde-Akintunde and Akintunde, 2004; Gharibzahedi *et al.*, 2009), rapeseed (Brassica napus L.) (Cahsir *et al.*, 2005), safflower (Carthamus tinctorius L.) (Baumler *et al.*, 2006), flaxseed (Linnum usitatissimum L.) (Coskuner and Karababa, 2007), wild sunflower

(Helianthus petiolaris Nutt.) (Perez *et al.*, 2007) and black cumin (Nigella Sativa L.) (Gharibzahedi *et al.*, 2010). Having found that not much work has been done on the physical properties of negro pepper seed to enhance its processing with the attendant benefit to humans, this work was then carried out with the following objectives. To determine some physical properties of negro pepper seeds such as axial dimensions, mass, bulk and true density and some parameters calculated were sphericity, surface area, geometric mean diameter coefficient of friction and angle of repose. These properties help to enhance handling (harvesting, cleaning, drying, milling and storing)

2.0 MATERIALS AND METHOD

2.1 Sample procurement and preparation

Negro pepper dried fruits were bought from a local market (*Urua Akpan Andem*) in Uyo, the viable seeds were manually extracted, sorted after removing the seed from the pods. The seeds were then wrapped in a polyethene bag and kept in a refrigerator

2.2 Size and Shape

From the selected samples,100 seeds were picked at random ,measurements of dimensions on three naturally perpendicular axes were made namely major, intermediate and minor diameters. The measurements were made with a digital micrometer screw gauge with a resolution reliability error of 0.01mm respectively. The most prevailing method for quantitative shape description involves calculations of similarity to a sphere:

$$Sphereci ty(S) = \left({(abc)}/{a} \right)^{1/3} \qquad (1)$$

where: a is the major axis of the product(mm)

b is the intermediate (medium) axis of the product and(mm)

c is the minor axis of the product (mm)

$$Roundness R_d = {A_p}/{A_c} \qquad (2)$$

where A_p is the largest projected area of the object in natural rest position(mm^2) and Ac is the smallest circumscribing circle. A value of roundness (R_d) equal to unity is a perfect sphere, and increase in the value indicates more sharpness in the product. Other practical methods of determining the, sizes of fruits and vegetables are diameter or length measurements, and counts per weight or volume. With fruits, the larger size is most desirable for the trade market. The other way of expression is weight per 100 or 1000 seed.

2.3 Geometric Mean Diameter (D_G)

The geometric mean diameter was determined from the Length (L), Width (W) (intermediate axis)and Thickness (T) using Equation (3)

$$D_G = [LWT]^{1/3} \qquad (3)$$

Where: geometric mean diameter (D_G)

2.4 Equivalent mean diameter (D_E)

The equivalent mean diameter was determined from the relationship:

$$D_E = L\left[\frac{(L+T)^2}{4}\right]^{1/3} \qquad (3a)$$

2.5 Arithmetic Mean Diameter (D_A)

The arithmetic mean diameter was determined from the three principle diameter using the relationship by Mohsenin (1970):

$$D_A = \frac{(L+W+T)}{3} \qquad (4)$$

where:
L is the length, (dimension along the longest axis in(mm);
W, is the width, (dimension along the longest axis perpendicular to (L) in mm) and
T, is the thickness, (dimension along the longest axis perpendicular to both (L) and (W) in mm).

2.6 Volume and Density

. The product is weighed in air and in water (using analytical balance, or a special gravity balance) and the volume is calculated:

$$Volume = (Weight \quad in \quad air - Weight \quad in\, water)/Weight\, density\, of \quad water \qquad (5)$$

Density of solids was calculated as the ratio of weight and volume. Separation by density in floatation is also used with many agricultural commodities to remove defective materials and extraneous matter.

The volume of the seed was determined by using the following formula

$$Volume = \pi BL^2 \big/ 6(2L - B) \qquad (6)$$

where;
B = (WT)^{1//2}
L = Major diameter, mm
W = Intermediate diameter, mm
T = Minor diameter, mm
$\pi =$ a constant

2.7 Bulk and True densities

The bulk density was determined by filling an empty 1000ml graduated cylinder with the seed and weighed (Mohsenin, 1986). The weight of the seeds was obtained by subtracting the weight of the cylinder from the weight of the cylinder and seed. To achieve uniformity in bulk density the graduated cylinder was tapped 10 times for the seeds to consolidate as reported by Irtwange (2000). The volume occupied was then noted. The process was replicated 24 times and the bulk density for each replication was calculated from the following relation:

$$\rho b = Ws \big/ Vs \qquad (7)$$

where: the p_b is the bulk density in kg/ m^3;
W$_s$ is the weight of the sample in kg;
V$_s$ is the volume occupied by the sample in m^3.

The mean value, variance, SD and CV for the 24 replications was determined to obtain the bulk density.

The true density was determined using the water displacement method. This method was used having certified that the seed coat is very hard and does not absorb water. Prior to the experiment, some seeds were weighed and soaked in water for 60 min and thereafter weighed to ascertain increase in weight due to absorption. A known weight of the seeds (34.3 g) was measured and the number of seeds (N) in the sample was carefully counted. Water was poured into a Eureka can and allowed to level up with the fraction. The seeds were then poured into the can and the volume of water displaced was measured using a 50ml measuring cylinder. The process was replicated 24 times and the true density taken as the average of the 24 replications was calculated for each reading as:

$$\rho_t = W_s / V_w \qquad (8)$$

where: p_t is the true density in kgm^{-3};

The surface area was determined by using the following equation as cited by Sacilik *et al*., (2003), Tunde-Akintunde and Akintunde (2004) and Al-Tuntas *et al*., (2005):

$$Sa = \pi GMD^2 \qquad (11)$$

where;

Sa = surface area (mm^2)

GMD = geometric mean diameter (mm)

2.8 Determination of Moisture Content

The moisture content of the samples was determined by oven drying method at 130℃ for 19hours, and all weight loss was considered to be moisture, according to the standardized procedure for moisture content determination by ASABE standard S352.2 (2007). The moisture of the seed in % (wet and dry basis) was calculated using the following formula (Mohsenin, 1970).

$$Mc_{wb} = (W_2 - W_3) / (W_2 - W_1) \qquad (12)$$

where Mc_{wb} = moisture content wet basis of seed (%) respectively, W_1 is the weight of the can, W_2 is weight of the can + moist sample and W_3 is the weight of the can + dry sample (g) respectively.

2.9 Angle of repose

A vertical cylinder container was placed open at both ends on a flat surface. The empty cylindrical container was filled with clean negro pepper seeds and cylindrical container was carefully lifted gradually and form a pile (Irtwange, 2000). The radius of spread and the height of the cone formed by the heap of seed were measured. This procedure was repeated in five (5) replicates and their average was used to calculate the angle of repose from:

$$\phi_r = \tan^{-1}[2h/r] \qquad (13)$$

Where: ϕ_r is the angle of repose;

h is the height of the cone in mm,

r is the radius of spread in mm.

2.10 Coefficient of friction on some material surfaces

The coefficient of friction on some material surfaces was determined using the set up similar to the one used for determination of coefficient of internal friction except that instead of the guide frame, the seeds were placed on a table with changeable surface. The experiment was conducted on three material surfaces; (wood, glass and metal surface) by a method described by Dutta *et al*.,(1998). The experiments were replicated ten (10) times for each surface. The seeds were placed inside a cylindrical container on plane of a named material slightly raised to avoid direct contact between the surface and the cylinder. The plane was gently tilted and the angle of inclination at which the sample start sliding was read off the protractor attached to the apparatus. The tangent of this angle is reported as the coefficient of static friction

$$\phi s = \tan\phi \qquad (14)$$

ϕ_s = Coefficient of friction

ϕ = Angle of inclination

3. RESULTS AND DISCUSSION

3.1 Size

The mean length, width and thickness with their respective standard deviation of Negro pepper seeds were found to be 5.99 $\pm 0.42mm$, 3.51 $\pm 0.0,25mm$ and 3.05 $\pm 0.14mm$ as compared to that obtained by Fashina (1996) which was 5.87mm, 3.51mm and 3.10mm respectively. The geometric mean diameter, Equivalent mean diameter and arithmetic mean diameter were found to be 3.8 ± 0.13mm, 15.29 ± 0.21mm and 3.99 ± 0.15mm respectively. The length, width and thickness varied statistically significantly for all the measurements taken ($p<0.05$).

Table 1. Summary of results for Some Physical Properties of Negro Pepper Seeds analyzed

Physical Property	Mean	SD
Length (mm)	5.99	0.421
Width (mm)	3.51	0.250
Thickness (mm)	3.05	0.146
Geometric Mean Dia, Dg (mm)	3.8	0.13
Equivalent Mean Diameter, D_p	15.29	0.21
Arithmetic Mean Diameter, D_a	3.99	0.15

Bulk Density (kg/m^3)	0.56	0.25
Solid Density(kg/m^3)	1.12	0.31
Porosity (%)	49.5	0.22
Sphericity Determination (%)	65.53	0.11
Estimated Surface Area(mm)	45.37	0.18
One Thousand Seed Mass(g)	34.3	-
Moisture Content on Wet Basis	3.75	0.12
Angle of Repose	35^0	
Coefficient of friction (glass)	30.99^0	
Coefficient of friction (wood)	29.34^0	
Coefficient of friction (steel)	30.64^0	

3.2 Angle of Repose

From the results on Table 1, after five replicates of the angle of repose of the negro pepper seeds, the mean height and radius of spread were 1.74 and 5.03cm respectively as compared to that obtained by Fashina (1996) which was 1.70cm and 5cm respectively. Substituting the result obtained into equation (13), gave the angle of repose as $\phi_r = 35^o$.

3.3 Coefficient of friction on Some Materials

The results of the coefficient of friction on four surfaces are as presented on Table 1 . Since the coefficient of friction is a function of the angle of internal friction, it is inevitable that changes that affect the internal friction of the material also affects the coefficient of friction of the material. The coefficient of friction on glass ,wood and steel were 30.99,29.34,and 30.64^0 respectively. From the table, the coefficient of friction increased in all the four surfaces used as the height of inclination increased.

3.4 Bulk and True Densities

Food powders pose problems in volume and density measurements because of their packing characteristics. Generally, two types of measurements are useful: free flow density and tapped density, the difference being in the manner of filling the volumetric container. Tapped density as used in the bulk density evaluation in this work gives a higher number than free flow density because of partial displacement of air from between the particles. Free flow and tapped density relate to the container fill and settling during shipment and handling. The fact that the densities of the seeds are less than the density of water can be used to design separation or cleaning processes for the grains since lighter fractions will float. The values recorded for the Bulk and True densities of negro pepper seeds is as presented in Table 1. From the results, the values of the bulk density and true density of the negro pepper seeds were revealed as 0.56 $\pm$ 0,25kg/m^3 and 1.12 $\pm$ 0.31 kg/m^3 respectively. This shows that the bulk weight of the seeds per volume is less than the mass per volume of the seeds. The result obtained was in cognizance of that obtained by Showalter (1973) which was 0.567kg/m^3 and 1.12kg/m^3 respectively.

3.5 Surface Area

The value of the estimated mean surface area was $45.37.\pm 0.18$ mm.^{2} The surface area of an agricultural product is generally indicative of its pattern of behavior in a flowing fluid such as air, as well as the ease of separating extraneous materials from the product during pneumatic transport. It is also important in heat and mass transfer processes such as drying and other thermal applications.

3.6 Sphericity

Published values for the sphericity of fruits are of the order 89-97. These values are expressed as the percentage; the higher the number, the greater the similarity to a sphere. Oblong-shaped products, such as rice, would exhibit a low value of sphericity (Mohsenin, 1986). The value of the sphericity had a mean of 65.53 ± 0.11 %. This shows that the seeds are entirely curved without sharp edges and that it is 65.53% compared to a sphere of 100%.

3.7 One thousand Seed Weight

From the experiment, values recorded for a thousand-seed weight was found to be 34.3g on the average and this agrees with the work done by Waziri and Mittai, (1997); and Jaeger, (1997).

3.8 Moisture Content

The moisture contents of Negro Pepper Seed was found to be $3.75 \pm 0.12\%$ $_{(wb)}$. The moisture content simply indicates the amount of water present in that agricultural produce and this is of great importance to food scientists and processing engineers as it assists them to determine certain adaptation and resistance to processing stages such as drying, bagging, storage, cooking and even consumption.

4. CONCLUSION

The parameters investigated include length, width and thickness of the negro pepper seed. Others are geometric, equivalent and arithmetic mean diameters, bulk and solid density, porosity, sphericity, moisture content, Coefficient of friction and angle of repose. From the result, length, width and thickness were 0 5.99 $\pm 0.42mm$, 3.51 $\pm 0.0{,}25mm$ and 3.05 $\pm 0.14mm$ respectively. Also geometric, equivalent and arithmetic mean diameters were 3.8 ± 0.13mm, $15.29 \pm$ 0.21mm and 3.99 $\pm$ 0.15mm respectively. The bulk density was $0.56 \pm$ 0,25kg/m^3 whereas solid or true density was

1.12 $\pm$ 0.31 kg/m^3. Porosity and sphericity were as follows $49.5 \pm 0.22\%$ and 65.53 $\pm$ 0.11 % whereas angle of repose was 35^0 . respectively. Coefficient of friction ranged between 29.34 and 30.990 depending on the engineering material used for the test.

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Sensory, Textural and Cooking Quality of Instant Noodles Produced from *Musa spp* - Wheat Composite Flours

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Enormous post-harvest losses (35 - 60%) associated with banana and plantain products in Nigeria and other producing countries in the tropics culminate in great losses for farmers. In Nigeria, unripe plantain is normally processed into flour with limited consumption only as reconstituted dough in local food systems. Previous studies established that Nigerians have acquired taste for noodles and it is widely consumed across all strata of the economic divide. Information regarding the production of instant noodles from *Musa spp.* is rarely found in literature; hence in this study the quality characteristics of instant noodles produced from *Musa spp* – wheat composite flours was investigated. *Musa spp* – wheat composite flours in the ratios 0:100; 5:95; 10:90; 15:85; 20:80 and 25:75 were processed into instant noodles. The proximate composition, sensory, textural and cooking quality of the instant noodles were determined following standard procedures. The results showed a corresponding increase in the crude fat, ash and fibre contents of instant noodles as the percentage substitution with *Musa spp* flour in the instant noodle formulation increased. Significant differences ($p<0.05$) were observed in the taste, colour, flavor, texture and overall acceptability of the products. It was observed that cooking time and cooking loss decreased from 4.38 – 3.40 min and 7.61 – 5.51% as percentage substitution increased, respectively; whereas cooking gain, moisture and fat uptake increased as substitution level increased. The force–deformation curve of *Musa spp* - wheat instant noodle obeyed the Hooke's law showing a decrease in the strength characteristics of noodles as percentage substitution with *Musa spp* flour increased. The production of instant noodles from banana and plantain offers means of promoting and extending its utilization, thereby boosting the income obtainable from its production.

Keywords: Instant Noodles, *Musa spp*, Cooking, Quality characteristics

1. INTRODUCTION

Instant noodle has increasingly become an important food item globally, with annual production of 101,420 million packs in 2012, and a steady increase of 3% annually since 2010 (World Instant Noodle Association, 2013). Most instant noodles are made of wheat as the base material, thus instant noodle consumption led to dependency on massive importation of wheat in non-wheat producing countries Nigeria inclusive. Apart from high cost of wheat importation, excessive consumption of wheat has been associated with allergy, asthma, autoimmune response, or gluten sensitivity (Rosell *et al.*, 2013) in some parts of the world. Several works have been done on gluten-free noodle using different types of flour, although rice flour (Inglett *et al.*, 2005; Yadav *et al.*, 2011; Heo *et al*., 2013) seems to be the best replacement for its small granule sizes to benefit noodle textural characteristics. Some other raw materials for gluten-free noodle include sorghum (Liu *et al*., 2012), and corn starch (Yuan *et al.*, 2008; Yousif *et al*., 2012) or corn flour (Padalino *et al.*, 2013). Lately, sweet potato starch (Silva *et al.*, 2013), pseudo-cereal such as amaranth flour in combination with cassava starch (Fiorda *et al*., 2013) have also been used for the making of gluten-free pasta.

The absence of gluten in non-wheat noodle composition often adversely affects noodle quality; hence non-gluten noodle requires treatment to improve its textural quality. Several techniques commonly used for starch textural improvement are annealing, hydrothermal treatment (Hormdok and Noomhorm, 2007), gelatinization (Yousif *et al.*, 2012) and fermentation (Yuan *et al*., 2008). In addition, the use of hydrocolloids such as carboxymethylcellulose (Choy *et al.*, 2012), konjac glucomannan (Zhou *et al.*, 2013), β-glucan (Inglett *et al.*, 2005; Heo *et al*., 2013a), transglutaminase (Gan *et al*., 2009; Kim *et al*., 2014), and acetylated starch (Choy *et al.*, 2012) have also been reported. However, in this work, the sensory, textural and cooking quality of instant noodles produced from *Musa spp* and wheat flours is investigated with the view to providing baseline information on the production of instant noodles from *Musa spp* fruits.

2. MATERIALS

2.1 Source of material: Freshly harvested bunches of *Musa spp* fruits (Plate 1) were obtained from Obafemi Awolowo University Teaching and Research Farm, Ile-Ife. The extent of maturity was based on the stage one colour classification documented (Ahenkora *et al.*, 1997 and Dadzie and Orchard, 1997). Other materials such as white wheat flour (Dangote brand), iodized table salt (Dangote brand), potato starch, guar gum, potassium carbonate (food grade), sodium carbonate (food grade) and sodium tripolyphosphate (STTP, food grade) were bought from a local market in Ile-Ife, Osun State. The chemicals used for analysis were of analytical grade.

2.2 Preparation of *Musa spp* flour: About 10 kg of freshly harvested debunched *Musa spp* fruits were immersed in a plastic bowl containing potable water on individual variety basis for 5 min. The fruits were removed from the bowl and peeled with the aid of a stainless kitchen knife. The pulp was sliced into cylindrical discs with thickness of about 5 mm and

Plate 1: A freshly harvested matured plantain (*agbagba*) *Musa spp* fruits

dipped in citric acid (CIT) (1% w/v) for 1 min to prevent enzymatic browning reaction (Adeyemi and Oladigi, 2009). Accumulation of moisture on the sliced surface as a result of the pretreatment was drained with a cheese cloth before samples were transferred to dryer set at 70 °C (Adeniji *et al.*, 2010). The citric acid treated *Musa spp* fruit slices were dried in a convective air-oven at +70 °C (±1°C) air velocity of 2.2 m/s (Adeyemi and Oladigi, 2009; Adeniji *et al.*, 2010). Prior to loading of the fruit slices, the dryer was run for 30 min to reach drying air temperature conditions. The sliced fruits were dried in thin layer for 48 h to constant weight at which the chips were considered to have attained its equilibrium moisture content. The chips were milled using laboratory milling machine (sieve size 500 µm aperture) and stored in an air tight bottle until the time of use. Figure 1 shows the flow chart for the production of pretreated *Musa spp* flour samples.

2.3 Blend formulation of *Musa spp*-wheat composite flour: The processed *Musa spp* flour was blended with wheat flour at 0, 5, 10, 15 20 and 25% replacement (Arshad *et al.*, 2010) using a Kenwood food processor (Model 49074, Kenwood Ltd, Hants, UK) operated at full speed

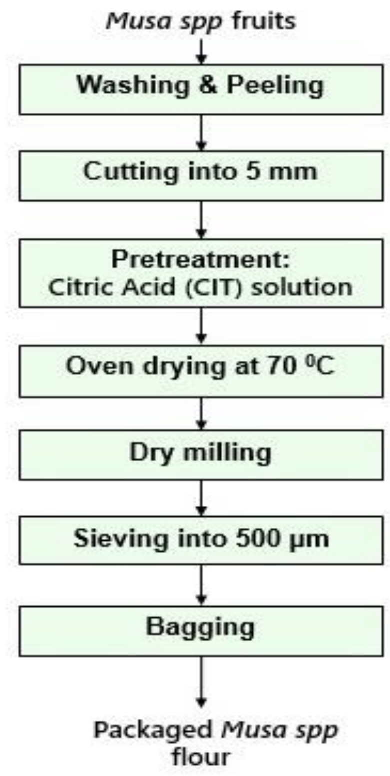

Figure 1: A flow chart showing production of *Musa spp* flours
Source: Adeniji *et al.* (2010)

for 10 mins. The blends were stored in high density polyethylene bags (0.77 mm thick) prior to use.

2.4 *Musa spp* - wheat instant noodle production: A laboratory model rotating single screw extruder was used to produce extrudate. The barrel diameter and length-diameter (L/D) ratio were 37 mm and 27:1, respectively with screw configuration standardized for processing flour-based products. The screw profile comprises self-wiping elements to improve mixing and apply shear to the material being extruded, while restricting flow and building up pressure. The exit diameter of the circular die is 1 mm. The extrusion of *Musa spp*-wheat flour composite dough was conducted at barrel temperature, 100 °C and screw speed, 85 rpm. The formulations and flow chart for the instant noodle production are shown in Table 1 and Figure 2, respectively; while Plate 2 shows samples of the instant noodles.

3. METHODS

3.1 Proximate analysis: The proximate composition of instant noodles samples was determined according to AOAC (2002) method. The parameters investigated are: moisture content, crude protein, crude fat, ash, crude fibre and carbohydrate. All reagents used are of analytical grade (BDH Chemicals, Poole, UK).

3.2 Determination of optimum cooking time: The optimum cooking time was determined following the method of Widjaya *et al.* (2008). About 10 g of instant noodle was boiled in 1000 ml of boiling water and after each minute of cooking for the first 2 min, noddle was removed and squeezed between clear glass slides. This procedure was then repeated by removing the noodles every 15 s until the white core becomes unnoticeable. Therefore, the time taken for the white core to disappear when the noodle strand was boiled in the distilled water is taken as the optimum cooking time.

3.3 Determination of cooking weight and cooking loss: Cooking weight and cooking loss were determined by methods of Oh *et al*. (1985) and AACC International (2000) Approved Method 66 – 50, respectively. Ten grams (10 g) of instant noodle was cooked in 300 ml of distilled water in a beaker to their optimum cooking time, rinsed with distilled water, drained and left to cool for 5 min at room temperature. The noodles were weighed and % increase in weight was obtained by gravimetry. Residual water was removed by drying in the oven at 100 °C until there was no trace of water in the beaker. The samples were cooled and weighed

Table 1: Formulation of instant noodle from *Musa spp*-wheat composite flour

	Formulations					
Ingredients	0%NOD	5%NOD	10%NOD	15%NOD	20%NOD	25%NOD
Wheat flour, g	100	95	90	85	80	75
Musa spp flour, g	0	5	10	15	20	25
Water, ml	34	34	34	34	34	34
Salt, g	1.6	1.6	1.6	1.6	1.6	1.6
Potato starch, g	12	12	12	12	12	12
Guar gum, g	0.2	0.2	0.2	0.2	0.2	0.2
Potassium carbonate, g	0.12	0.12	0.12	0.12	0.12	0.12
Sodium carbonate, g	0.8	0.8	0.8	0.8	0.8	0.8
STTP, g	0.1	0.1	0.1	0.1	0.1	0.1

0%NOD (Control) =100% wheat flour; 5%NOD = 95% wheat+ 5% *Musa spp* flour; 10%NOD = 90% wheat+ 10% *Musa spp* flour; 15%NOD = 85% wheat+ 15% *Musa spp* flour; 20%NOD = 80% wheat+ 20% *Musa spp* flour and 25%NOD = 75% wheat+ 25% *Musa spp* flour (Hou *et al.,* 1997)

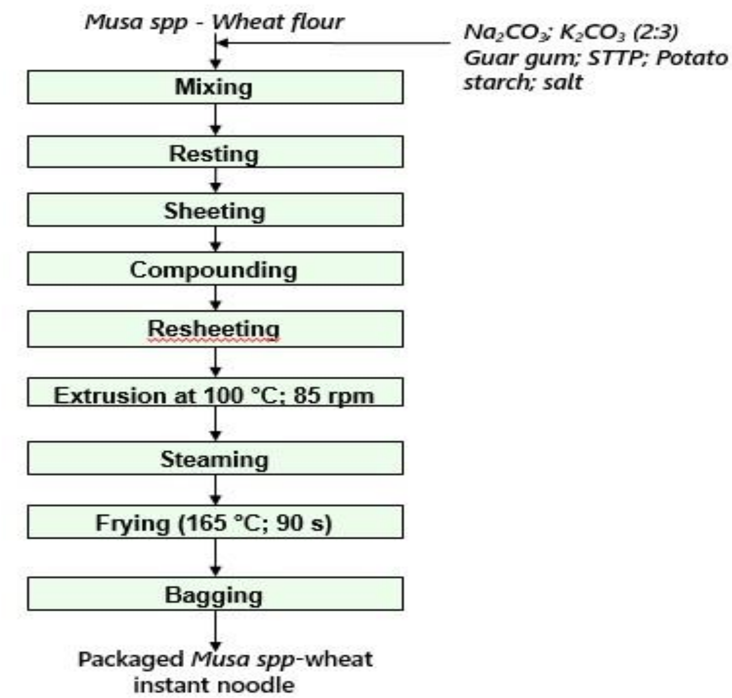

Figure 2: A schematic diagram showing production of fried instant noodle

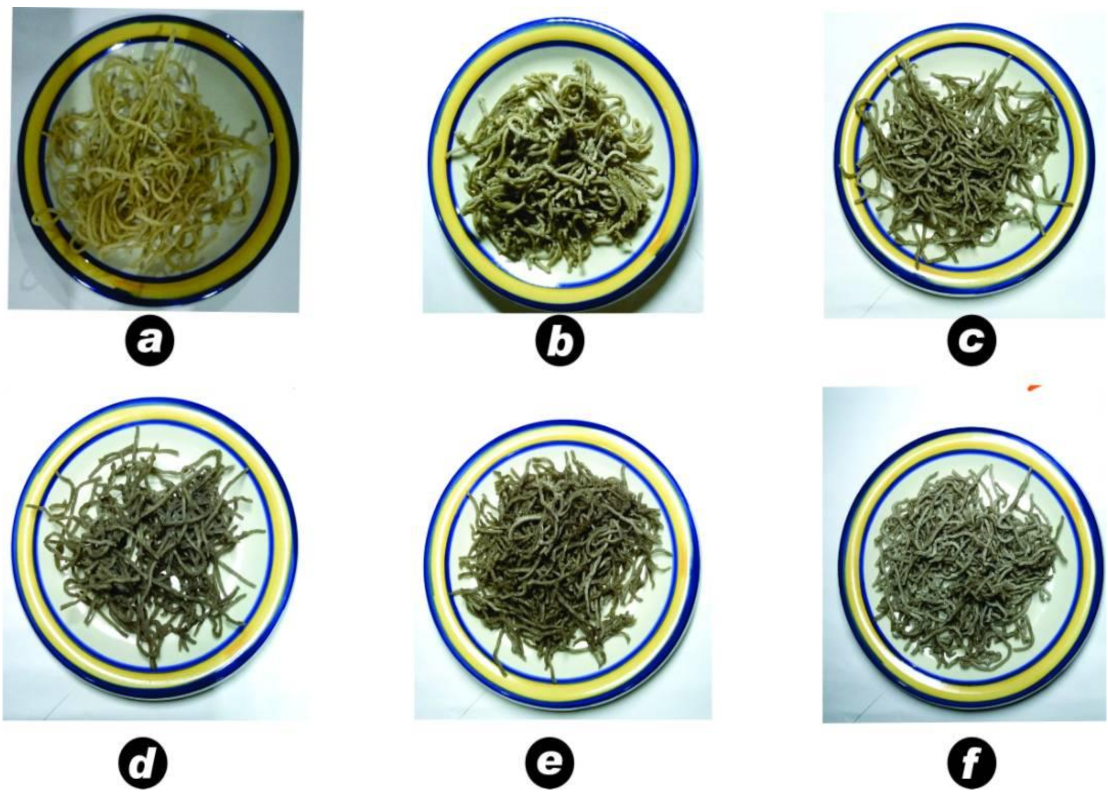

Plate 2: Fried instant noodles produced from *Musa spp*-wheat flours:
(a)100% wheat flour instant noodle; (b) 5% *Musa spp* flour + 95% wheat flour instant noodle; (c) 10% *Musa spp* flour + 90% wheat flour instant noodle; (d) 15% *Musa spp* flour + 85% wheat flour instant noodle; (e) 20% *Musa spp* flour + 80% wheat flour instant noodle; (f) 25% *Musa spp* flour + 75% wheat flour instant noodle

again. The percentage weight loss during cooking was obtained by gravimetry. Values reported are average of five replications.

$$C_w = \frac{W_C - W_D}{W_D} \times 100 \quad (3.1)$$

Where: C_W = Cooking weight (%); W_C = Weight of cooked instant noodle, g and W_D = Weight of dried instant noodle, g.

$$C_L = \frac{W_L}{W_D} \times 100 \quad (3.19)$$

Where: C_L = Cooking loss, %; W_L = Weight of loss solid, g

3.4 Determination of crude fat: Ground instant noodle (3 g) was subjected to soxhlet extraction with n-hexane for about 6 h. The was desolventized by flash evaporation and further drying in a hot-air oven at 100 °C for 30 min. to remove residual organic solvent and moisture. The oil was allowed to cool in a dessicator and weighed. The quantity of oil obtained was expressed as percentage of the original sample weight used.

$$\%\ CF = \frac{W_{oil}}{W_{sample}} \times 100 \quad (3.20)$$

Where: $\mathrm{CF} = \mathrm{Crude\ fat\ content}, \%;\ W_{\mathrm{oil}} = \mathrm{Weight\ of\ extracted\ oil, g;}$
$W_{\mathrm{sample}} = \mathrm{Weight\ of\ sample, g}$

3.5 Sensory Evaluation of Produced Instant Noodle: A semi-trained twenty-six panelist was used from the Department of Agricultural and Environmental Engineering of Obafemi Awolowo University, Ile-Ife, South-Western Nigeria (McWatter *et al.*, 2008). Criteria for selection are that panelists are 18 and above years of age; regular consumers of noodles; and not allergic to any food. The panelists filled a consent form approved by the University Institutional Review Board and received instructions on how to use the sensory booth signal lights to communicate with the server. They were instructed to evaluate appearance and colour first and taste each sample afterwards to evaluate flavour, texture and overall liking. A rating scale of l – 7 points (1 = dislike very much; 7 = like very much) was used (McWatter *et al.*, 2008). The formulated products were evaluated 3 h after production. Water and unsalted crackers were provided to panelists to cleanse their palates between samples and covered expectoration cups if they did not wish to swallow the samples. Samples were identified with 3 - digit code numbers and presented in a random sequence. Panelists were also asked if they would buy the product if it were commercially available and how much they would be willing to pay (lower, same, or higher price) compared with similar commercial products. They were also asked to comment freely on the samples. Evaluation was conducted in a climate-controlled sensory evaluation laboratory equipped with individual partitioned booths without special lighting

3.6 Determination of textural quality: Compression test was conducted using a Universal Testing Machine (Instron Electromechanical Testing Systems, Model 3369, 50 kN, Instron Corporation, USA) at Centre for Energy Research Development, Obafemi Awolowo University, Ile Ife. The samples were discreetly loaded at the rate of 10 mm/min. The test results and graphs were automatically generated. The data obtained included compressive load at yield, compressive strain at yield, compressive stress at yield and energy at yield. The experiment was replicated fifteen times.

4. RESULTS AND DISCUSSION

The proximate composition values of *Musa spp*-wheat instant noodle were expressed on dry basis (Table 2). The carbohydrate content of the *Musa spp*-wheat instant noodle samples ranged from 73.67 – 76.32 % with samples 25%NOD and 0%NOD having the minimum and maximum values, respectively. There is significant difference ($p< 0.05$) in the carbohydrate content of all the noodle samples, with all the instant noodle samples being of high calorie values. The carbohydrate content of *Musa spp*-wheat instant noodle compared favourably with 64.6 – 79.1%; 70.39- 73.80% and 68.30% reported for cassava instant noodle (Sanni *et al.*, 2004), sweet potato-wheat instant noodle (Taneya *et al.*, 2014) and corn-tapioca-wheat instant noodle (Pakhare *et al.*, 2016). The crude protein content values of *Musa spp*-wheat instant noodle samples ranged from 9.46 to 11.86% with samples 25%NOD and 0%NOD having minimum and maximum values, respectively, indicating significant differences at $p<0.05$. This implies that substitution of wheat flour with *Musa spp* flour reduced the crude protein content of the instant noodles. The crude protein values compared favourably with 5.8 – 12.4% and 11.66 – 12.51% reported for cassava-wheat instant noodle (Sanni *et al.*, 2004) and sweet potato-wheat instant noodles (Taneya *et al.*, 2014), but lower than 14.29% and 14.9% reported by Pakhare *et al.* (2016) for defatted rice bran-soybean-wheat noodle, respectively. The crude fat, crude fibre and ash values of *Musa spp*-wheat instant noodles ranged from 10.35 –14.74%; 0.40 – 0.88% and 1.09 – 1.17%, respectively. Increased addition of *Musa spp* flour as replacement for wheat in instant noodle production affected the crude fat, fibre and ash contents of the products significantly ($p < 0.05$).

Table 2: Proximate composition of *Musa spp*-wheat instant noodle

Sample	Moisture content, d.b (%)	Crude fat (%)	Crude fibre (%)	Ash (%)	Crude protein (%)	Carbohydrate (%)
0%NOD	$3.72^{a}\pm0.32$	$10.35^{f}\pm0.27$	$0.40^{f}\pm0.02$	$1.09^{c}\pm0.01$	$11.86^{a}\pm0.02$	$76.30^{a}\pm 0.25$
5%NOD	$3.78^{a}\pm0.41$	$10.79^{e}\pm0.24$	$0.44^{e}\pm0.02$	$1.09^{c}\pm0.01$	$11.37^{b}\pm0.12$	$76.32^{a}\pm0.14$
10%NOD	$3.88^{a}\pm0.38$	$11.13^{d}\pm0.10$	$0.55^{d}\pm0.01$	$1.12^{b}\pm0.01$	$10.81^{c}\pm0.03$	$76.20^{a}\pm0.50$
15%NOD	$3.95^{a}\pm0.26$	$12.82^{c}\pm0.06$	$0.70^{c}\pm0.02$	$1.13^{b}\pm0.01$	$10.43^{d}\pm0.01$	$74.92^{b}\pm0.10$
20%NOD	$4.02^{a}\pm0.35$	$13.97^{b}\pm0.07$	$0.83^{b}\pm0.02$	$1.15^{a}\pm0.00$	$9.96^{e}\pm0.08$	$74.08^{c}\pm0.14$
25%NOD	$4.05^{a}\pm0.29$	$14.74^{a}\pm0.05$	$0.88^{a}\pm0.01$	$1.17^{a}\pm0.01$	$9.46^{f}\pm0.05$	$73.67^{c}\pm0.09$

Values are mean ± standard deviation of triplicate

Values followed by the same letter in the same column are not significantly different ($p < 0.05$)

0%NOD = 100% wheat flour instant noodle; 5%NOD = 5% *Musa spp* flour + 95% wheat flour instant noodle; 10%NOD = 10% *Musa spp* flour + 90% wheat flour instant noodle; 15%NOD = 15% *Musa spp* flour + 85% wheat flour instant noodle; 20%NOD = 20% *Musa spp* flour + 80% wheat flour instant noodle; 25%NOD = 25% *Musa spp* flour + 75% wheat flour instant noodle.

The improved crude fat content may be as a result of the absorption of fat during frying. The crude fat results compared favourably with 11.1 – 18.4% documented by Sanni *et al.* (2004) for cassava-wheat instant noodle but higher compared with 5.3 – 6.25% and 4.98% documented by Taneya *et al.* (2014) for sweet potato-wheat instant noodle and Pakhare *et al.* (2016) for corn-tapioca-wheat instant noodle. In addition, the crude fiber results compared favourably with 0.2 - 0.8% and 0.54 – 0.58% documented by Sanni *et al.* (2004) for cassava-wheat instant noodle and Taneya *et al.* (2014) for sweet potato-wheat instant noodle, respectively; although, Pakhare *et al.* (2016) reported a higher crude fibre value (4.02) for corn-tapioca-wheat instant noodle. The ash content also compared favourably with 0.6 – 1.2% and 1.54% documented by Sanni *et al.* (2004) for cassava-wheat instant noodle and Pakhare *et al.* (2016) for corn-tapioca-wheat instant noodle but lower compared with 2.21- 2.44% documented by Taneya *et al.* (2014) for sweet potato-wheat instant noodle.

4.1 Cooking properties: The cooking time ranged from 3.40 – 4.38 min for the instant noodle samples with sample 25%NOD and 0%NOD having minimum and maximum values, respectively (Table 3). The values showed that as percentage of substitution of glutten-rich (wheat) flour with non-gluten (*Musa spp*) flour, there is reduction in cooking time of the instant noodle. This may be attributed to discontinuity within the gluten matrix, which resulted in weak dough properties (Manthey *et al*., 2004; Omeire *et al*., 2015).

Table 3: Cooking properties of *Musa spp*-wheat instant noodle

Sample	Cooking time, min	Cooking gain, %	Cooking loss, %	Moisture uptake, %	Fat uptake, %
0%NOD	4.38±0.01	183.55±2.11	5.51±0.01	9.79±0.55	9.37±0.32
5%NOD	4.17±0.01	173.78±1.78	6.31±0.01	10.27±0.81	9.94±0.51
10%NOD	4.06±0.02	173.68±1.83	6.31±0.01	10.7±1.09	10.01±0.23
15%NOD	4.09±0.01	173.45±1.21	7.19±0.02	11.16±0.95	11.17±0.64
20%NOD	3.48±0.01	169.68±1.56	7.65±0.02	11.59±0.27	12.47±1.02
25%NOD	3.40±0.01	168.11±1.97	7.61±0.01	12.01±1.02	12.82±1.17

Values are mean ± standard deviation of triplicate analysis

Values followed by the same letter in the same column are not significantly different ($p < 0.05$)

0%NOD =100% wheat flour instant noodle; 5%NOD= 5% *Musa spp* flour + 95% wheat flour instant noodle; 10%NOD = 10% *Musa spp* flour + 90% wheat flour instant noodle; 15%NOD = 15% *Musa spp* flour + 85% wheat flour instant noodle; 20%NOD = 20% *Musa spp* flour + 80% wheat flour instant noodle; 25%NOD = 25% *Musa spp* flour + 75% wheat flour instant noodle

There is significant difference ($p< 0.05$) in the instant noodles cooking time at all levels of substitution. The cooking time values of *Musa spp*-wheat instant noodle compared favourably with 3.11 – 4.77 min for breadfruit-konjac-pumpkin-wheat instant noodle; 4.5 – 8.29 min for plantain-wheat instant noodle and 4.3 – 5.41 min for corn-tapioca-wheat instant noodles (Purwandari *et al.*, 2014; Ojure and Quadri, 2012; Pato *et al.*, 2016) but lower than 5.6 – 6.6 min reported by Ritika *et al.* (2016) for malted and fermented cowpea-wheat instant noodle; 7.33 – 8.67 min for sago starch-wheat instant noodle (Purwani *et al.*, 2006); 7.30 min for defatted rice bran-soy- wheat instant noodle (Pakhare *et al.*, 2016) and 7.16 – 9.36 min reported for raw jackfruit-wheat instant noodle (Kumari and Divakar, 2017). The cooking gain values ranged from 168.11 – 183.55% with samples 25%NOD and 0%NOD having the minimum and maximum values, respectively. There is significant difference ($p<0.05$) among the instant noodles' cooking gain. The results obtained compared favourably with 120.7 – 160.3% reported by Ritika *et al.* (2016) for malted-fermented cowpea-wheat instant noodle but lower than 252 – 379% and 287 – 362% reported by Purwani *et al.* (2006) for sago starch-wheat instant noodle and Foo *et al.* (2011) for soy protein isolate-wheat instant noodle respectively. Cooking loss values ranged from 5.51 – 7.65 with samples 0%NOD and 20%NOD having lowest and highest values, respectively. The optimum solution (cooking loss of 7.03%) is found at barrel temperature of 100 °C and 85 rpm conveying shaft speed. The cooking loss results obtained compared favourably with 6.39 – 10.40% reported by Ojure and Quadri (2012) for cassava-wheat instant noodle but higher than 0.93 – 1.63% and 2.01 – 6.19% reported by Ritika *et al.* (2016) for malted-fermented cowpea-wheat instant noodle and Purwani *et al.* (2006) for sago starch-wheat instant noodle, respectively. Purwandari *et al*. (2014) reported that cooking loss of instant noodles from blends of breadfruit, konjac, pumpkin and wheat flours, ranged from 12.45 – 17.04%. These results are in the agreement with the study of Martinez *et al*. (2007) who reported that partial or complete substitution of durum wheat semolina with fibre material can result in negative changes to pasta quality, including increased cooking loss. The high cooking loss recorded by *Musa spp*-wheat instant noodle as substitution increases could be due to a weakening of the protein network by the presence of *Musa spp* (non-gluten protein) flour which allows more solids to be leached out from the noodles into the cooking water (Yu and Ngadi, 2004; Wu *et al.*, 2006). The moisture uptake ranged from 9.79 – 12.01% with samples 0%NOD and 25%NOD having minimum and maximum values, respectively. The fat uptake values ranged from 9.37 – 12.82% with samples 0%NOD and 25%NOD having lowest and highest values, respectively.

4.2 Sensory evaluation: The values of sensory attributes of *Musa spp*-wheat instant noodle are presented in Table 4. Overall acceptability of the instant noodle products ranged from 1.15 – 5.96% with products 0%NOD and 25%NOD having minimum and maximum values, respectively on a 7-point hedonic scale. There is decline in overall acceptability of the instant noodle from like moderately to dislike very much as percentage of substitution of wheat flour was increased in the formulation. The products 5%NOD and 10%NOD were slightly liked by the panelists but further decline in wheat flour percentage proportion in the formulation beyond 10% (w/w) led to dislike of the products by the panelists. The taste, colour and texture values of the *Musa spp*-wheat instant noodles ranged from 2.42 – 6.15%, 1.19 – 6.15% and 3.77 – 6.23%, respectively. The taste values showed that as the proportion of wheat substitution increased, the panelists' assessment of taste changed from being like moderately to dislike moderately. The panelists liked the taste of the instant noodle as the proportion of wheat flour replacement is not beyond 10% (w/w). Another important organoleptic property in instant noodle is colour because it influences purchasing decisions of its consumers. The panelists assessed the colour of the product 0%NOD as like moderately but as the inclusion of *Musa spp* flour into the instant noodle formulation.

Table 4: Sensory evaluation score of *Musa spp*-wheat composite flour instant noodle

Products	Taste	Colour	Flavor	Texture	Overall acceptability
0%NOD	$6.15^{a}\pm0.77$	$6.15^{a}\pm0.72$	$5.58^{a}\pm0.49$	$6.23^{a}\pm0.69$	$5.96^{a}\pm0.71$
5%NOD	$5.73^{b}\pm0.59$	$2.38^{b}\pm0.49$	$5.15^{b}\pm0.53$	$5.42^{b}\pm0.68$	$4.69^{b}\pm0.77$
10%NOD	$5.31^{c}\pm0.67$	$2.42^{b}\pm0.49$	$5.42^{ab}\pm0.68$	$5.27^{b}\pm0.81$	$4.39^{b}\pm0.49$
15%NOD	$4.23^{d}\pm0.57$	$1.62^{c}\pm0.48$	$3.50^{c}\pm0.50$	$3.96^{c}\pm0.71$	$2.08^{c}\pm0.73$
20%NOD	$3.19^{e}\pm0.62$	$1.50^{c}\pm0.50$	$3.39^{c}\pm0.49$	$3.62^{c}\pm0.56$	$1.58^{d}\pm0.49$
25%NOD	$2.42^{f}\pm0.49$	$1.19^{d}\pm0.39$	$1.73^{d}\pm0.59$	$3.77^{c}\pm0.42$	$1.15^{e}\pm0.36$

Values are mean ± standard deviation of triplicate

Values followed by the same letter in the same column are not significantly different ($p< 0.05$)

0%NOD = 100% wheat flour instant noodle; 5%NOD = 5% *Musa spp* flour + 95% wheat flour instant noodle; 10%NOD = 10% *Musa spp* flour + 90% wheat flour instant noodle; 15%NOD = 15% *Musa spp* flour + 85% wheat flour instant noodle; 20%NOD = 20% *Musa spp* flour + 80% wheat flour instant noodle; 25%NOD = 25% *Musa spp* flour + 75% wheat flour instant noodle increased, the panelists' assessment of the instant noodle changed to dislike very much. This showed that the colour of *Musa spp*-wheat instant noodle was not acceptable to the panelists. The instant noodle flavour was liked moderately by the panelists till 10% (w/w) substitution of wheat flour with *Musa spp* flour. Further increase in percentage proportion of *Musa spp* flour in the formulation made the panelists to dislike very much the instant noodle flavour.

4.3 Mechanical Properties of *Musa spp*-Wheat Instant Noodle: The force – deformation characteristics exhibited by *Musa spp*-wheat instant noodles at different levels of substitution under compressive loading is presented in Figure 2. For all levels of substitution, the deformation of *Musa spp*-wheat uncooked instant noodle increased with an increase in

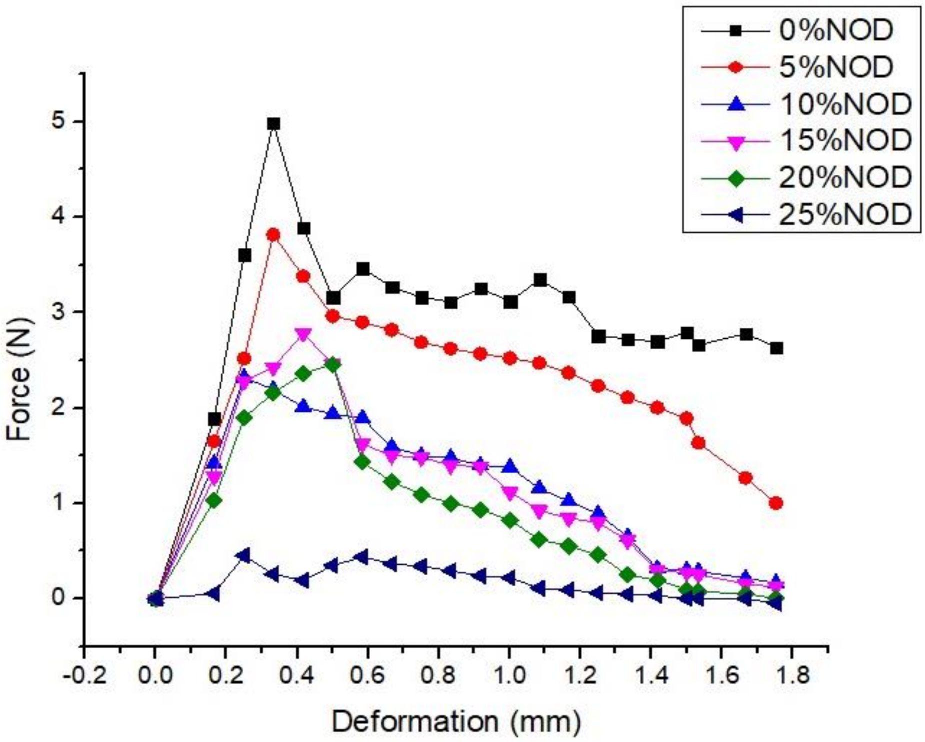

Figure 2: The force-deformation curve of uncooked *Musa spp*-wheat instant noodles

compressive force. Deformation decreased after rupture occurred in the samples and the compressive at this point was denoted as the bio-yield point or load at break (Gupta and Das, 2000). The force beyond the bio-yield point represented the force required to crush the instant noodle after rupture had occurred (Poulsen, 1978; Gupta and Das, 2000). As the levels of substitution increased, there was a fall in force – deformation characteristics curves of *Musa spp*-wheat instant noodles. The fall in force – deformation characteristics curves of the instant noodle correlate well with its yield stress of *Musa spp*-wheat dough. The fall in force – deformation curves of *Musa spp*-wheat instant noodle may be attributed to the weakening of the protein network by the presence of *Musa spp* (non-gluten protein) flour (Yu and Ngadi, 2004; Wu *et al.*, 2006). The texture parameters obtained from the force – deformation curves of *Musa spp*-wheat instant noodles thereafter investigated were bio-yield point or load at break, energy at break, tensile stress at break and maximum tensile stress. Figure 3 showed the texture parameters of *Musa spp*-wheat instant noodle. The bio-yield point or load at break ranged from 0.747 – 4.21 N. The values showed that as percentage of substitution increased, there was reduction in load at break due to the weakening of the protein network by the presence of *Musa spp* (non-gluten protein) flour (Yu and Ngadi, 2004; Wu *et al.*, 2006). The load at break is an indication of how the instant noodle strands resist breakdown (Seib *et al.*, 2000). It also gives an indication on how the noodles bind together during cooking reflecting the cooking tolerance and quality (Bhattacharya *et al.*, 1999). The energy at break of the instant noodle values ranged from 0.00054 - 0.0068 J. The values followed similar trend as bio-yied point values. It showed that as percentage of

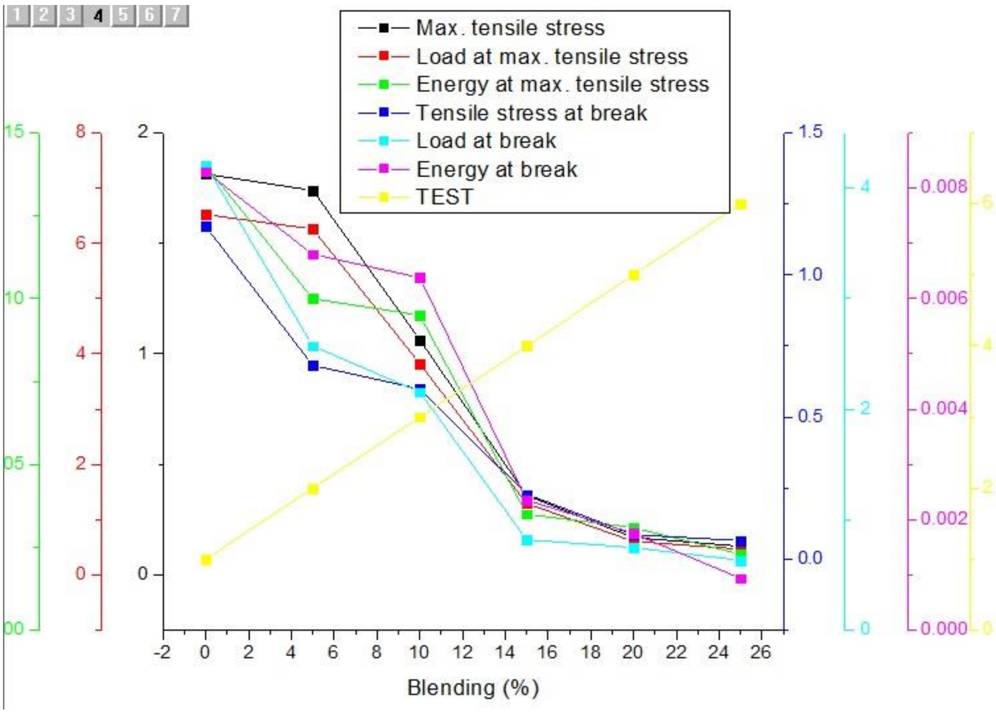

Figure 3: Mechanical properties of uncooked *Musa spp*-wheat instant noodle

substitution increased, there was reduction in energy at break of *Musa spp*-wheat instant noodle. The values showed that as percentage of substitution increased, less energy would be required by the noodle strands to resist breakdown. This is as a result of weakening of protein network by the presence of *Musa spp* flour in the instant noodle (Seib *et al.*, 2000). The energy at maximum tensile stress values ranged from 0.02 – 1.3 J. The values also followed energy at break pattern showing that increase in percentage of substitution reduced the energy at maximum tensile stress of the instant noodles. The tensile stress at break of the instant noodle values ranged from 0.130 – 1.81 MPa. The values also followed a similar pattern with bio-yield points and energy at break. The values showed that as percentage of substitution increased, there was corresponding decrease in tensile stress of the noodles. The tensile stress of the instant noodle correlated well with cooking loss of the noodle. The result obtained compared favourably with 0.113 – 0.158 MPa reported by Chen *et al*. (2002) for sweet potato-wheat noodles.

5. CONCLUSIONS

The proximate and cooking properties of *Musa spp*-wheat instant noodle decreased as percentage of substitution with *Musa spp* flour increased. All the sensory attributes of *Musa spp*-wheat instant noodle were assessed above average except colour. Colour being one of the major factor for consumers' choice affect panelists' acceptability of the instant noodle. The optimum percentage of substitution in *Musa spp*-wheat instant noodle is 10% as further increase in substitution affected panelist acceptability. The production of a *Musa spp* based food product like instant noodle promises value addition to the crop while abating the associated post-harvest losses.

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Design, Fabrication and Performance Evaluation of Palm Kernel Nut Cracking Machine

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ABSTRACT

Palm kernel oil production is an important cottage industry that involves rural women. Most of these women still crack their nuts with stones which often takes time and injurious. Thus, for improved productivity, a palm kernel nut cracking machine was designed, fabricated, and evaluated. It consists of hopper, control shuttle, cracking chamber and discharge outlet, discharge for the chaff of the kernel and the blower. A 7.5hp electric motor was used to operate the machine. The components of the kernel nut cracking machine were designed and constructed from locally available materials. The palm kernel nut cracker was evaluated at shaft speeds of 1200, 1480, and 1850 rpm. Three repetitions were carried out and the means were used to evaluate the throughput capacity, feed rate, palm kernel nut damage and efficiency. The machine has throughput capacity of 480kg/hr, kernel damage of 7.0% and an overall efficiency of 73.9%; both moisture content and rotor speed had significant effect on the crack-ability of the palm nut. Dominant physical properties found to influence nut cracking were rotor speed, nut size, and nut variety.

Keywords: Design, Construction, Performance, Evaluation, Palm Kernel, Nut, Cracking, Machine, Nigeria.

1. INTRODUCTION

The Oil Palm tree (*Elaesis guineensis*) is a great economic asset. The fruit of the oil palm is well known for its economic importance and nutritive values. It bears its fruits in bunches which vary from 10 to 40kg. The individual fruit ranging from 60 to 70g and made up of outer skin (exocarp), a pulp (mesocarp), which contain the palm oil in a fibrous matrix, a central nut consisting of a shell (endocarp) and the kernel which itself contain an oil that is quite different from palm oil, but resembles coconut oil (FAO, 2004). The byproduct after the extraction of palm kernel oil can also be used as a substitute for cocoa butter and palm kernel cake, animal feed, soap, candle and variety of industrial used. Harvested palm bunches undergoes processing stages of sterilization, striping, digestion and palm oil extraction, palm nuts and fibres as residue. The nuts are dried and cracked into palm kernel and shell. The rate of vegetable oil consumption is increasing compared to animal fat due to its health implication. The industry is challenged by demands of high quality products at reduced prices. Importance of oil crops as a vital part of the world's food supply was envisioned in world agricultural trade statistics. In 2007, the value of world trade in oil seeds and oilseed products was estimated to be $ 83 billion, equivalent to 13% of the total agricultural trade and it was the third most valuable component in total world agricultural trade, next to meat and cereal (FAO, 2008), This report further revealed that palm kernel oil accounted for 4.7% of the total value.

A palm fruit consists of the pulp and the nut (shell and kernel). Palm oil is extracted from the pulp and the kernel oil from the kernel. The processes involved in palm kernel oil production are: drying of the nut after removal of pulp during palm oil production, cracking of the palm nut, toasting of the kernel, milling of the toasted kernel and pressing of the milled product to obtain the oil.

According to Adebayo (2004), current locally manufactured centrifugal nutcrackers are used for the cracking step. Although, this has improved productivity, the process has a number of deficiencies which include, breaking of kernels in the course of cracking too many which may be due to insufficient drying of nut as well as high rotor speed. Inappropriate spacing of the impactors (blow bars) may also result in a number of un-cracked nuts in the finished product as well as the feeding rate of the nut into the cracking chamber (Ofei, 2007). Kernel breaking also results partly because the kernel upon release from the nutshell rebound in the cracking chamber and is subjected to secondary impacts which induce breakage. The interaction between the adjacent nuts may obstruct the direct impingement of the individual nut to the cracking wall, so that some of the nuts are discharged un-cracked (Koya, 2006). It was reported by Poku (2002) that the level of free fatty acids (FFA) is higher in broken kernels than in whole kernels, therefore breaking of kernels should be kept as low as possible.

Kernel oil production is an important cottage industry that involves rural women. If the production is carefully engineered, the product could compete internationally thereby increasing the foreign exchange base of the country and offering employment to the youth especially women.

1.2 Objective

The objective of this project is to design, construct, and evaluate a palm oil cracking machine.

1.3 Statement of Problem

In the existing cracking machines, the different sizes of nuts were not put into consideration. When a mixture of different nuts is fed into the cracking machines some are too small or too big to crack which is the major reason for the low efficiency of the machine.

1.4 Scope of study

This project entails the production of a mechanical nut cracker by multiple impacts from spontaneous bouncing on the nut. This involved determination of the physical properties of the palm kernel nut viz: size and shape of the nut, and mass of the nut. The results of the physical properties were used in the design and fabrication of the nut cracker. Performance evaluation of the machine was carried out to determine the throughput capacity, feed rate, and efficiency of the machine.

2. LITERATURE REVIEW

2.1 Kernel Crackers and Shell Separation

Removal of kernel from its shell basically involves cracking and separating processes. There are two widely methods commonly used for these processes.

a. Manual (traditional) method and
b. Mechanical method

2.2 Manual (or traditional) method

The manual method of palm nut processing is the traditional way of cracking and separating palm kernel. It is a typical business venture for local youth and old women in the villages in which nuts are cracked using stones and kernel separated by hand picking from the shell at the same time. This method is labour intensive, time consuming, cumbersome, and very slow to meet demand of growing industry (Badmus, 1990).

2.3 Mechanical method

Palm nut cracking machine are developed on the principle of hurling of the palm nuts at a fairly high speed against a stationary hard surface (Okoli, 1997).

There are two basic mechanical effects that can be used to crack the shell of the nut. The shock caused by an impact against a hard object and the application of direct mechanical pressure to crush, cut or shear through the shell. Generally two types of nutcrackers are used in palm mill; roller cracker and centrifugal impact cracker.'

2.4 Roller cracker

In rollers cracker the mites cracked in between the two fluted rollers revolving in opposite directions. The clearance between the rollers is invariable but the nuts are of different sizes, which make the machines to be operating at reduced efficiency.

2.5 Centrifugal impact cracker

This uses the principle of centrifugal force to flap the palm kernel nuts on the stationary hard surface. This method involves using a shock caused by an impact against hard object to shear, crush or cut through the shell (Badmus, 1990).
The nut is fed into the hopper and it falls into the housing where a plate attached to the rotor is rotating. According to some researchers shelling has always posed a major problem in the processing of bio material and they attributed this to the shape and the brittleness of the kernel, rendering them susceptible to damage.

Ndukwu and Asoegwu (2010) designed a centrifugal palm nut cracker prototype testing model. The palm kernel cracker is powered by 1600 kW electric motor and operates with centrifugal action. It consists of a conical shaped hopper that opens up into a cylindrical cracking chamber with a force-fitted mild steel cracking ring. A vertical-shaft is fitted into the cracking chamber from the bottom and is attached to a channel for directing the palm nut falling on it. The centrifugal action of the shaft flings the nut on the cracking ring with the nut cracking on impact. The process has a number of deficiencies because different sizes of nuts were not put into consideration.

Jimo and Olukunle (2013) designed an effective automated machine for quality palm kernel production, with an efficiency of 99% and throughput capacity of 625 – 1270kg/hr. The performance evaluation was done on two varieties of the palm kernel, Dura and Tenera. Adebayo (2004) developed a machine with a efficiency of 98% with processing rate of 95 nuts per seconds, this is an improvement over existing ordinary palm kernel machine that has efficiency of 90% with processing rate of 87 nuts per second without separation.

Mechanical method will only crack the nuts and leave the product as a mixture of shells and kernels, which needs to be separated before it can become a useful product. Picking by hand is too cumbersome at this stage; the separation process is done by a pot containing vicious mixture of water and clay. The purpose of the clay is to aid the shells to sink while the kernels float on top of the water – clay mixture. This method consumes a lot of time in washing and drying the kernel and makes the palm kernel to be liable to quick infection of fungal thereby reduces the quality of oil produced. Another mechanized west method of separation is the hydro-cyclone where the principle of flow resistance is applied (Oguma *et al.*, 1993). This method of separation has wide industrial application but is capital intensive.

At present, most of research work is tailored into modeling of the variables which determine the functionality of processing machines. Most of these models are specific and related to a particular design of a machine, which implies that the functional parameters need to be established. Most of the data of kernel crackers are generalized. A search through the literature shows that literature on centrifugal palm nut cracker is very scarce. Therefore, the present study is undertaken to identify the parameters that affect the efficiency of the palm nut cracker at different operating conditions and their inter-relationships, and will serve as a guideline for further research and designs. Base on this, an experiment was carried out to determine the average mass, moisture content, strength and coefficient friction of the shell and kernel to aid in the design and fabrication of the machine.

3. MATERIALS AND METHODS

3.1 Materials

The following apparatus was used in the experiment: electronic balance, vernier caliper, set of standard sieve series, set of Canadian sieves series with 16, 19, 22.5 and 25mm apertures, pins, standard masses, flexible cord, meter rule, Scissors, retort stand and palm kernel of different sizes.

3.2 Method

3.2.1 Sample preparation

Two varieties of the oil palm have been established to be useful in palm oil and palm kernel processing namely Dura and Tenera, The Dura variety was used in this work and were obtained from the market. The mesocarps (pulp) were scraped off to expose the shell to open drying and since we are working with the *Dura* variety, it became necessary to characterize the nuts with a view to understanding the properties that may affect the design of machines to handle the processing of the nuts.

3.2.2 Determination of physical properties

The following properties were determine; size, sphericity, mass, strength, thickness of shell, coefficient of friction for both shell and kernel with respect to steel.

3.2.3 Determination of size

From the sample, 50 fruits of Dura variety were selected at random for determining the physical axial characteristics. For each nut, three linear dimensions were measured, that is length (L), width (W), and the thickness (T) using a Mitutoyo digital vernier caliper-150mm-0.01mm, model-500-196.

3.2.4 Determination of shape

The size and shape of palm kernels are important in the design of hoppers, press auger, and press barrel for efficient oil extraction using the screw press. They are also important in the design of grading or separating equipment.

The sample was passed through a set of Canadian standard sieve series (WS Tyler Model) with 16mm, 19mm, 22.5mm, and 25 mm apertures to grade the nuts. This was done so that, in the experiments, impact force may be related to nut sizes. The nut shape was expressed in terms of its sphericity index which expresses the shape character of the nut relative to that of a sphere of the same volume. It was assumed that the volume of the solid is equal to the tri-axial ellipsoid with intercepts *L*, *W*, *T*, and the diameter of the circumscribed sphere is the longest intercept *L* of the ellipsoid. For the sphericity index ɣ, the dimensions obtained for the 50 palm nuts selected at random were computed ((Mohsenin, 1986; Orji, 2001; Olukunle and Atere, 2011) as

$$\text{ɣ} = \frac{GMD}{L} \quad . \qquad (1)$$

Where;

$GMD = (LWT)^{1/3}$ is the geometric mean diameter in mm and L, W, T is the length, width and thickness of the nut in mm.

3.2.5 Determination of nut mass and strength

The mass of individual nut of each *Dura* nuts were determined by using an electronic balance (Tanita 1479V - China) with an accuracy of 0.01 g. Measurements were made in the nut's natural position and was replicated 50 times.

The ultimate strength of the palm kernel nut was determined by weight of fall from varying elevated height on palm kernel until the weight actually cracked the kernel by cutting cord with scissors.

3.3 Description of the machine

The palm kernel nut cracker machine consists of the following components: hopper, cracking chamber, horizontal shaft with beaters, discharge outlet, main frame and prime mover. It also has an electric motor which powers the machine with the aid of belt and pulley arrangement. Figure 1a and 1b shows the orthographic and pictorial view of the machine

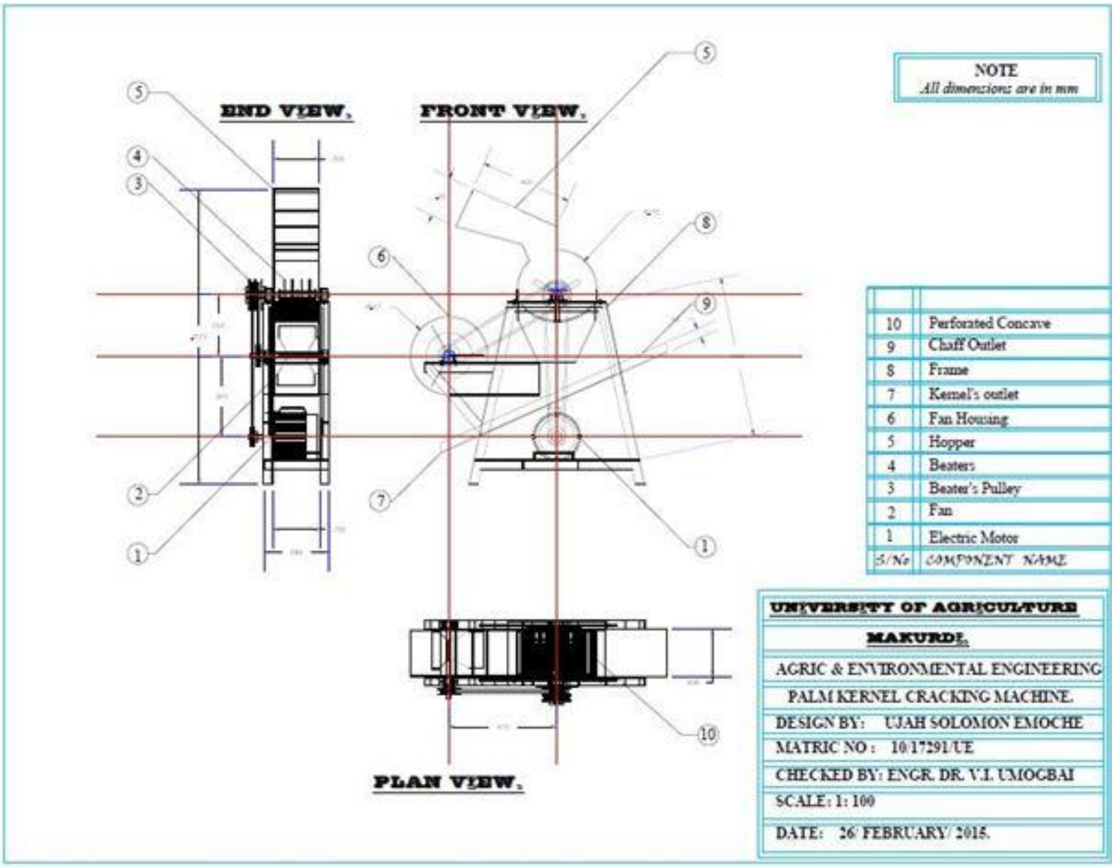

Figure 1a Orthographic projection of the Palm kernel nut cracking machine

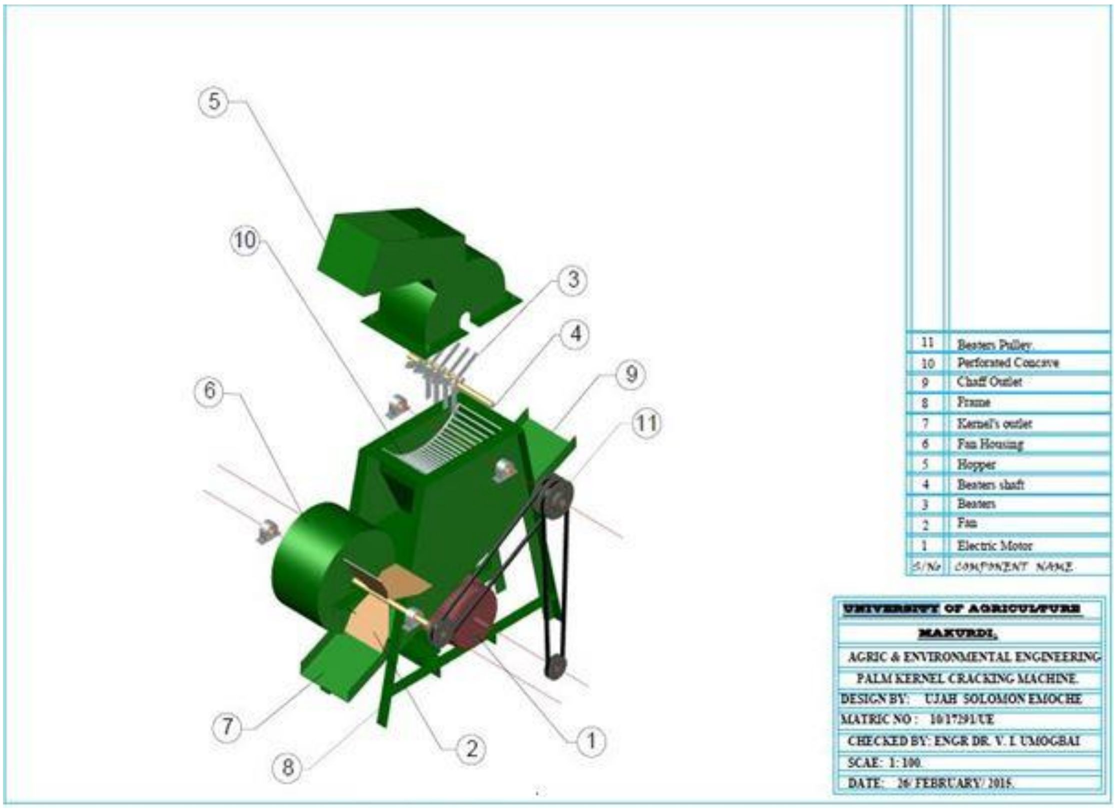

Figure 1b Pictorial view of the Palm kernel nut cracking machine

3.3.1 Operation of the Machine

The nuts are either fed into a slot on a rotor turning at a very high speed or are fed into a cracking chamber where they are impacted upon by metal beaters turning at a high speed which throws the nuts against a cracking ring. The speed is adjusted for acceptable cracking efficiency. The nuts impinge the wall at random orientations but with repeated impact due to bouncing until they are cracked and discharged.

3.4 Design Calculations

3.4.1 Feed rate

This is the time taken to completely empty the nut into the cracking chamber. The feed rate was calculated as the mass of the palm kernel per unit time taken to empty the palm nut into the cracking chamber.

$$\text{Feed rate} = \frac{WT}{t} \qquad (2) \qquad \text{(Ologunagba, 2012)}$$

Where;

WT = weight of the palm kernel that filled the hopper (kg), t = time taken to empty the whole palm kernel into the cracking chamber (kg)

Calculated Feed rate = $\frac{8}{0.01455}$ = 481kg hr $^{-1}$

3.3.2 Feed hopper

The feed hopper has an input opening of 400mm diameter, bottom opening of 60mm and a side length of 180mm that is incline at 75^{o} (angle greater than the dynamic angle of repose of the material on mild steel sheet) to ensure the easy flow of mixture into the cracking chamber.

3.4.3 Power requirement

The power requirement of the machine was determined with the expression by Khurmi and Gupta (2005).

$$p = \frac{2\pi nT}{60} \quad (3) \quad \text{(Khurmi and Gupta, 2005)}$$

Where;

P = power (Watt), n = shaft speed (rpm) and T = torque required to turn the shaft at the circumference of the driven pulley (Nm).

Power required to drive the shaft = 7.833 KW

Assuming, 10% power loss due to friction, total power required = 8.62 KW

Therefore, an electric motor of 10 KW (7.5hp) was selected.

3.4.4 Pulley and belt drive

The mechanisms and systems in the machine are driven through the V- belt and pulley arrangement with the impeller shaft taken its drive directly from 10KW electric motor of 1840 rpm speed. With the power rating, a belt of type-A cross-sectional symbol was selected (PSG Design Data, 1982)

Calculated belt speed, S= 4.8 m/s

3.4.5 Calculation of torque acting on the shaft

Pulley motor rated horse power = 7.5 Hp

Power required = Design horse power x 0.746 KW

=10.5 x 0.746 = 7.833KW

$$\text{Torque} = \frac{Power\ transmitted}{2\pi N} \quad (4) \quad \text{(Khurmi and Gupta, 2005)}$$

Where N = Shaft speed rpm

Torque M_t = $\frac{7.833 \times 1000 \times 60}{2 \times \pi \times 1000}$ = 39.37 Nm

3.5 Shaft Design Consideration

The shaft is a cylindrical with circular cross sections, with impeller blades, pulley and bearings mounted on it. The shaft will be subjected to fluctuating torque and bending moments, and therefore combined shock fatigue factors are taken into account. To determine the shaft diameter, the equivalent bending moment, M_c is used

$M_c = {}^{1}/_{2}[(Km \times M) + \sqrt{(K_m + M)^2 + (K_t \times T)^2}]$ (5) (Khurmi and Gupta, 2005)

Where;

M = maximum bending moment (Nm), T = maximum torsional moment (Nm), K_m = Combined shock and fatigue factor for bending, K_t = Combined shock and fatigue factor for torsion

Belt tension F_b = 787.4N

Weight of pulley =50 N

Estimated distributed load =120 Nm^{-1}

Force at A =787.4 + 50 =837.4 N

Force at E (weight of impeller blade) = 650 N

$R_b + R_d$ = 837.4 + 122.4 + 650 =1609.8 N

Taking moment about B

R_D x 1.2 + 837.4 x 0.1125 =122.4 x 0.6 + 650 x 1.3125

$R_D = \frac{832.36}{1.2}$ = 693.63 N

3.5.1 Shear forces acting on the shaft

The shear forces on the shaft were calculated as follows;

Taking downward force to be negative (-) and the upward force to be positive (+).

For point A = - 837.4 N

For point B = - 837.4 + 916.17 = 78. 77 N

For point C = 78.77 – 122.4 = - 43.63 N

For point D = - 43. 63 + 693.63 = 650 N

For point E = 650 – 650 = 0 N

3.5.2 Bending moments in a shaft

Also, the bending moments were analyzed as follows:

M_A = 837. 4 x 0 = 0.

M_B = 837.4 x 0.1125 – 916.17(0.1125 – 0.1125) = 94.21 Nm.

M_C = 837.4 x 0.7125 – 916.17 x (0.7125 – 0.1125) + 122.4 x (0.7125 – 0.7125) = 46.95 Nm

M_D = 837.4 x 1.3125 – 916.17 x (1.3135 – 0.1125) + 122.4 x

(1.3125 – 0.7125) = 73.12 Nm

MD = 834.4 x 1.425 – 916.17 x (1.425 – 0.1125) + 122.4 x (1.425 – 0.7125) - 693.63 (1.425 – 1.3125) = 0

The shear force and bending moment diagram were presented in the figure 2 below

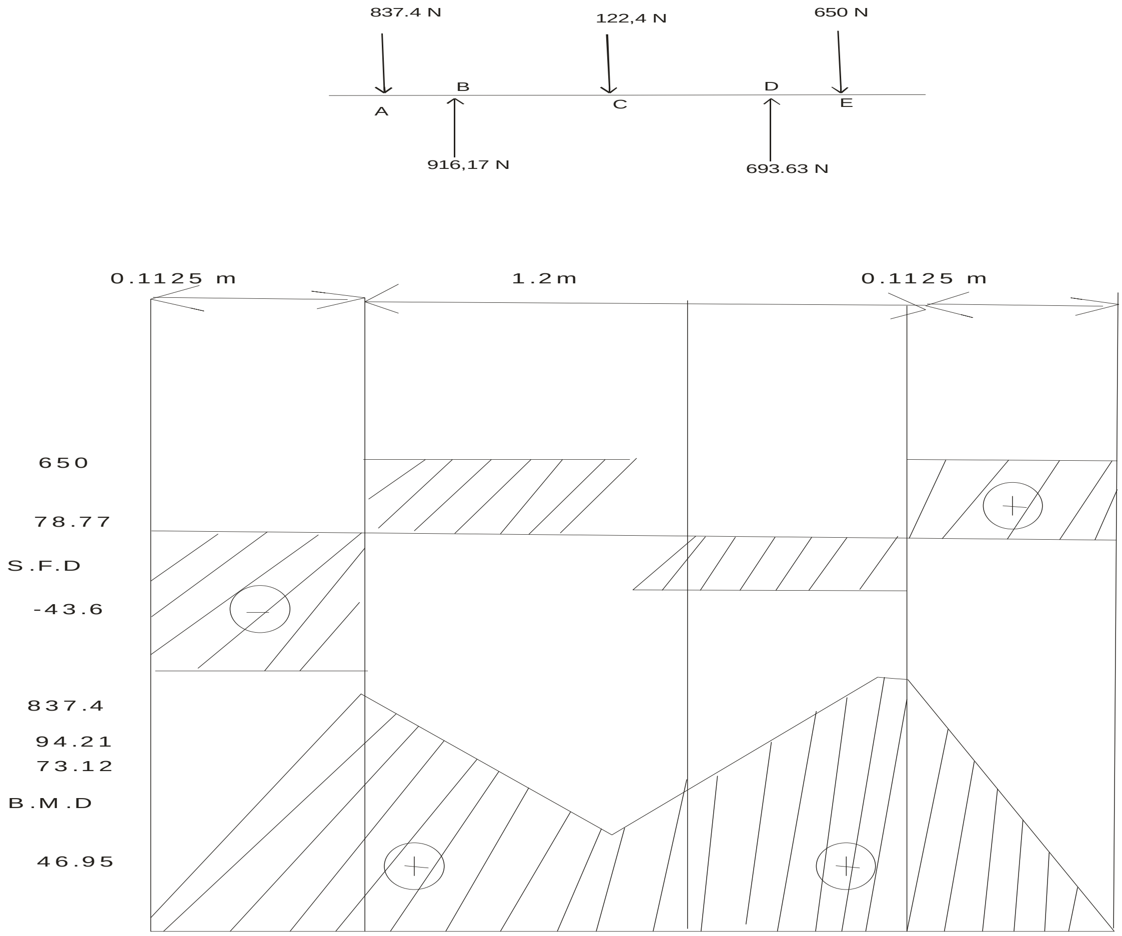

Figure 2 Shear force and bending moment diagram of the drive shaft

3.5.3 Diameter of the shaft

Choosing shaft material of 0.26 carbon steel (BS 070m26) cola drawn with maximum permissible working stress, σ_b = 84MPa (ASME CODE – Khurmi *et al.*, 2005).

The maximum bending moment $M_{max} = M_B$ = 94.21 N

Using equivalent bending moment M_c we have:

Torque = 39.35 x 10^3 Nmm

$$M_C = \frac{1}{2}\left[(K_M \times M_B) + \sqrt{(K_m \times M_B)^2 + (K_t \times M_t)^2}\right] \quad \textbf{(ASME Code)} \qquad (6)$$

Where $K_m = 1.5$, $K_t = 1.0$

$$Mt = {}^{1}/_{2}[(1.5 \times 94.21 \times 10^3) + \sqrt{(1.5 \times 94.21 \times 10^3)^2 + (1.0 \times 39.35 \times 10^3)^2}]$$

$= 143 \times 10^3 Nmm^{-2}$

Also,

$$M_C = \frac{(\pi \sigma_b d^3)}{32} \quad (7)$$

Thus $d = [\frac{(32 \times M_C)}{\pi \sigma_b}]\frac{1}{3} = [\frac{32 \times 143 \times 10^3}{\pi 84}]\frac{1}{3} = 26$ mm

As standard, 30 mm diameter shaft was chosen

3.5.4 Determination of shaft life

The following mathematical relations are used in the determination of the life of the shaft:

$$N_L = \frac{10^{\frac{b}{m}}}{Sr^{\frac{1}{m}}} \quad (8)$$

Where; N_L = Shaft life, S_f = Fatigue strength. M and b are constants to be determined; thus

$$m = \frac{{}^{1}/_{3}\log(0.9S_{ut})}{S_C} \quad (9)$$

$$b = \frac{\log(0.9S_{ut})}{S_c} \quad (10)$$

Substituting S_{ut} = 430 MPa, S_c = 98.98 MPa, M = 3.1975 and b = 3.1802

$N_L = 443 \times 10^8$ Cycles

3.5.5 Force required cracking palm nut (F)

The cracking strength of the palm kernel as determined from an experiment was 1423.25 N m^{-2}

$$F = A \times S \quad (11)$$

Where A = area of the kernel cracking = 0.00084m^2, S = cracking strength = 1423.25 N m^{-2}

Force required F = 1.28N

3.6 Selection of the Materials for the Various Components of the Machine

The criteria for material selection of the materials for the various components of the machine are based on following:

1. The type of force that will be acting on them
2. The work they are expected to perform
3. The environmental condition in which they will function

4. Their useful physical and mechanical properties
5. Cost, toxicity of materials and their availability in the local market or the environment (Cornish, 1991).

The table below shows the materials selected for the design, the criteria considered, properties, specification and other comments.

Table 1 Material selection for the design

SN	Component	Material selected	Selection criteria	Properties, specification and comments
1.	Shaft of the machine	mild steel of 0.26% carbon	Easy machinability, local availability, non-toxicity and its strength	it is cold drawn with yield strength, Q_y of 230 MPa, a maximum permissible working stress, Q_b = 84 MPa and permissible tensile stress Q of 56 MPa Overall length = 1425 mm and the Diameter = 30mm
2.	Pulley of the machine		cheap and affordable, resistant to heat and wear and ease of machining	Recommended pulley pitch diameter = 75 mm
3.	Belt	Tanned leather V-belt	It is of high efficiency, resistant to static oil and heat, soft, flexible and strong	Belt of type-A cross-sectional symbol
4	Impeller blades	Mild steel	Non-poisonous, not easily worn out, ease of machining and strong	Breath = 80 mm, Radius = 120 mm, thickness = 10 mm

5	Base of machine	Mild Steel (Equal angle section)	Locally available and is of high carrying capacity	Overall dimension (7300 x 5mm)
6.	Feed hopper	Mild steel plate	Easy Fabrication and non-toxicity	Overall dimension (450 x 900 x 6mm)
7.	Cracking drum	Mild steel plate	Non-toxicity, not easily worn out, strong and easy fabrication.	Overall dimension (1150 x 200 x 10mm)
8.	Bearings	Stainless steel	High tensile strength	All Bearing (6306)

3.8 Evaluation Test Procedure

A total of 72kg of palm nuts was acquired for the performance test. Prior to cracking, the nuts were dried to a moisture content of 9% (db) to liberate the kernel from the shell. 8kg of nuts was used for each test. The machine was tested at speeds of 1200, 1480 and 1850 rpm of shaft

After each operation, the quantity of cracked and un-cracked palm nuts, damaged and undamaged kernel were sorted out and weighed. Each experiment was carried out in 3 replicate and the average calculated for the determination of cracking efficiency, feed rate, and through put capacity, under each variety.

After cracking, each nut was examined and categorized as either:

1. Fully cracked (FC) in which case the kernel was whole and free of shell attachments.
2. Partially cracked (PC) meaning that there are some shell adhering to the kernel
3. Split and loosely attached (SLA) in this case the kernel was cracked and split into two or more parts but free of any shell attachment.
4. Not cracked (NC) in which case the nut was not cracked at all.

These following formulae were used to calculate the parameters investigated;

Feed rate, Fr is express as

$$Fr = {}^{Wt}/_{t} \qquad (12)$$

Through put capacity Ct

$$C_t = \frac{WT}{Td} \qquad (13)$$

Functional efficiency E_F

$$E_F = \frac{Wcc}{WLO} \times 100 \qquad (14)$$

Where:

W_t = Weight of palm nut that fill the hopper (kg), t = Time taken to empty the whole palm nut into the hopper (hr), W_T = Total weight of palm nut fed into the machine (kg), T_d = total time take for the crack mixture to leave the discharge outlet (hr), Wcc = weight of completely cracked nut (Kg), W_{Lo} = weight of kernel for each loading (kg)

4. RESULTS AND DISCUSSION

4.1 Results

The results from the analysis were presented and are discussed as follows.

Table 2 Summary of physical properties of nut samples

Sieve size property	Measurement for Nut particle on sieve size			
	16mm	**19mm**	**22.4mm**	**25mm**
Dura Variety				
Axial Dimensions, mm				
Length, L	24.46(5.73)	26.89(6.35)	33.58(5.97)	33.66(7.22)
Width, w	17.01(2.32)	18.47(2.21)	22.89(3.69)	24.74(3.95)
Height, T	13.35(2.52)	15.25(2.73)	19.11(3.19)	19.80(4.83)
Geometric mean diameter, mm	17.20	19.01	23.48	24.22
Sphericity	0.73	0.72	0.72	0.75
Averages mass, g	2.60	4.62	7.19	9.83
Shell thickness, mm	2.80	4.20	4.20	4.90

Table 3 Results of design calculations

Volume of hopper	4320m^3
Shaft diameter	30mm
Torque action on shaft	39.37 Nm
Shaft life	443 x 10^8 cycles
Power requirement	10 kw (7.5 hp)
Shaft speed	173.74 rad s^{-1}
Force required to crack palm nut	1.28 N

Table 4 Results of cracked kernel cracked at 1200 rpm

S/N	Mass of kernel (kg)	Time taken (sec)	Mass of nut put (kg)				Nut damage (%)
			FC*	PC	SLA	NC	
1	8	78	3.1	0.4	1.6	3.0	16
2	8	78	3.6	0.8	1.3	2.2	13.2
3	8	78	3.5	1.0	1.5	2.0	15

*Legend: FC – Fully Cracked, PC – Partially Cracked, SLA – Slightly Cracked, but Loosely Attached, NC – Not Cracked

Table 5 Result of cracked kernel cracked at 1480 rpm

S/N	Mass of kernel (kg)	Time taken (sec)	Mass of nut put (kg)				Nut damage (%)
			FC*	PC	SLA	NC	
1	8	58	6.0	0.53	1.06	0.4	9.0
2	8	60	5.87	0.8	0.67	0.4	6.7
3	8	57	5.86	0.82	0.68	0.42	6.8

*Legend: FC – Fully Cracked, PC – Partially Cracked, SLA – Slightly Cracked, but Loosely Attached, NC – Not Cracked

Table 6 Result of cracked kernel at 1850 rpm

S/N	Mass of kernel (kg)	Time taken (sec)	Mass of nut put (kg)				Nut damage (%)
			FC*	PC	SLA	NC	
1	8	52	4.8	0.8	2.0	0.3	20.0
2	8	53	5.0	1.0	1.1	0.8	10.1
3	8	50	5.3	1.2	1.0	0.5	10.0

*Legend: FC – Fully Cracked, PC – Partially Cracked, SLA – Slightly Cracked, but Loosely Attached, NC – Not Cracked

Table 7 Cracking kernel at different rpm

	1200rpm	1480rpm	1850rpm	P-Value
FC**	3.40 ±0.15^{c}	5.91±0.05^{c}	5.03±0.15^{b}	0.001
PC	0.73±0.18^{c}	0.72±0.09^{a}	1.00±0.11	0.311
SLA	1.47±0.09^{b}	0.80±0.13^{a}	1.37±0.32^{a}	0.121
NC	2.40±0.31^{a*}	0.41±0.01^{b}	0.53±0.15^{b}	0.001

*Means in the same column with different superscript differ significantly (P>0.05)

**Legend: FC – Fully Cracked, PC – Partially Cracked, SLA – Slightly Cracked, but Loosely Attached, NC – Not Cracked

Table 8 Cracking efficiency and throughput capacity at different rpm

	1200rpm	1480rpm	1850rpm	P-Value
%Nut damaged	14.73±0.82[a]	7.50±0.75[b]	13.37±3.32[ab]	0.030
Cracking efficiency	42.07±0.03[c]	73.90±0.58[a]	62.93±0.03[b]	0.001
Throughput capacity	391.60±0.06[c]	493.83±0.09[b]	557.73±0.03[a]	0.001

Means in the same column with different superscript differ significantly (P>0.05)

Table 9 Results of cracking efficiency and throughput capacity at 1200, 1480 and 1850 rpm.

Shaft speed (rpm)	1200	1480	1850
Cracking efficiency (%)	42.1	73.9	62.9
Throughput capacity (kg/hr)	391.7	493.8	557.7
Kernel damage (%)	14.7	7	10.1

4.2 DISCUSSION

The results of the physical properties of nut sample shows that the average sphericity of Dura variety was found to be 73.0% as shown in Table 2. The high sphericity of the palm nut is indicative of the tendency of the shape towards a sphere. The results provide support for differential cracking of palm nuts based on nuts sizes. Otherwise, some nuts will experience excessive impacts with attendant kernel breakage, while some will be discharged without cracking.

The results of design calculations presented in the Table 3 are the calculated useful parameters used in the fabrication of the machine. This shows that the hopper has a volume of $4320 m^3$, a shaft speed of 173.74 rad/s^{-1} with a shaft life of 443 x 10^8 cycles and a pulley diameter of 30 mm.

The results of cracked kernel cracked at speeds of 1200, 1480 and 1850 rpm are presented in Table 4 to Table 6 with their means shown in Table 7. The means of the machine at different speed as presented in Table 8 shows that the efficiencies of the machine operated at different speed of 1200, 1480, 1850 rpm produced different values. However, operating the machine at the speed of 1480 rpm gave a better result with 73.9%, 493.8kg/hr, 7 % as the cracking efficiency, throughput capacity and palm kernel nut damage respectively, as seen in Table 9.

Furthermore, the evaluated result showed that the throughput capacity increased with increase in shaft speed at the same condition. Both moisture content and rotor speed had significant effect on the crack-ability of the palm nut.
Dominant physical properties found to influence nut cracking were rotor speed, nut size, and nut variety. The figure 3 below shows the pictorial view of the fabricated work.

Figure 3 Pictorial view of the fabricated work.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the result obtained on this study, it could be concluded that:

i. Operating the machine at the speed of 1480 rpm gave a better result with 73.9%, 493.8kg/hr, 7 % as the cracking efficiency, throughput capacity and palm kernel nut damage respectively.
ii. Both moisture content and rotor speed had significant effect on the crack-ability of the palm nut.
iii. Dominant physical properties found to influence nut cracking were rotor speed, nut size, and nut variety.

5.2 Recommendation

From the result obtained, the following recommendation can be made;

i. Based on the output and efficiency, the machine is recommended for small and medium scale farmers.
ii. The machine must be installed on reinforce concrete to reduce noise and vibration.
iii. Collector should be constructed to the discharge opening to limit the splashing of cracked nut.

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Recent Advances in Solar Drying of Agricultural Produce in Nigeria: NSPRI Experience

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ABSTRACT

Agricultural products are dried to enhance storage stability, in order to reduce post harvest losses, minimize packaging requirement and reduce transport weight. Crop drying through the sun is the most common practice in the country due to its no energy cost but often result in poor quality, unhygienic and contaminated products. This has been a major threat to food safety. Energy consumption and quality of dried products are critical parameters in the selection of drying process. An optimum drying system for the preparation of quality dehydrated products is supposed to be cost effective with less drying time and damage to the product. To reduce the energy utilization and operational cost as well to further produce high quality safe products, new trends in solar drying system were developed by the Nigerian Stored Products Research Institute (NSPRI) in order to proffer solutions to the threat in food safety as well as farmers and processors quest for drying with minimal energy cost. The technologies include mobile solar tent dryers, green house solar tent dryers and parabolic solar tent dryers. These entire dryers have great scope for the production of quality dried products and powders. These advancements have taken the advantage of material selection, design calculations to improve on the technology in order to achieve quality output in terms of environmental parameters and product quality. The advancement has also taken care of times of low solar irradiance especially during the rainy season which is highly humid. The temperature range obtained from the mobile, green house and parabolic solar dryers are 20 – 59.5°C, 21.5 - 68°C, and 25-78°C respectively while their respective average relative humidity are 71.64%, 60.21%, 49.77%. The ambient temperature range and relative humidity are 20 – 42.5°C and 74.88%. Experimental studies on the performance of the varied solar tent dryers were conducted using Chilli Pepper, Yam, Meat, Fish, Vegetables and plantain have been carried out the Beef meat, Chilli pepper and

Telefeiria occidentalis vegetable were dried in the mobile solar tent dryer, greenhouse solar dryer and parabolic solar dryer. The beef of 71.243% initial moisture content was dried to 12.15%, 12.01% and 10.09% in the aforementioned respective dryers within a period of 5 days. Also, the chilli pepper of 89.40% initial moisture content was dried to 12%, 11.3% and 9.3% moisture content respectively in the dryers within a period of 8 days; while the Telefairia Occidentalis vegetable of 11.0% initial moisture content was dried within a period of 5 hours to 6.0%, 5.5% and 4.0% moisture content.

Keywords: Solar Tent Dryers, Green House Film, Acrylic, Temperature, and Relative Humidity.

1. INTRODUCTION

The preservation of foods by drying is without doubt the oldest method practised and it remains most commonly used method worldwide (Mujumdar and Sakamon, 2012). Drying, which affects the physical parameters food products, by removal of water causes weight reduction and increased storability (Robert *et al*,. 2014). While grains and pulses are the most important, in term of tonnage, the range of products dried is wide and includes meats, fish, fruits, vegetables, spices, and nuts. The conventional drying system to preserve fruits, vegetables, grains, fish, meat, wood and other agricultural products is sun drying which is a free and renewable source of energy. But, for large-scale production, there are various known limitations of sun drying as damage to the crops by animals, birds and rodents, degradation in quality due to direct exposure to solar radiation, dew or rain, contamination by dirt, dust or debris. Also this system is labour- and time intensive, as crops have to be covered at night during bad weather, and have to be protected from attack by domestic animals. There is also a chance of insect infestation and growth of micro-organisms due to non-uniform drying. The advancement of sun drying is solar drying systems whereby products are dried in a closed system in which inside temperature is higher (Rajkumar, 2007; Kumar and Shrivastava, 2017). Major advantage includes protection against flies, pests, rain or dust. Several significant attempts have been made in recent years to harness solar energy for drying mainly to preserve agricultural products and get the benefit from the energy provided by the sun. Sun drying of crops is the most widespread method of food preservation in Nigeria because of solar irradiance being very high for most of the year. Due to no energy cost, it is more beneficial to the small scale farmers who can't afford the electricity or other fuel for drying. If it is necessary to dry product in the night or during bad weather, an additional bio-fuelled heater can be used for heat supply. The high temperature dryers used in industrialized countries were found to be economically viable, in developing countries only on large agro sectors and generally it is not affordable by small and medium entrepreneurs because of high cost and process variability (Ibrahim *et al*, 2009). Therefore, the introduction of low cost and locally manufactured solar dryers provides a promising alternative to reduce the grand postharvest losses. The opportunity to produce high quality marketable products appears to be a chance to improve the economic status of the farmers. Taking into account the low income of the rural population in developing countries, the relatively high initial investment for solar dryers still remains a barrier to a wide application (Chapman *et. al.*, 2006). However, if it is manufactured by locally available material such as wood, glass etc., it will be economically affordable for the farmers. Amongst all, with the submission of Kumar and Shrivastava, (2017), the objective of a solar dryer is to provide ample amount of heat more than ambient heat under given humidity. This heat increases the vapour pressure of the moisture confined within the product and decreases the relative humidity of the drying air as to increase the moisture carrying capacity of the air.

2.0 Description of Solar Dryers

2.1 Mobile Solar Tent Dryer (MSTD)

A mobile greenhouse solar tent dryer (MSTD) of 8ft x 4ft is made of polyurethane insulators. This material makes up the walls and floor of the solar tent dryer. It is comprised of a drying platform made of steel with 6 drying trays. The inner surfaces are painted black to increase the rate of heat absorption while the top frames were made of ½ inch galvanised hollow pipes to form arcs which serve as a support for the transparent sheet/film. The top of the MSTD is installed with a pneumatic extractor fan which absorbs the moisture from the products being dried (Plate 1). All the parts of the MSTD are dismountable for easy carriage from one location to the other and better erected in an East-West direction for effective solar radiation.

Plate 1: NSPRI's Mobile Solar Tent Dryer

2.2 Greenhouse Solar Dryer

The greenhouse dryer was designed to combines the function of the solar collector with a greenhouse system. The roof and wall of this dryer can be made of transparent materials such as glass, fibre glass, UV stabilized plastic or polycarbonate sheets. The transparent materials are fixed on a steel frame support or wooden roofs with bolts and nuts and sealed to prevent humid air or rain water leaking into the chamber other than those introduced from the inlet opening. The surface of the floor is painted black in order to increase absorption rate. Inlet and exhaust fans are placed at proper position within the structure to guarantee even distribution of the drying air.

NSPRI has developed a natural convection greenhouse dryer with dimension (12 x10)ft^2 and dwarf wall of 3.3ft high (Plate 2). The drying chamber consists of two parallel rows of 4 drying platforms made up of 24 trays with an effective drying space of 112ft^2. The construction materials were greenhouse film, wooden supports, a manual extractor fan, wooden drying racks with galvanised mesh as trays, a black surface painted with food grade enamel paint. This dryers were erected in East-West longitudinal and North South width direction for efficiency.

The floor of the solar dryer is made of concrete floor sandwiched with a polyurethane material to serve as an insulation to prevent heat sink and painted with black food grade enamel paint. The drying chamber is made of 24 trays and a wind power extractor fan to remove moisture out of the drying chamber, 6 vents to induce required air flow in the system, a black surface to absorb heat energy, and a greenhouse film to trap solar radiation. Air is drawn through the dryer by natural convection or sometimes by a fan. It is heated as it passes through the collector and then partially cooled as it catches moisture from the material. The green house film which is the transparent material is laid on the wooden roof. The inclined transparent roof allows solar radiation over the product. Vents with shutters at the outer length sides of the building regulated the air inlet while a pneumatic extractor fan is place at the centre of the ridge of the roof to extract moisture from the products being dried. As this heated air rises and flows up the hurricane to the outside of the dryer, fresh replenishing air is drawn in through the vents for the drying process to continue.

Plate. 2: The NSPRI's Greenhouse Solar Tent Dryer

2.3 Parabolic Greenhouse Solar Dryer (PGSD)

NSPRI has developed a Parabolic Greenhouse Solar Tent dryer. The PGSD is a 26ft x18ft with an effective drying area of 22ft x14ft as depicted in (plate 3). The frame supports are made of steel which had been shaped into a parabola of height 7.5ft. It has 2 drying racks made of steel which comprise of 56 trays with an effective drying space of 224ft^2. The floor of the PGSD is a concrete floor sandwiched with polyurethane to avoid heat sink. The concrete floor is tiled with glazed black tile which was painted with food grade black enamel paint. The transparent material is made of a 2mm thick acrylic material with the trademark name Perspex. The Perspex sheet were laid on the parabolic frame support and fixed with bolts and nuts.

The PGSD is installed with 2 blowers powered by 100amperes solar battery which is being charged by 2 units of 180W solar panels. These blowers serve as a dehumidifier which will enhance the drying process during the rainy season. The top of the PGSD is also installed with 2 units of pneumatic extractor fans of diameter 18'' to aspirate the moisture being driven out by the hot air from the products undergoing drying process.

Plate. 3: NSPRI's Parabolic Greenhouse Solar Tent Dryer

3.0 Evaluation of the Solar Dryers

3.1 Evaluation of the Solar Dryers at No-Load Test

The solar dryers were evaluated at a no load test. The dryers were installed with data loggers to record the temperature and relative humidity of the solar dryers and the ambient conditions and comparisons of their environmental conditions were defined as shown in figure 1, 2, 3, 4 and table 1.

3.2 Evaluation of the Solar Dryers Loaded with Agricultural Products

The following products Telefaria Occidentalis, Meat and Chilli pepper were dried using the solar dryers. The samples of products were sorted, cleaned and weighed. The initial moisture content of the products were also determined using the oven dried method as prescribed by ASABE 2007 prior to drying in the solar dryers.

The vegetables were sorted, washed, drained and shredded with knives into thickness of 10mm. Its moisture content was determined using the oven method and products were weighed and put in dryers simultaneously to dry appropriately. Also weighed portions were kept in the open sun as control. Weights of the vegetables were monitored periodically.

The beef meat was procure and cleaned to remove fat deposits. Meat was thinly filleted into 2mm. The moisture content was determined using the oven method. Meat was weighed, spread on trays in all the solar dryers and also in the open sun as control. Weights were monitored periodically.

The chilli pepper were procured, sorted, cleaned, and blanched at a temperature of 80^{o}C. Moisture contents of pepper was determined using the ASABE 2007 standard, weighed and spread on trays in the solar dryers and also in the open sun simultaneously as control.

The final moisture contents of the products and the duration of the drying from the different solar dryers are depicted in table 2.

4.0 RESULTS

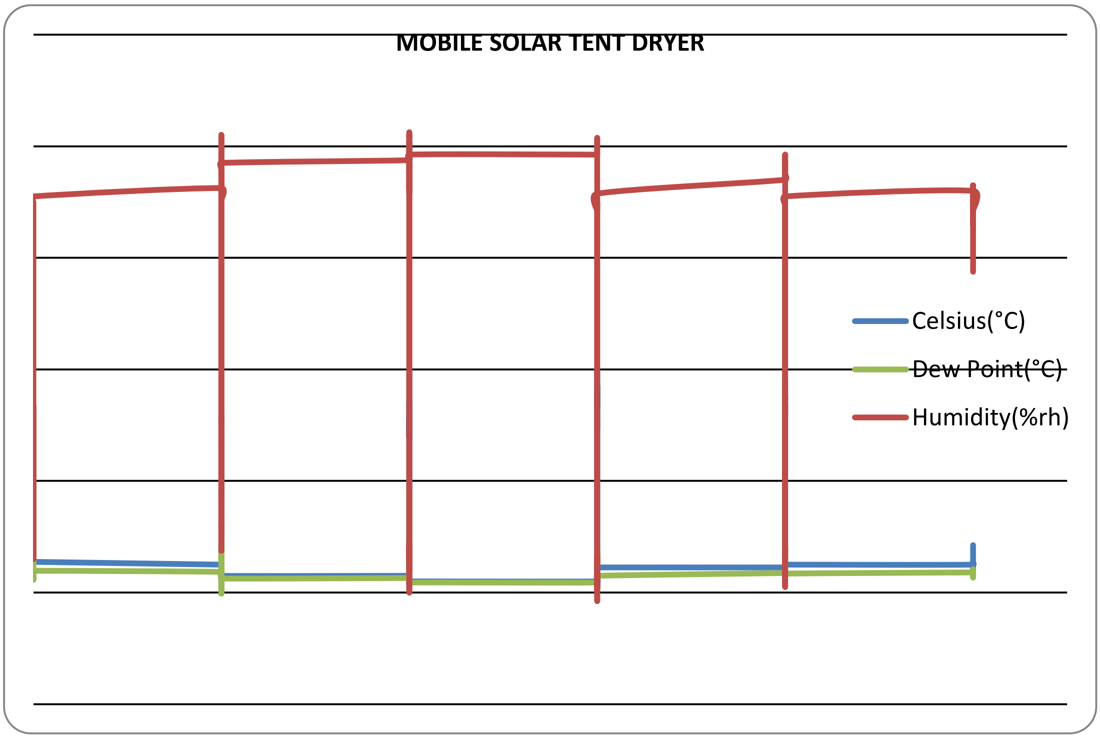

Figure. 1; The No Load Test of the Environmental Conditions of the Mobile Solar Tent Dryer for duration of 5 days.

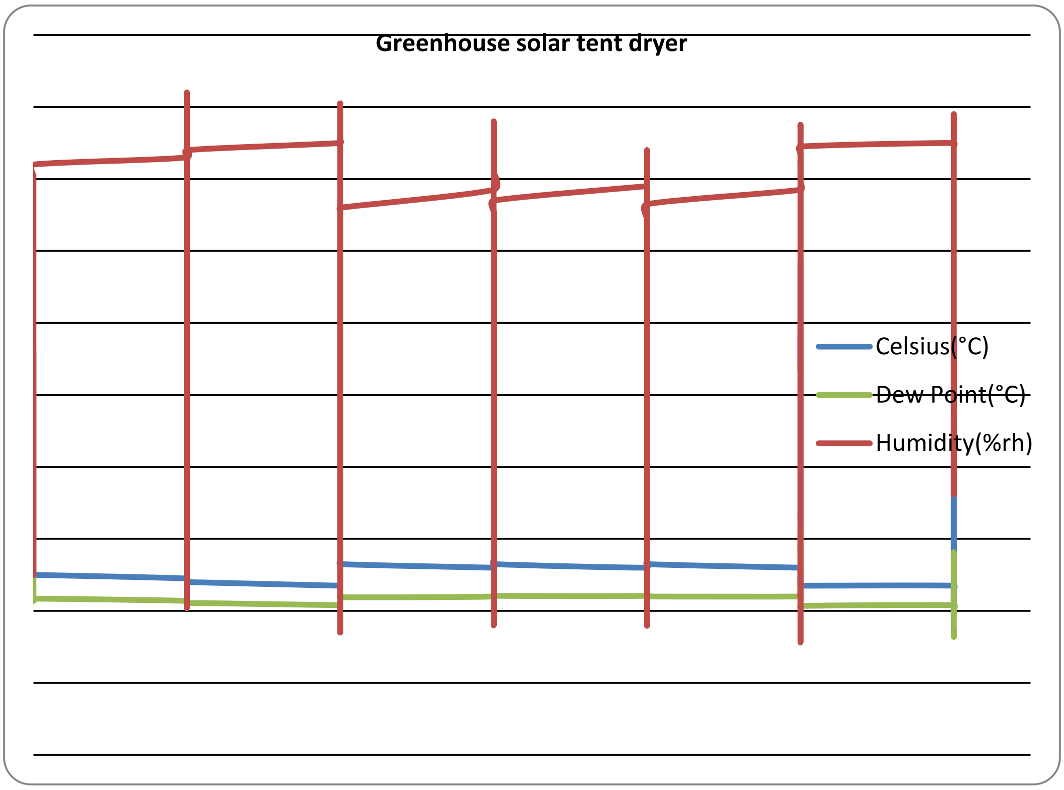

Figure. 2; The Chart of the No Load Test of The Environmental Conditions of the Greenhouse Solar Tent Dryer for Duration of 5 Days

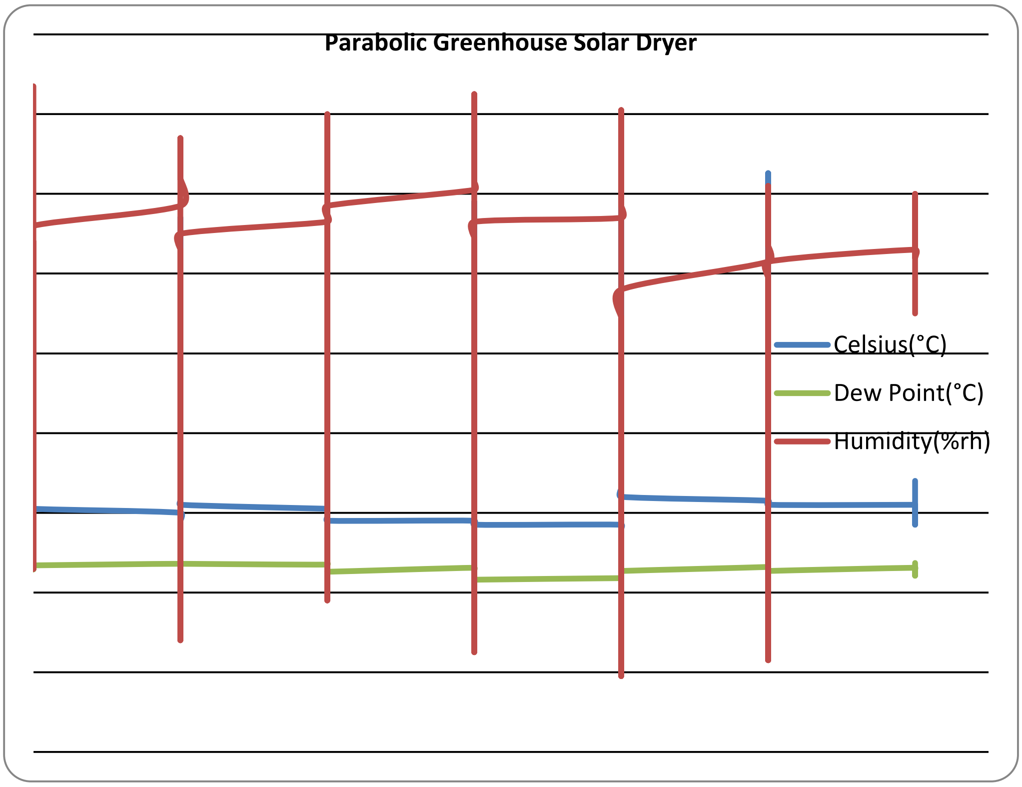

Figure. 3; The No Load Test of the Environmental Conditions of the Parabolic Solar Dryer for duration of 5 days

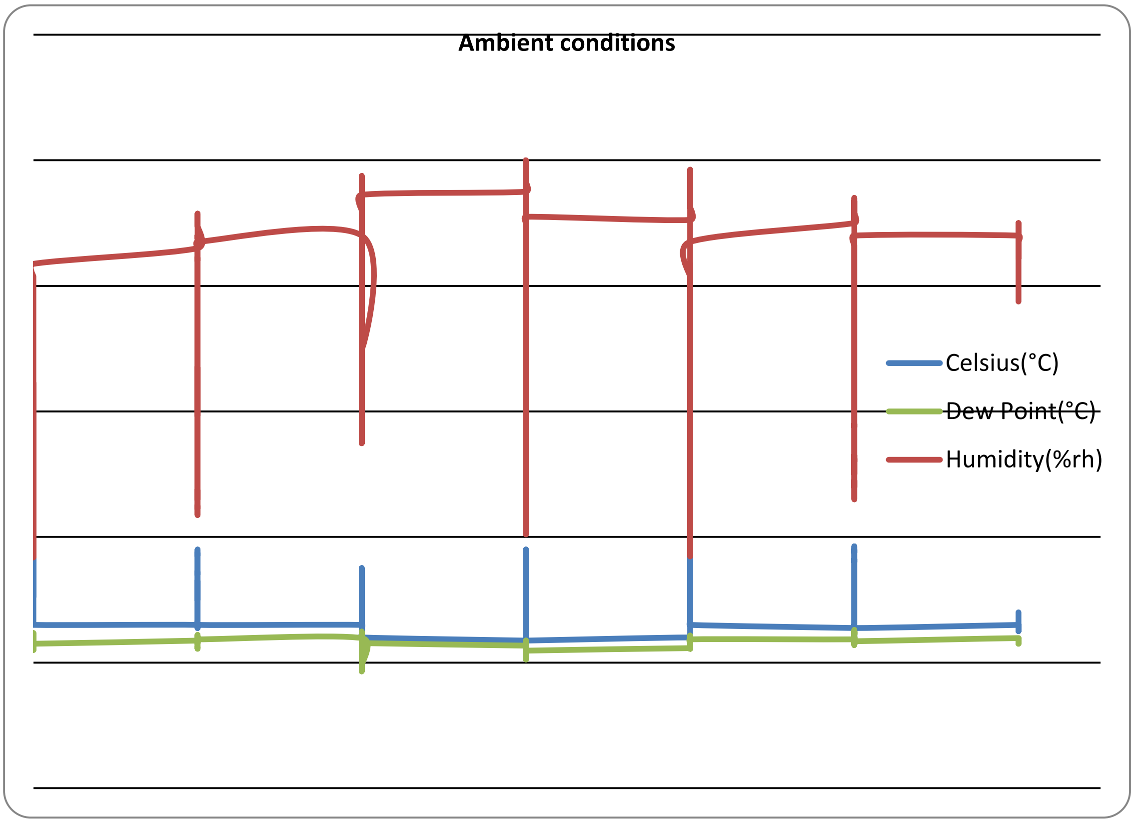

Figure. 4: Chart of Environmental conditions of The Ambient

Table 1;F-Test of the Environmental conditions of all the solar dryers in NSPRI

Dryers	Temperature °C	Humidity %	Dew Point °C
Mobile tent	33.28±12.61[b]	70.15±30.68[c]	24.24±2.48[b]
Greenhouse Solar Tent	35.72±13.67[b]	60.48±25.44 [b]	24.26±3.32[b]
Parabolic	40.5±15.15[c]	48.49±23.25[a]	23.96±2.17[b]
Ambient Control	28.39±5.06[a]	63.85±26.87[d]	23.17±0.78[a]
F-value	31.354	44.244	8.502
Sig. value	0.000	0.000	0.000

Environmental conditions (Columns) with the same alphabet are the same while those with different alphabet are different at $P_{value}=0.05$

H_o: There is significance difference in the environmental conditions

H_1: There is no significance difference in the environmental conditions

Table 2; Moisture Contents of Different Products dried in the Solar Dryers

	Moisture Contents of products					
Products	**Fresh products %**	**Parabola %**	**Greenhouse Dryer %**	**Mobile Solar Dryer %**	**Control %**	**Drying Duration**
Beef (Meat)	71.243	10.09	12.01	12.15	71.243	5 days
Chilli Pepper	89.4	9.3	11.7	12	27.67	8 days
Telefairia Occidentalis vegetable	11	4	5.5	6	6.3	5 hours

4.0 DISCUSSION

The different solar dryers developed by the Nigerian Stored Products Research Institute have proven to have better environmental conditions in terms of temperature and relative humidity for drying of agricultural produce.

The no load test carried out on the MSTD depicted a minimum temperature of 20.4°C and a maximum temperature of 59.5°C with an average of 32.49 ± 12.10°C. The relative humidity recorded a mean relative humidity of 71.64 ± 29.65%.

The graphical illustration depicted in figure 2 for the Greenhouse Solar Dryer shows that the temperature range is 21.5-68°C and a mean relative humidity of 60.21% while the figure 3 for the Parabolic Greenhouse Solar Dryer has a temperature range of 25.0 -78°C. It has an average temperature of 39.4±14.24°C. The relative humidity had a minimum of 14.5% and a maximum of 83.5% and mean value of 49.77 ± 22.64%.

The ambient environmental conditions as illustrated graphically in figure 4 has an average temperature of 28.56 ± 5.15°C while it has a minimum and a maximum temperature of 20°C and 42.5°C respectively. It has an average relative humidity of 74.88 ±17.94%.

The statistical analysis to compare the environmental conditions in the different solar dryers which are implied in Table 1 above indicates that in terms of temperature, there is no difference in the mobile solar tent and greenhouse solar tent while a significant difference exists between the temperature obtained in the parabolic solar dryer and other solar dryers. Also there is a significant difference in the relative humidity observed in all the dryers as indicated in table 1.

The Parabolic solar dryer has the highest temperature followed by solar tent but the least is control followed by mobile. Also the parabolic solar dryer has the least relative humidity while the mobile solar tent has the highest humidity followed by control. These environmental conditions exhibited by the parabolic solar dryer makes it highly effective for high moisture crops.

In the advances, the average relative humidity in the Greenhouse parabolic solar dyer is 48.49%. This indicates that the products that will be obtained in the parabolic solar dryer can be considered safe from a microbiological point of view since they are characterized by a low water activity (a_w), and usually no growth occurs below water activity of about 0.62 (Sagar & Kumar, 2010).

The table 2 which indicate the moisture contents and the drying duration of the agricultural products (beef meat, chilli pepper, and T*elefairia occidentalis* vegetable) showed that products dried well in all the solar dryers. The beef meat, chilli pepper and telefeiria occidentalis vegetable were dried in the mobile solar tent dryer, greenhouse solar dryer and parabolic solar dryer. The beef of 71.243% initial moisture content was dried to 12.15%, 12.01% and 10.09% in the aforementioned respective dryers within a period of 5 days. Also the chilli pepper of 89.40% initial moisture content was dried to 12%, 11.3% and 9.3% moisture content respectively in the dryers within a period of 8 days; while the Telefairia Occidentalis vegetable of 11.0% initial moisture content was dried within a period of 5 hours to 6.0%, 5.5% and 4.0% moisture content. Among solar dryers, the parabolic solar dryer attained a lower moisture content followed by those in the green house dryers, that of the mobile solar dryers and the control which were placed under direct sun. This implies that the parabolic solar dryer has the best and optimal performance as compared with the other solar dryers. It is therefore imperative to know that the choice of materials used in the parabolic solar dryers have given it an advancement over the two other solar dryers.

5.0 CONCLUSION

Various model of solar dryers developed by NSPRI was found to have better performance in comparison to the conventional open air system practice. The choice of the different construction materials for the solar tent dryers developed by NSPRI has played a very major role in the achievement of the optimal environmental condition gotten in the dryers. It has also further enhanced the advances in the development of solar dryers. These advances, which has gotten to the height of the parabolic greenhouse solar dryer, although expensive but with a higher life span has made it possible to be able to carry out drying process even in the humid season of the year; thereby taking care of the shortcomings of the low solar irradiance.

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Moisture-dependent Mechanical Properties of Neem (*Azadirachta indica*) Seeds.

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ABSTRACT

A study of moisture dependent mechanical properties of neem (*Azadirachta indica*) seeds from the three senatorial districts of Adamawa State was conducted. A randomized complete block design comprising twelve treatments with three replications was used. The initial moisture contents of the neem seeds were determined before and after oven drying. Moisture conditioning was obtained in four moisture levels (12.1, 14.6, 17.5 and 20.4% d.b). The mechanical properties investigated were compressive force, stress, strain, energy, deformation and Young's modulus and were found to be in the range of 18.430 – 66.510 N, 12.085 – 27.654 N/mm^2,1.627 – 9.499 mm/mm, 5.805 – 18.809 Nm, 0.244 – 0.589 mm and 3.106 – 9.810 N/mm^2 in the axial orientation respectively. The corresponding values in the transverse orientation are 9.433 – 42.613 N, 1.387 – 9.293 N/mm^2, 4.164 –14.724 mm/mm, 3.667 – 21.269 Nm, 0.419 – 0.997 mm and 0.238 – 0.794 N/mm^2. More so, the coefficient of friction increased on galvanized steel (0.71 - 1.23) and plywood (1.75 – 2.00) but decreased on plastic (1.37 – 0.98) as moisture content increased. The results obtained will provide useful information for potential processors and engineers in handling and developing neem seed processing machines.

Keywords: Moisture content, Mechanical properties, Axial and Transverse orientations, Neem seeds.

1. INTRODUCTION

The neem tree (*Azadirachta indica*) is native to the seasonally dry, tropical woodlands of north-east India, and perhaps parts of Asia. It is a member of the *Meliaceae* family. The latinized name of neem, *Azadirachta indica*, is derived from the Persian (National Research Council [NRC], 1992). Two species of Azadirachta have been reported, *Azadirachta indica A. Juss* – native to Indian sub- continent and *Azadirachta excelsa Kack.* – confined to Philippines and Indonesia (Jattan *et al.*, 1995; Hegde, 1995). The Neem tree and its seeds are spread across Nigeria, particularly in Northern Nigeria and popularly called *dogonyaro* for centuries, having been introduced into the country by Cameroonian traders through Borno State (Olatunde, 2011; Ahmed, 2014). Neem tree has been effective in the control of erosion and desert encroachment. More so, it is a multi-purpose tree which has a number of socio-economic and ecological significance – one of which is combatting desertification. The tree comes in handy in the erection of shelter belts, as wind breakers, shade and woodlots in arid regions like Adamawa, Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe and Zamfara States, with a density of about 1,200 trees/ha (Fujinmi *et al.*,1990). Thass (2008) stated that neem oil is used to cure diseases related to glands, leprosy, ulcers, rheumatism (external application), hair tonic, sore throat, soap production, medicines, pesticides and coating urea to reduce nitrogen loss in fertilized soil. The oil and powder are also used in medicated soaps, both pastes and washing soap etc. However, potential processors find it difficult to store neem seeds (including its fruits/kernel) and develop machines for its processing. The difficulty ranges from preferred moisture content for storage, processing and mechanical properties (including other engineering properties/parameters) for designing, developing and constructing machines for neem seed processing. This study determined the moisture content of the neem seeds at harvest and the effects of moisture content on the mechanical properties of the seeds in order to provide useful information and data on the behavior of neem seeds as a function of moisture in a bid to mechanize the various unit operations involved in its post-harvest processing.

2. METHODOLOGY

2.1 The study Area

Adamawa State is located on the north eastern part of Nigeria. It lies between latitude 7° and 11°N, and longitude 11° and 14°E of the Greenwich Meridian and shares boundaries with Taraba State in the south- western part, Gombe State in the north-western part and, Yobe and Borno States to the north (Alfred and Mathias, 2015). The major vegetation formations in the state are the Southern Guinea Savannah, Northern Guinea Savannah and the Sudan Savannah. Within each formation is an inter species of thick tree savannah, open grass savannah and fringing forest in the river valleys (Akosim *et al.*, 1999).

2.2 Sample Collection and Treatments

Ripe neem (*Azadirachta indica*) fruits were obtained from the three Senatorial Zones of Adamawa State and used for the purpose of this study. They were manually cleaned to remove all contaminants/foreign materials and damaged or broken ones. The fruits from the different locations were depulped separately to obtain the seeds, which was sundried for three days (Kawuyo *et al.*, 2011) to reduce the moisture content to a level at which mould growth and germination can be prevented. The moisture content at this stage was calculated using Equation 1;

$$M.C\ \% = \frac{M_i - M_f}{M_f} \times 100$$

1

Where;

M.C = Moisture Content (%)

M_i = initial moisture content of sample (%)

M_f = final moisture content of sample (%)

The initial moisture content at dry basis (dry basis) of the seeds were determined by oven drying (at 103±1 °C) the samples until a relatively constant weight was achieved/reached (Adedeji and Owolarafe, 2015; Kawuyo *et al.*, 2011). Distilled water was added to the sample and sealed in separate polythene bags which were kept in a refrigerator at 4°C (Yang *et al.*, 2002) for seven days to allow even distribution of water to the seeds. The quantity of distilled water added was calculated using Equation 2;

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_f)}$$

2

Where; Q = mass of water added (kg)

W_i = mass of sample (kg)

M_i = initial moisture content of sample (%)

M_f = final moisture content of sample (%)

The moisture content determination was replicated three times and the mean and standard deviation values were calculated. The mechanical properties considered were determined by using eighteen (18) seeds for each of the properties. The mechanical properties considered in this study include; static coefficient of friction and compressive strength.

2.3 Determination of Static coefficient of friction

The static coefficient of friction μ was determined for three structural materials namely; plywood, plastic and galvanised sheet. For this measurement, one end of the friction surface was attached to an endless screw. The seed was placed on the surface and gradually raised by the screw (Sunmonu *et al*,, 2015), the angle between the vertical and horizontal height was read when the seed started sliding over the surfaces, and then the coefficient of static friction was calculated using the tangent value of that angle (Equation 3);

$\mu = \tan\theta$ 3

Where;

μ = coefficient of static friction

θ = the angle from the horizontal plane

2.4 Compressive strength

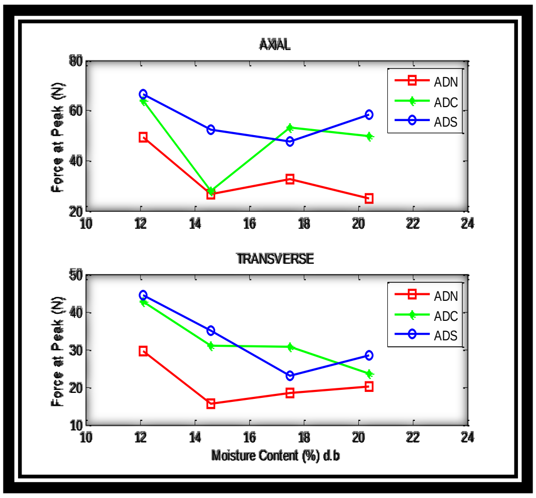
The compressive strength of the *neem* seed was determined using a computerized Universal Testing Machine (UTM) No. 0500-10080 at the National Center for Agricultural Mechanization (NCAM) Idofian, Kwara State. The seeds at different orientations (axial and transverse) were loaded and the test result and graphs were automatically generated. The data obtained include force at peak, break and yield, strain at peak, break and yield, and deformation at peak, break and yield. Stress at peak, break and yield, energy at peak, break and yield and Young's modulus were calculated. Experiments were replicated three times for each of the four moisture levels.

3. RESULTS AND DISCUSSION

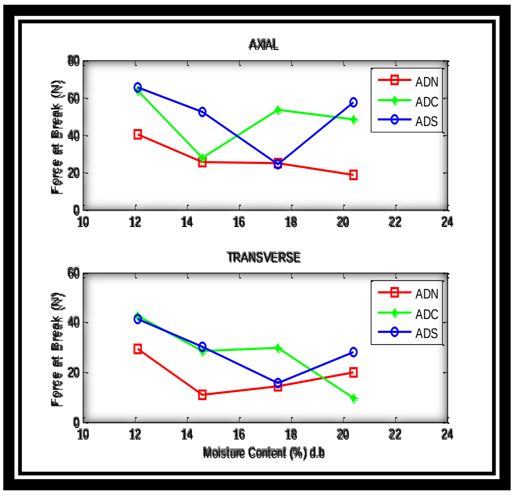
The initial moisture contents of the neem seeds were determined before and after oven drying were 21.66, 20.75 and 21.40% (d.b) and 9.7, 7.5 and 8.9% (d.b) for Adamawa northern, central and southern senatorial districts respectively. These seeds were later conditioned to 12.1, 14.6, 17.5 and 20.4% (d.b) moisture levels, which were used for the experiments at two loading orientations (axial and transverse).

3.1 Compressive Force

It was found that the force at peak, break and yield were in the range of 18.43 – 66.51 N and 9.433 – 42.613 N in the axial and transverse orientations respectively. It can be observed from Figures 1a, b and c that the force at peak, break and yield decreased with increase in moisture content from the zones under study. It was observed that the force in cracking the seed in axial orientation was greater than when in transverse position. This may be due to the fact that the more the moisture content, the softer the seeds hence less force required for breakage. In addition, the lesser the moisture content, the harder the seeds hence high force would be required Similar trend were obtained by Fabunmi *et al.* (2017) for raphia seeds, Fadeyibi and Osunde (2012) for rubber seeds. The effect of moisture content on force was significant ($p \leq 0.05$) except in the axial position of force at peak.


AXIAL
Force at Peak (N)
ADN
ADC
ADS
TRANSVERSE
Force at Peak (N)
ADN
ADC
ADS
Moisture Content (%) d.b

1a.


AXIAL
Force at Break (N)
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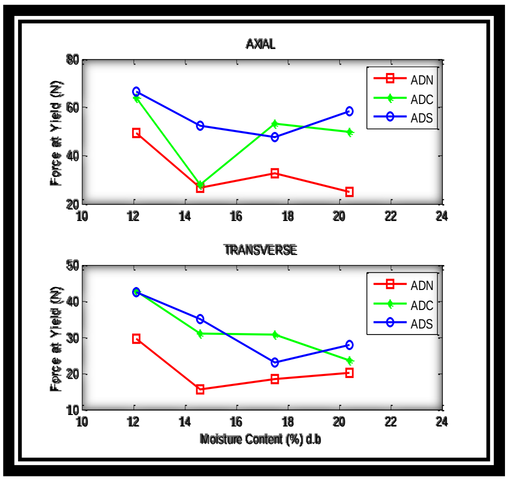
TRANSVERSE
Force at Break (N)
ADN
ADC
ADS
Moisture Content (%) d.b

1b.



1c.

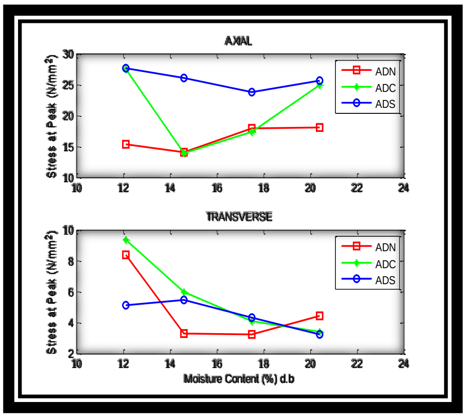
Figures 1a: Relationship between Force at peak and Moisture Content

1b: Relationship between Force at break and Moisture Content

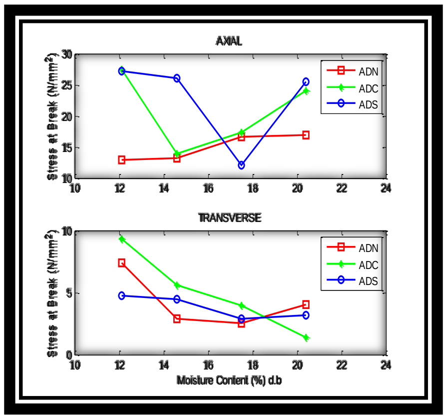
1c: Relationship between Force at Yield and Moisture Content

3.2 Stress

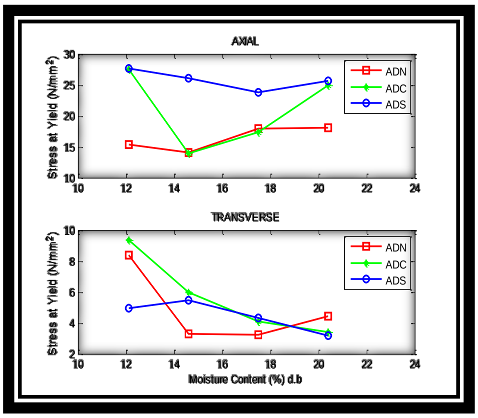
The stress of the neem seeds decreased (Figures 2a, b and c) with increase in moisture level (12.1 to 20.4% d.b) and ranges from 12.085 – 27.654 N/mm^2 and 1.387 – 9.293 N/mm^2 in the axial and transverse orientations respectively. The decrease in stress might be due to the decrease in the force at peak to cause fracture on the seeds during compression and also an increase in contact area between the seed and the compression jaws of the testrometric machine. Similar trends were observed by Ajav and Fakayode (2013) for moringa seeds and for cocoa beans, shea and cashew nuts and kernel (Bart-Plange, 2014). At 19% moisture level the stress at break (4 N/mm^2) was found to be the same in the transverse orientation. This means that during cracking process, the seeds should be conditioned to 19% moisture content d.b for all zones so that same stress can act on them at a time. The effect of moisture content was significant ($p \leq 0.05$) except in the axial position of stress at peak and break.



2a



2b

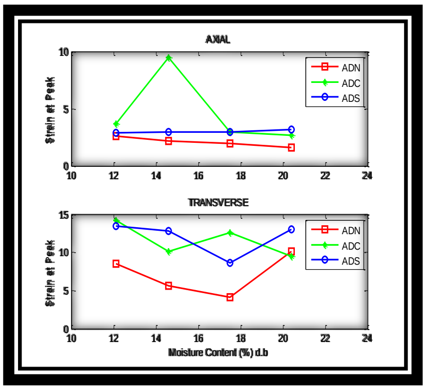


2c

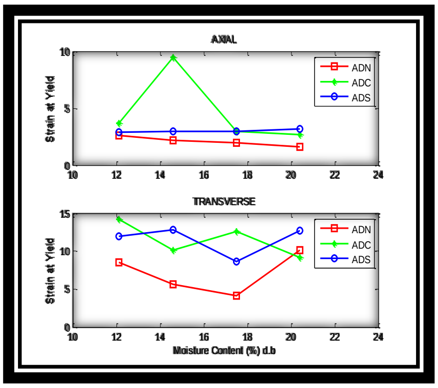
Figures 2a: Relationship between stress at peak and Moisture Content
2b: Relationship between stress at break and Moisture Content
2c: Relationship between stress at Yield and Moisture Content

3.3 Strain

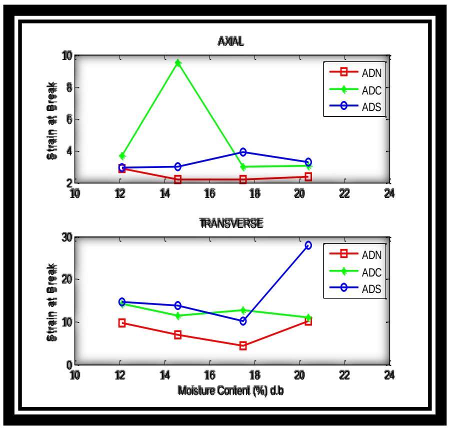
The strain values of both axial and transverse orientations (positions) for all the zones decrease with increase in moisture content (Figures 3a, b and c). The value ranges from 1.627 – 9.499 mm/mm and 4.164 – 14.724 mm/mm respectively. The strain values for transverse position were higher than the values for axial position. This might be due to the areas of contact between the compressive surfaces of the UTM and neem seeds. Similar results were obtained by Bart-Plange (2014) for cashew nuts and Awolu and Oluwafemi, (2013) for dika fruits and nuts. The effect of moisture content on neem seed was significant ($p \leq 0.05$). There was an increase in strain as the moisture level exceeds 17.5% d.b in Adamawa south in the transverse orientation ($ADS_{transverse}$) and might be due to the seeds being softer with increase in moisture.



3a



3b

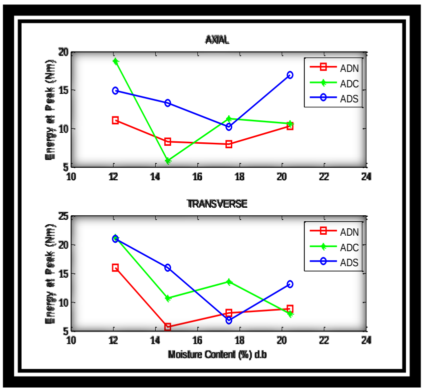


3c

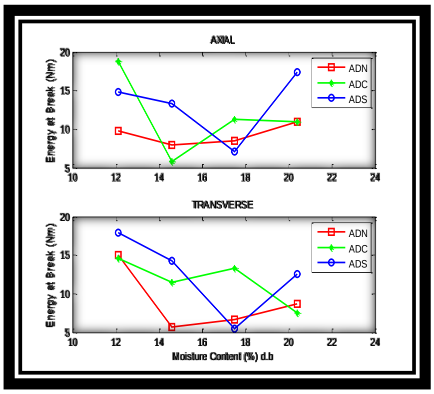
Figures 3a: Relationship between strain at peak and Moisture Content
3b: Relationship between strain at break and Moisture Content
3c: Relationship between strain at Yield and Moisture Content

3.4 Energy

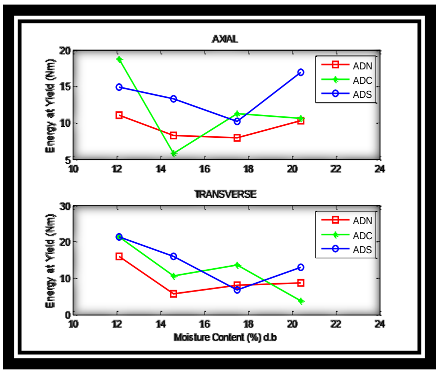
The energy required to crack neem seed as a function of seed moisture content decreased in the range 5.805 – 18.809 Nm and 3.667 – 21.269 Nm in the axial and transverse orientations respectively. The values of energy were found to be higher in the transverse position in all the zones than in the axial position. Similar trends were reported by Mamman *et al.*, (2005) for balanite nut and Kalkari and Kara (2011) for popcorn kernels. The effect of moisture content on neem seed was significant ($p \leq 0.05$) (*Table 5*). There was an increase in energy as seed moisture exceeds 17.5% in Adamawa North (ADN) and Adamawa Central (ADC) and it might be due to increase in flexibility of the seeds fiber as moisture increases. Figures 4a, b and c presented the graphs of energy trend at peak, break and yield.



4a



4b

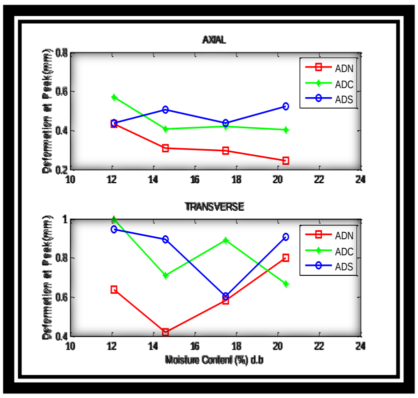


4c

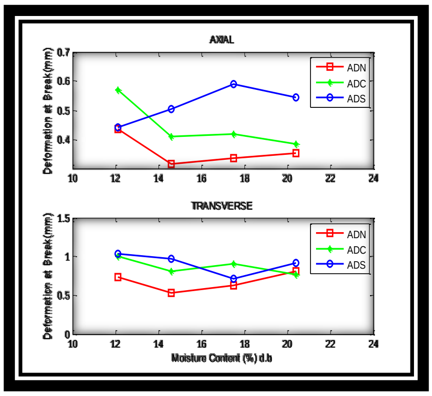
Figures 4a: Relationship between energy at peak and Moisture Content
4b: Relationship between energy at break and Moisture Content
4c: Relationship between energy at Yield and Moisture Content

3.5 Deformation

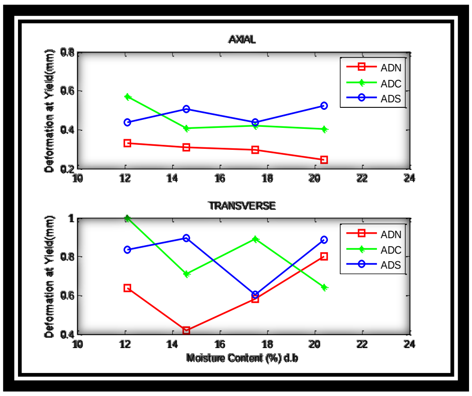
The deformation at yield decreases with an increase in moisture content of the seeds (Figure 5a, b and c) ranges from 0.244 – 0.589 mm and 0.419 – 0.997 mm in the axial and transverse positions respectively. The effect of moisture content on the neem seed was significant ($p \leq 0.05$) and R^2 above 80% in all the zones. Moisture content can only be said to affect deformation when R^2 is above 70% while below 70% cannot be used to describe how moisture content affects neem seed in these positions. This trend was similar to the report of Karaj and Muller (2010) and Bamgboye and Adebayo (2012) for jatropha seeds. There was an increase in deformation as seeds moisture content exceeds 17.5%. This showed that neem seed required less energy to deform at low moisture content than at high moisture content because of their level of brittleness.



5a



5b

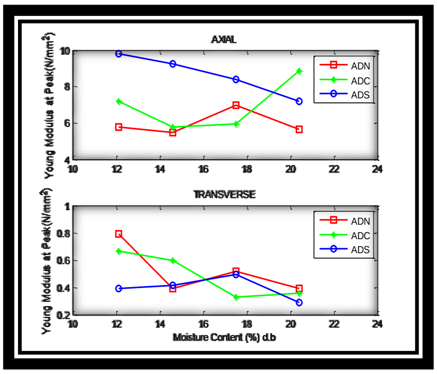


5c

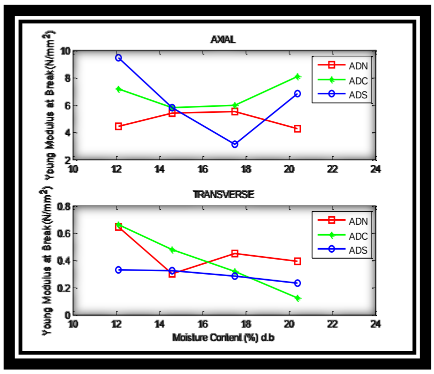
Figures 5a: Relationship between deformation at peak and Moisture Content
5b: Relationship between deformation at break and Moisture Content
5c: Relationship between deformation at yield and Moisture Content

3.6 Young's Modulus

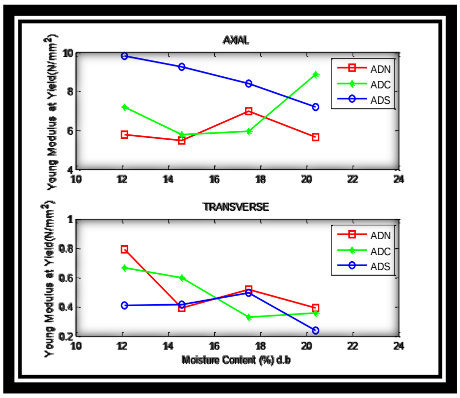
The relationship between Young's Modulus at peak and moisture content is presented in Figures 6a, b and c. Young's modulus decreases in the range of 3.106 – 9.810 N/mm^2 in the axial orientation and 0.238 – 0.794 N/mm^2 in the transverse orientation respectively. The values of Young's Modulus in the axial positions were observed to be higher than those in the transverse position. This might be due to the cleaving action of water as it diffuses through the intermolecular spaces of the seeds and may have caused swelling and weakening of the cohesive forces. Published results by Delwiche (2000) suggest a decrease in Young's Modulus as wheat kernel moisture content increased in the range of 3% to 28% (db). Bart-Blange *et al.* (2014) also reported the same for cocoa beans, Mamman *et al.* (2005) for *aegyptiaca* nut and Abbaspour-Ford *et al.* (2012) for pumpkin seeds. The effect of moisture content on neem seed was significant at $p \leq 0.05$ level.



6a



6b



6c

Figures 6a: Relationship between Young's Modulus at peak and Moisture Content 6b: Relationship between Young's Modulus at break and Moisture Content 6c: Relationship between Young's Modulus at yield and Moisture Content

3.7 Coefficient of Friction

The coefficient of friction was also affected by moisture content of range 12.1 to 20.4% (db). Figure 7 shows that the static coefficient of friction increased on galvanized steel (0.71 - 1.23) and plywood (1.75 – 2.00) but decreased on plastic (1.37 – 0.98) as moisture increase. The increase might be due to the increase in adhesive force which made it difficult to move on the surfaces and the decrease due to increase in cohesive force owing to the smothness and more polished surface of plastic which made it easy to move on it. This result is in agreement with Fadavi *et al.* (2013) for wild pistacho nuts, Idowu *et al.* (2012) for sandbox seed and Hazbavi (2013) for Iranian okra seeds. The effect of moisture content was significant (p≤0.05) on coefficient of friction.

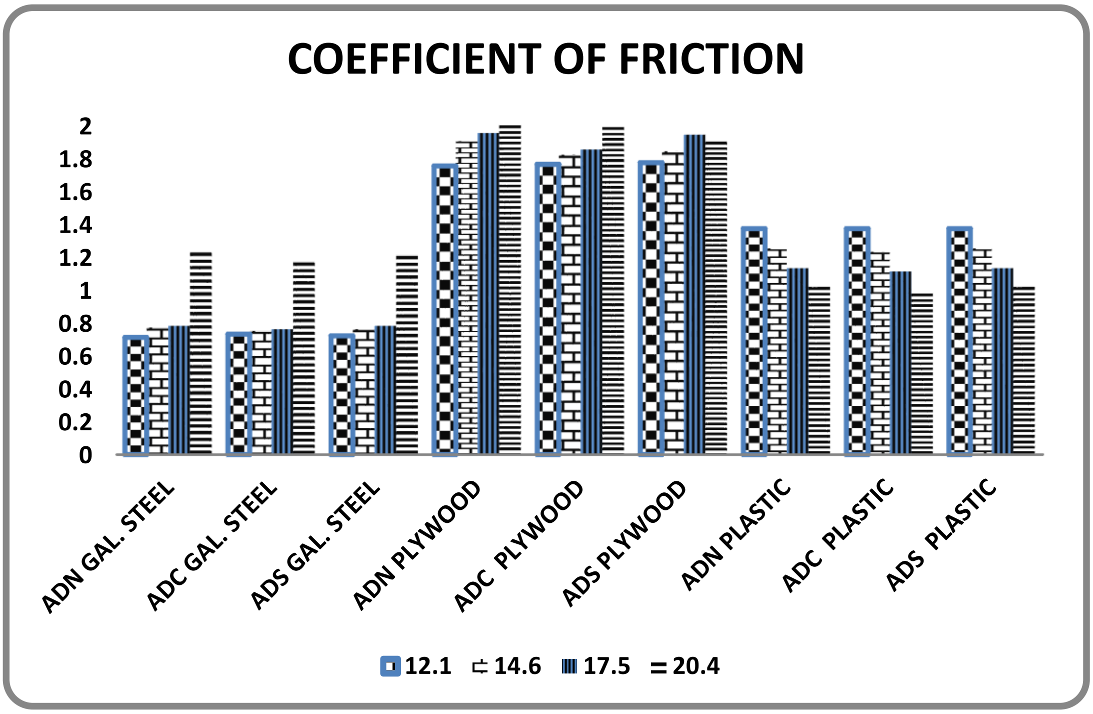


Figure 7: Relationship between Coefficient of Friction and Moisture Content
12.1, 14.6, 17.5 and 20.4 are moisture contents (M.C, %) d.b

4. CONCLUSION

The results obtained in this study showed that the mechanical properties (force, stress, strain, energy, deformation, Young's Modulus and coefficient of friction) of neem seeds in all the zones (districts) studied were dependent on moisture content. These results provide useful information for potential processors and engineers in handling and developing neem seed processing machines. It can be used for texture analysis and better understanding of neem product quality. It is useful in the mechanization of various unit operations involved in post-harvest processing and also in the development and evaluation of optimization parameters for efficient and effective processing equipment. Further studies on other engineering properties of neem seed (physical, terminal velocity, aerodynamics etc.) are needed to have comprehensive data in the study area.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Practical Application of Near-infrared Spectroscopy for Determining Rice Amylose Content at Grain Elevator

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ABSTRACT

The major chemical constituent contents of rice are moisture, protein and starch (amylose and amylopectin). Those constituent contents associate with eating quality of rice. Near-infrared (NIR) spectroscopy is one of the non-destructive methods for determining grain chemical contents. At grain elevator, moisture and protein contents can be measured with high accuracy using an NIR spectrometer by the effort of our research activities in Japan. However, the accuracy to determine amylose content is not sufficient. Thus, the objective of this study was to develop non-destructive method to determine rice amylose content for practical use at grain elevator. Milled rice amylose content measurement was performed using an auto-analyzer for reference (chemical) analysis. Spectra data of milled rice were obtained using an NIR spectrometer with a wavelength range of 850 to 1048 nm. Calibration model to determine amylose content was developed using non-waxy Japonica-type rice samples. Partial least squares (PLS) regression analysis was used to develop calibration model. The accuracy of the model was validated and the validation statistics were shown: coefficient of determination (r^2) was 0.72, bias was -0.04%, standard error of prediction (SEP) was 0.92%, and ratio of SEP to standard deviation of reference data (RPD) was 1.90. Production year of the validation set (2017) was different from that of the calibration set (2008 to 2016). This means the same condition as practical use of this method at grain elevator. The result obtained in this study indicated that this calibration model enables non-destructive determination of rice amylose content at grain elevator.

Keywords: Rice quality evaluation, amylose content, rice grain elevator, non-destructive method, Japan

1. INTRODUCTION

Rice is staple food for people in the large part of the world, especially in Asian countries. The major chemical constituent contents of rice are moisture, protein and starch (amylose and amylopectin). Those chemical constituents associate with eating quality of rice. The moisture content of rice is closely related to storage quality and milling characteristics. Protein and amylose contents are important constituent contents associated with texture and eating quality of cooked rice (Allahgholipour *et al.*, 2006). Texture of cooked rice greatly affects eating quality and is one of the most important quality factors of rice (Natsuga, *et al.*, 1999).

Environmental temperature during the ripening period of rice greatly affects amylose content in rice (Matsue *et al*., 2002; Kinoshita and Sato, 2004; Igarashi *et al*., 2009; Tanno, 2010; Yamaguchi *et al*., 2012; Tsujii *et al*., 2015). Lower environmental temperature during the ripening period of rice causes higher rice amylose content. Hokkaido is the northernmost island in Japan. In Hokkaido, therefore, the temperature of rice ripening period is lower than that in the other areas in Japan and rice amylose content increases than the other areas. East Asian people including Japanese, Korean and most of Chinese people prefer low amylose content rice, because it becomes soft and sticky cooked rice. Thus, Hokkaido makes effort in development of low amylose content rice cultivar.

In Hokkaido, we have bred low amylose rice cultivar called Yumepirika from 2008. Yumepirika is the original brand rice in Hokkaido. We want to make higher quality of rice. Thus, it was decided that the good taste combination of amylose and protein content about Yumepirika. For example, when amylose content is less than 19%, protein content is less than 7.5%, or when amylose content is 19% or more, protein content is 6.8% or less (Kawamura *et al*., 2013). The combination is selected finely. Therefore, there is a need for the highly accurate measurement of rice protein and amylose content.

Near-infrared (NIR) spectroscopy is one of the non-destructive methods for determining grain chemical contents. There have been many studies on the usefulness of NIR spectroscopy as a non-destructive method for determining chemical constituent contents of agricultural products such as grain, fruits and vegetable. Now, it has been shown that determination of moisture and protein contents of rice by NIR spectrometer is sufficiently accurate for practical use at rice grain elevators (Fujita *et al*., 2010; Li *et al*., 2013). However, the accuracy for determination of rice amylose content by NIR spectrometer is lower than those of moisture and protein contents. However, rice amylose content has great impacts on the eating quality of rice and farmer's income. Thus, there is a strong need for the highly accurate measurement of rice amylose content using non-destructive method such as NIR spectroscopy.

The overall objective of this study was to develop non-destructive and more accurate calibration model to determine rice amylose content for practical use at grain elevator.

2. MATERIALS AND METHODS

2.1 Rice Samples

For this study, a total number of 1069 milled rice samples were collected from Hokkaido, Japan. Table 1 shows the detail of the rice samples collected. The rice samples consisted of 14 cultivars of non-waxy Japonica-type rice grown in Hokkaido, Japan from 2008 to 2017. The cultivar names of the rice samples were Aya, Ayahime, Daichinohoshi, Fukkurinko, Hoshimaru, Hoshinoyume, Kitakurin, Kirara397, Nanatsuboshi, Oborozuki, Sorayuki, Yukihikari, Yumepirika and Yukisayaka. Ayahime, Aya, Oborozuki, Yumepirika and Yukisayaka are low amylose content rice cultivars, and the others are ordinary amylose content rice cultivars.

2.2 Reference (Chemical) Analysis of Amylose Content

Amylose content measurement was performed using an auto-analyzer (Bran-Luebbe, Solid Prep III, Tokyo, Japan) for reference (chemical) analysis following the protocol of Williams *et al*. (1958) with modifications by Inatsu (1988). The absorption of the amylose-iodine complex was measured at 620 nm with a spectrophotometer, and the apparent amylose content was quantified against a calibration curve. In this study, Hoshinoyume cultivar of rice (moisture content: 13.09%, amylose content: 21.12%) grown in Hokkaido and Hakuchoumochi cultivar of glutinous rice (amylose content: 0%) grown in Hokkaido were used as standard amylose contents to calculate the apparent amylose content (AAC) of each sample. Apparent amylose content was expressed as a percentage (%).

Table 1. Rice samples used in this study

production years	Aya hime	Aya	Daichi nohoshi	Fukku rinko	Hoshi maru	Hoshino yume	Kita kurinn	Kirara 397	Nanatu boshi	Oboro zuki	Sora yuki	Yuki hikari	Yume pirika	Yuki sayaka	Total
2008	2	1	3	10		18		33	41	12					120
2009			16	9		14		12	11	13			45		120
2010			7	4	1	19		20	25	19			42		137
2011			1	10		6		18	25	8			42		110
2012				3					5				34		42
2013			9	13		7	6	18	27	5			15		100
2014			6	7		4	2	27	28	3		1	21		99
2015			10	11		9	11	9	36	12	14		32		144
2016			4	13	6	1	4	6	29	3	2		33	1	102
2017			2	20	5		1	4	25	2	2		33	1	95
Total	2	1	58	100	12	78	24	147	252	77	18	1	297	2	1069

2.3 Calibration Model from NIR Spectrometer

Spectra data of milled rice were obtained using an NIR spectrometer (Shizuoka Seiki, BR-5000, Fukuroi, Japan) (Figure 1) with a wavelength range of 850 to 1048 nm with 2-nm intervals.

The Savitzky-Golay derivative was used for pretreatment. The chemometric techniques partial least squares (PLS) regression within the statistical software The Unscrambler (Version 10.3 Upgrade 10.3.0r4) were used for processing the data.

Calibration model to determine amylose content was developed using the rice samples (calibration set, n=974, including 14 cultivars) grown from 2008 to 2016. And Partial least squares (PLS) regression analysis was used to develop calibration model. The accuracy of the calibration model was validated using the other rice samples (validation set, n=95, including 10 cultivars) grown in 2017. Figure 2 shows the flow chart of developing calibration model and validating the accuracy.

Figure 1. NIR spectrometer, model BR-5000

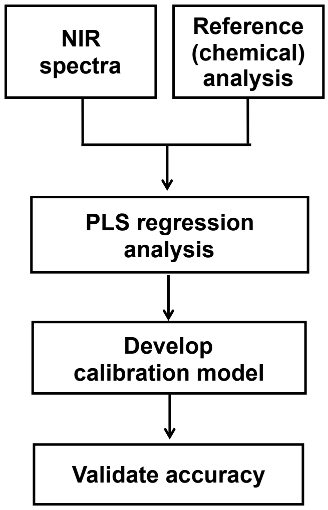

Figure 2. Flow chart of developing Calibration model and validating the accuracy

3. RESULTS AND DISCUSSION

The accuracy for determining amylose content of milled rice was shown in the following. Table 2 shows that when the production years for calibration set increased, standard error of prediction (SEP) values decreased and ratio of SEP to standard deviation of reference data (RPD) values increased. This means that the accuracy was improved by increasing production years of calibration sample set and this method got a step closer to practical use at grain elevator.

Amylose content of rice is affected by environmental temperature during the ripening period. In other words, the environmental temperature of each production years was different, amylose content of rice changed by each production year. Natsuga (1995) reported that to obtain high accuracy of calibration model, it is necessary to use samples collected over a period of several years. By increasing production years of calibration set, the information of variation in temperature and amylose content was added to the calibration model, then the accuracy of determination of milled rice amylose content was improved. This is the reason why the accuracy for calibration model increases when the production years for calibration set increases.

The correlation between reference (chemical) amylose content of milled rice and predicted amylose content of milled rice (calibration set: 2008 to 2016, validation set:

2017) is shown in Figure 3. The coefficient of determination (r^2) was 0.72, bias was -0.04%, SEP was 0.92% and RPD was 1.90. The production years of validation set (2017) was isolated from calibration set (2008 to 2016). This is the same condition in practical use of this non-destructive method at grain elevator. The result indicates that this method enables non-destructive determination of rice amylose content at grain elevator.

Table 2. Change of accuracy for determining amylose content of milled rice

calibtation set	n (2017)	r^2	Bias(%)	SEP(%)	RPD	Regression
3 years (2008-2010)	95	0.25	0.26	1.94	0.90	y=0.41x+12.5
4 years (2008-2011)	94	0.46	-0.99	1.40	1.25	y=0.67x+7.50
5 years (2008-2012)	95	0.41	-0.89	1.55	1.12	y=0.58x+9.19
6 years (2008-2013)	95	0.50	-2.00	1.27	1.37	y=0.80x+5.75
7 years (2008-2014)	95	0.49	-1.79	1.29	1.35	y=0.78x+6.09
8 years (2008-2015)	95	0.65	0.41	1.03	1.69	y=1.01x-0.72
9 years (2008-2016)	94	0.72	-0.04	0.92	1.90	y=0.99x+0.20

n: the number of validation set, r^2: coefficient of determination, Bias: difference of average values between predicted values and reference (chemical) values, SEP: standard error of prediction, RPD: ratio of SEP to standard deviation of reference data, Regression line: Regression line from predicted value (x) to reference value (y)

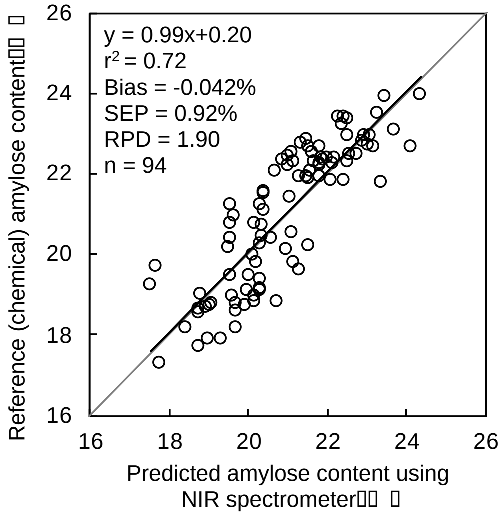

Figure 3. Correlation between reference (chemical) amylose content of milled rice and predicted amylose content of milled rice. This figure shows that the result which we validated the calibration model using 9-year production samples (2008-2016) for calibration set and 1-year production sample (2017) for validation set. Regression line is y=0.99x+0.20, r^2=0.72, Bias=-0.042%, SEP=0.92%, RPD=1.90, and n (the number of validation sample set)=94. (This result shows the most bottom of Table 2.)

4. CONCLUSION

The validation statistics between reference (chemical) amylose content and NIR spectrometer-predicted amylose content indicate that when the production years for calibration set increase, the accuracy for determining amylose content of milled rice improves. And in this study, the production year of validation set was isolated from that of calibration set. Thus, this is the same condition in practical use of this non-destructive method at grain elevator. The result obtained in this study indicates that the calibration model (developed using 9-year production samples (2008-2016)) enables non-destructive determination of rice amylose content at grain elevator.

5. ACKNOLEDGEMENTS

We thank for the Project of NARO Bio-oriented Technology Research Advancement Institution, Japan (the special scheme project on vitalizing, management entities of agriculture, forestry and fisheries) for their grant support.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Throughput Capacity and Efficiency Prediction at Variable Moisture Content and Chopping Time of Chopped Forages Using Response Surface Methodology (RSM)

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ABSTRACT

In this research, throughput capacity and efficiency prediction at variable Moisture content (Mc) and chopping time of chopped forages were examined using Response Surface Methodology (RSM) as a predicting tool. The experimental data used for prediction were obtained from the performance evaluation of a forage chopper. Three chopped forages were used for the evaluation including: Guinea grass, Siam weed and Maize Stover. Prediction was done after analyzing the experimental data by imputing assumed independent variables (Mc; 70, 80, 90… and chopping time; 100, 110, 120…) values into RSM package at an interval of 10 given rise to the predicted responses (Throughput capacity and efficiency) under the optimization note. The efficiency and throughput capacity obtained after point prediction were 97.02% and 54.76kg/h respectively at a predicted moisture content of 37.65% and operating time of 69secs. While 97.97% efficiency and 97.48kg/h throughput capacity at Mc of 62% and chopping time of 90secs are most desirable at 0.81 desirability. However, there was no significant difference ($P > 0.05$) between the predicted data and experimental data for chopping efficiency but significant ($P < 0.05$) for throughput capacity. It was also observed that forage chopping is most desirable at moisture content of 90%. More so, forages may be chopped between 90 to 150% moisture content for higher throughput capacity and chopping efficiency. Therefore, the experimental data obtained during this research may be used to forecast the operational behaviour of other forage choppers.

Keywords: RSM, Point Prediction (PP), Forage chopper, Mc.

1. INTRODUCTION

Historical data, machine learning and artificial intelligence are used to predict future happenings or otherwise unknown events. However, predictive analytics is the use of data, statistical algorithms and machine learning techniques to identify the likelihood of future outcomes based on historical data (SAS, 2018). The goal is to look beyond the known and as best assessment of what will happen in the future. Montgomery (2005) reported central composite rotatable design of response surface methodology for …….which is a statistical tool used in this work.

However, harvesting and storing forage at the proper moisture content is essential to producing a high-quality product for ruminant animals to aid digestion and absorption through size reduction of forages at reasonable moisture content. Susan *et al*. (2009) reported that forage moisture concentration can be estimated using hand method, moisture tester or drying forage in a microwave however, higher moisture content data beyond the experimental data was not reported. Silage is made from forages between moisture content of 40 to 85 percent prior to ensiling. Recommended ranges of moisture levels for various silage types are 70 percent to 85 percent for direct-cut silage, 60 percent to 70 percent for wilted silage, and 40 percent to 60 percent for low-moisture silage (Susan et al., (2009).

But forage parameters (Length, thickness, moisture content, texture, shape, density, etc.) determination is essential before designing a forage chopper because they go a long way in determining length of cut (Yinusa, 2016), operating time, machine efficiency and throughput capacity of forage choppers (Adgidzi, 2007; Ajav and Yinusa, 2015).
Therefore, this research examined throughput capacity and efficiency prediction at variable Moisture content (Mc) and chopping time of chopped forages using Response Surface Methodology (RSM) as a predicting tool.

2. METHODOLOGY

2.1 Sample Collection and Preparation

The data used for this work was obtained from the performance evaluation of the forage chopper designed as reported by Ajav and Yinusa (2015) and as shown in Table A1 of the Appendix. These data were used to carry out moisture content and chopping time predictions and their corresponding predictive effect on the efficiency and throughput capacity of the machine.

2.2 Data Analysis

The data obtained work was analyzed using response surface design expert of 6.0.6 version. The Response Surface Methodology (RSM) central composite was used as an initial design while quadratic model was suggested as the design model. Two responses Y_1 and Y_2 are the throughput capacity and efficiency of the machine respectively. The Lambda value was 1.0 which need no transformation because the ratios of maximum to minimum value of the responses were less than 10 but greater than 3.

2.3 The prediction

Prediction was done after analyzing the experimental data by imputing assumed independent variables (mc; 70, 80, 90… and chopping time; 100, 110, 120…) values into RSM package at an interval of 10 given rise to the predicted responses (Throughput capacity and efficiency) under the optimization note.

2.4 Box-Cox plot for power transformation (Diagnostics)

The Box-Cox plot (Figure 1) was used to observe the behavour of the normal curve which gave the best Lambda value of 0.78 (Green colour, Figure 1) that was close to the initial lambda value of 1.0 (Blue colour, Figure 1) used for the design. The low and high Confident Intervals (C.I) was -0.61 and 2.43 respectively (Table 1).

Table 1: Box-Cox and precision

Lambda		**Confident Intervals (C.I)**		**Adequate Precision**	**Desirable Precision**
Current = 1	Best = 0.78	Low = -0.61	High = 2.43	4.009	> 4

d. Variables

Factors	Responses
Moisture content, %	Throughput capacity, Kg/h
Chopping time, sec	Efficiency, %

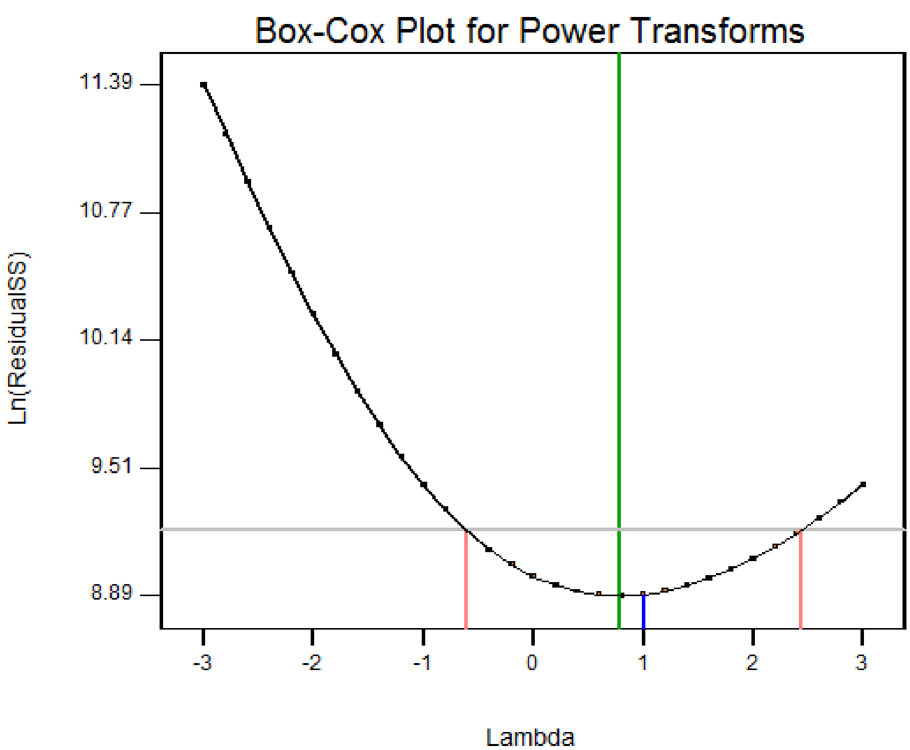

Figure 1: Box-Cox power transformation

3. RESULTS AND DISCUSSIONS

3.1 RSM statistical precision

Adequate precision measures the signal to noise (disturbance) ratio. A ratio greater than 4 is desirable as suggested by RSM but a ratio of 4.009 was obtained during the analysis which indicates an adequate signal as showed in Table 1. This shows that the model can be used to navigate the design space.

3.2 Effects of variable moisture contents at constant operating time on the predicted throughput capacity and efficiency.

Table 2 (Figures 2-10 of the appendix) showed the effect of moisture contents that range from 70-150% on throughput capacity and efficiency. It was observed that an increase in moisture content increases the throughput capacity while Saanoding *et al*. (2017) reported the effect of pulley diameters on throughput capacity as been increased at an increase in speed. Saanoding *et al.* (2017) did not consider the effect of moisture content on throughput capacity of forage chopper and they did not consider the most desirable pulley diameter for better throughput capacity. However, the throughput capacity (147.438 kg/h) at moisture content of 90% was most desired at 94.8% desirability level as showed in Table 2. And this may be due to the succulent property of the forages at higher moisture content and the ability of the machine parameters to crush forages with succulent cellular cells easily and to discharge such at discharge outlet.

More so, higher throughput capacities (229.337, 263.16, 300.242 and 340.502 Kg/h at desirability of 93.3, 92.8, 92.3, 91.8% respectively, (Table 2) were achieved (predicted) during this research as compared to the experimental evaluation reported by Ajav and Yinusa, 2015. Furthermore, it was observed that an increase in moisture content (70-150%) slightly decreases the efficiency from 97.8 to 96.06% of the forage chopper. However, efficiency of 97.36% at 90% moisture content was most desired (Table 2).

There was significant difference ($P < 0.05$) between the predicted data and experimental data for throughput capacity as showed in Table 3. However, Brian (2012) discovered that yield per acre and percent moisture of harvested corn silage were not significantly different for various forage harvester evaluated but he did not report if they are significant or not with individual forage harvester.

There was no significant ($P > 0.05$) difference between the predicted data and experimental data for efficiency of the machine as showed in Table 4. And this may be due to higher efficiencies obtained already and it may be unlikely for machine to attain 100% efficiency. Furthermore, other crop and machine parameters that were not considered may cause an increase in efficiency from 97.8% to higher efficiency.

3.3 Optimum moisture content prediction and its desirability

Table 2 showed that moisture content of the forages reached its optimum value at 90% and its maximum value at 150%. Because RSM suggested Mc of 90 and 150% as the most

(94.8) and least (91.8) desirable values respectively for throughput capacity and efficiency as showed in Table 2. Therefore, forages may be chopped between moisture content of 90-150%.

Furthermore, Table 2 showed that Mc has no resultant effect on the throughput capacity and efficiency of the machine beyond 150%. That is, No Result (NR) was obtained at Moisture content (Mc) of 160% and above (Table 2).

Table 2 Throughput capacity and Optimum Mc predictions and their desirability

Assumed Moisture content, %	**Chopping time, S**	**Throughput capacity, Kg/h**	**Efficiency, %**	**Desirability, %**	**Comment**
70	90	109.144	97.80	88.6	
80	90	126.66	97.58	93.7	
90*	90	147.43	97.36	94.8	Most desirable
100	90	171.47	97.15	94.3	
110	90	198.77	96.93	93.8	
120	90	229.33	96.71	93.3	
130	90	263.16	96.50	92.8	
140	90	300.24	96.28	92.3	
150**	90	340.58	96.06	91.8	
160	90	NR	NR	NR	
170	90	NR	NR	NR	

NR = No Result, *= optimum MC predicted, ** = Maximum MC predicted

Table 3: t-Test between the predicted throughput capacity and experimental throughput capacity at predicted moisture content of 70-150%

Statistics	*Predicted throughput capacity, kg/h*	*Experimental throughput capacity, kg/h*
Mean	209.6426667	88.31666667
Variance	6379.505794	952.36705
Observations	9	9
Pooled Variance	3665.936422	
Hypothesized Mean Difference	0	

Df	16
t Stat	4.250770638
P(T<=t) one-tail	*0.000305105
t Critical one-tail	1.745883676
P(T<=t) two-tail	*0.000610209
t Critical two-tail	2.119905299

*Significant at 0.05

Table 4: t-Test between the predicted chopping efficiency and experimental chopping efficiency

Statistics	predicted chopping efficiency	experimental chopping efficiency
Mean	96.93	97.08888889
Variance	0.353175	17.19111111
Observations	9	9
Pooled Variance	8.772143056	
Hypothesized Mean Difference	0	
Df	16	
t Stat	-0.113801224	
P(T<=t) one-tail	**0.455405561	
t Critical one-tail	1.745883676	
P(T<=t) two-tail	**0.910811122	
t Critical two-tail	2.119905299	

**Not Significant at 0.05

3.4 Effect of variable chopping time at constant Mc on the predicted throughput capacity and efficiency of forage chopper.

Table 5 showed the effect of chopping time on throughput capacity and efficiency. The throughput capacity and efficiency initially increase and remain constant (Table 5). However, No Result (NR) was obtained at chopping time of 180s and above and throughput capacity and efficiency of the machine were most desirable (99.7%) at 118.75s chopping time.

Table 5: Effect of variable chopping time on the predicted throughput capacity and efficiency of forage chopper.

Predicted Chopping time, S	Moisture content, %	Throughput capacity, Kg/h	Efficiency, %	Desirability, %	Comment
100	**62**	120.92	98.67	94.1	
110	**62**	149.93	99.38	98.9	
120 (118.75)	**62**	179.89	100	99.7	Most desirable
130	**62**	179.89	100	97.3	
140	**62**	179.89	100	95.2	
150	**62**	179.89	100	93.3	
160	**62**	179.89	100	91.6	
170	**62**	179.89	100	90.0	
180	**62**	NR	NR	NR	
190	**62**	NR	NR	NR	
200	**62**	NR	NR	NR	

4. CONCLUSIONS

In this research, throughput capacity and efficiency were predicted from existing experimental data of an evaluated forage chopper. Higher throughput capacities (229.337, 263.16, 300.242 and 340.502 Kg/h at desirability of 93.3, 92.8, 92.3, 91.8% respectively, Figures 3.6-3.9) were achieved (predicted) during this research as compared to the experimental data reported by Ajav and Yinusa, 2015. There was no significant difference ($P > 0.05$) between the predicted data and experimental data for chopping efficiency but significant ($P < 0.05$) for throughput capacity. It was also observed that forage chopping is most desirable at moisture content of 90%. More so, forages may be chopped between moisture content of 90 to 150% for higher throughput capacity and chopping efficiency. No Result (NR) was obtained at Moisture content (Mc) of 160% and above. No Result (NR) was obtained at chopping time of 180s and above and throughput capacity and efficiency of the machine were most desirable (99.7%) at 118.75s chopping time. Therefore, the experimental data obtained during this research may be used to forecast the operational behavour of other forage choppers.

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6. APPENDIX

Table A1: Experimental data

Samples trials	Weight of output, kg	Output capacity, kg/h	Weight of material in chamber, kg	Operating time, s	Weight of uncut material, kg	Total weight input, kg	Moisture content, %	Chopping efficiency, %
Guinea Grass								
1st	2.200	132.0	0.020	60	0.030	2.245	24.4	98.7
2nd	1.476	88.56	0.060	60	0.028	1.564	23.3	98.2
3rd	1.474	88.44	0.096	60	0.056	1.626	20.0	96.6
Siam weed								
1st	1.606	96.36	0.023	60	0.000	1.629	21.4	100
2nd	1.767	106.0	0.025	60	0.000	1.792	16.6	100
3rd	1.777	106.6	0.027	60	0.027	1.824	13.3	98.9
Maize Stover's								
1st	1.619	97.14	0.249	60	0.118	1.986	42.0	94.1
2nd	0.438	29.20	0.010	54	0.000	0.448	30.0	100
3rd	0.674	50.55	0.079	48	0.110	0.863	23.0	87.3
Mean	1.448	88.32	0.065	58	0.041	1.553	22.8	97.09

Samples trials	Weight of output, kg	Output capacity, kg/h	Weight of material in chamber, kg	Operating time, s	Weight of uncut material, kg	Total weight input, kg	Moisture content, %	Chopping efficiency, %
Guinea Grass								
1st	2.272	90.88	0.448	90	0.018	2.738	62	99.3
2nd	2.430	97.20	0.113	90	0.020	2.563	57	99.2
3rd	1.600	64.00	0.040	90	0.000	1.640	36	100
Maize Stover's								
1st	1.399	55.96	0.274	90	0.179	1.852	54	90.3
2nd	1.875	75.00	0.212	90	0.176	2.263	59	92.2
3rd	1.189	47.56	0.069	90	0.064	1.322	46	95.2
Siam weed								
1st	1.285	51.40	0.148	90	0.050	1.483	58	96.6
2nd	1.704	68.16	0.049	90	0.000	1.754	53	100
3rd	1.403	56.12	0.002	90	0.003	1.408	26	99.8
Mean	1.684	67.37	0.152	90	0.057	1.891	50	96.95

Source: Ajav and Yinusa (2015)

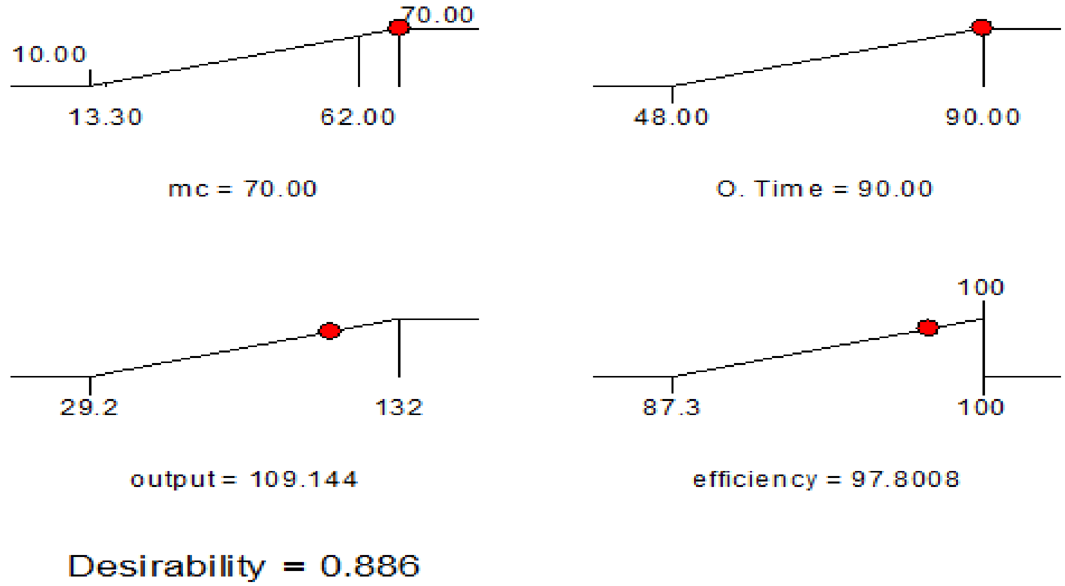

Figure 2: Throughput capacity and efficiency of a forage chopper at a predicted Mc of 70%.

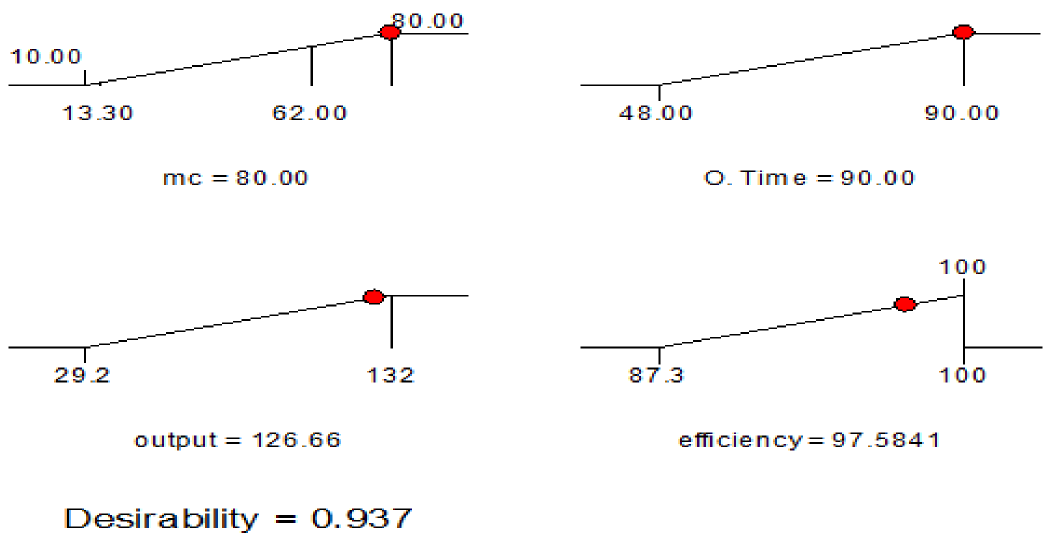

Figure 3: Throughput capacity and efficiency of a forage chopper at predicted Mc of 80%.

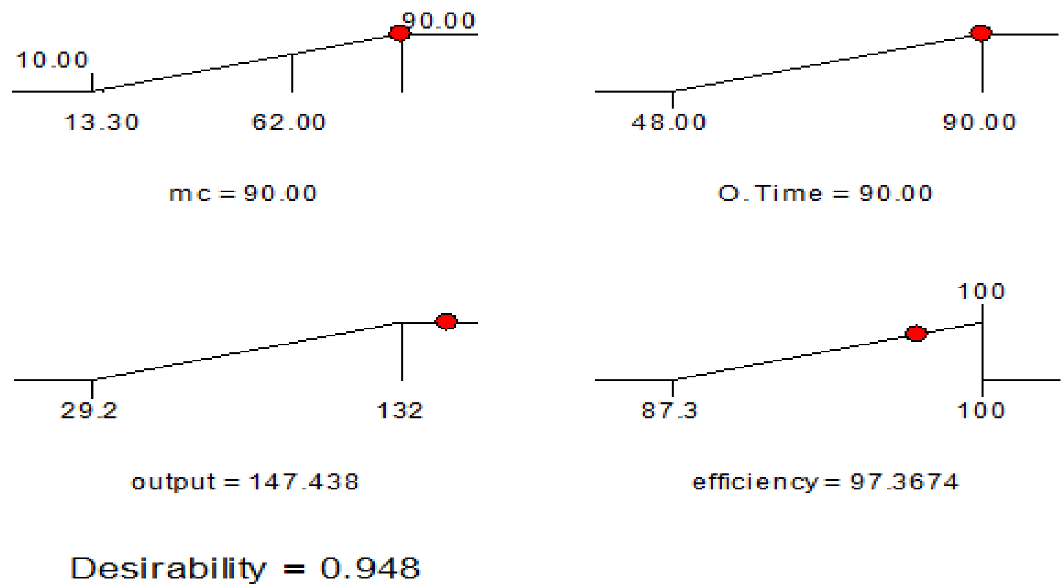

Figure4: Throughput capacity and efficiency of a forage chopper at a predicted Mc of 90%.

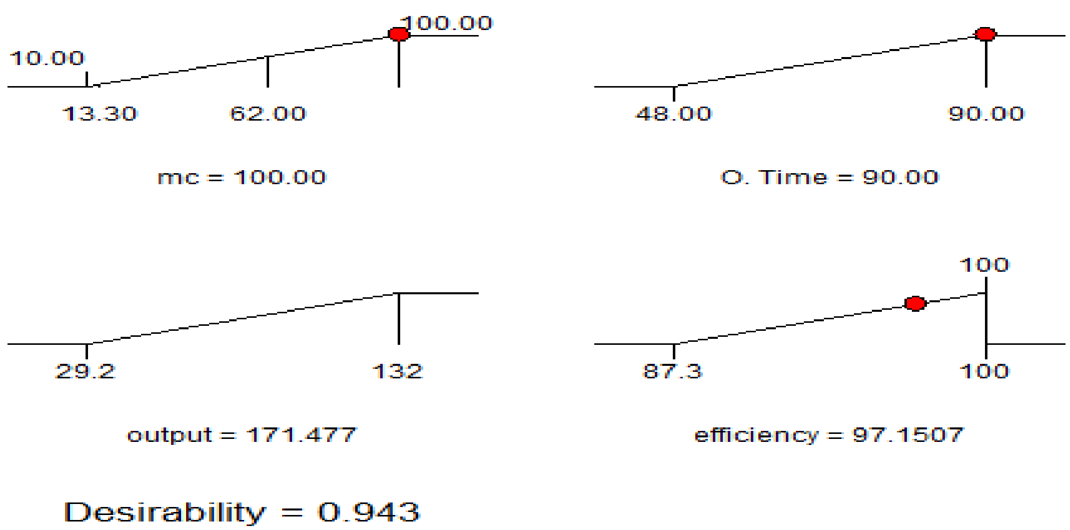

Figure 5: Throughput capacity and efficiency of a forage chopper at a predicted Mc of 100%.

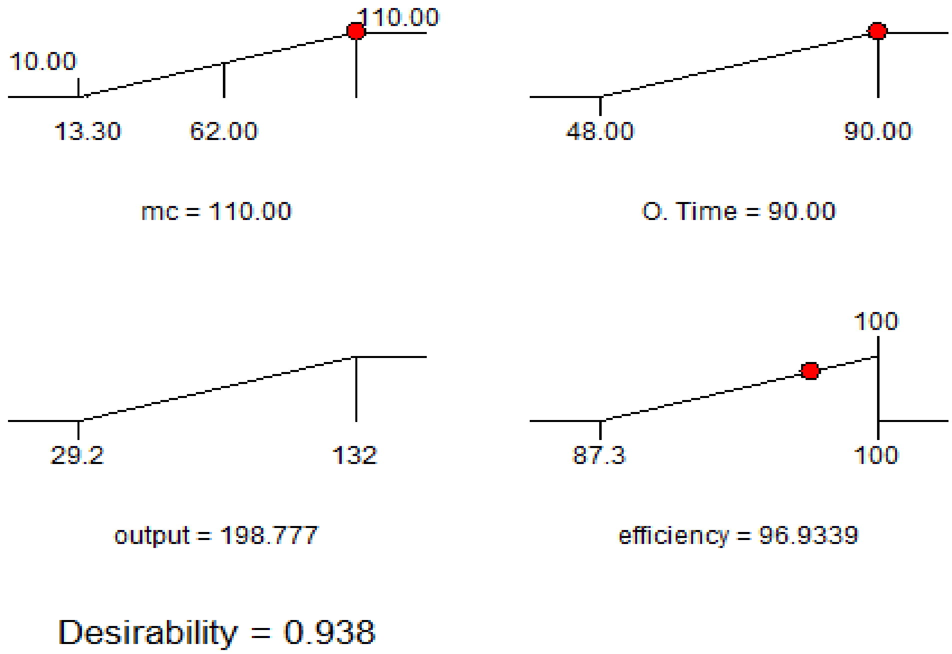

Figure 6: Throughput capacity and efficiency of a forage chopper at a predicted Mc of 110%.

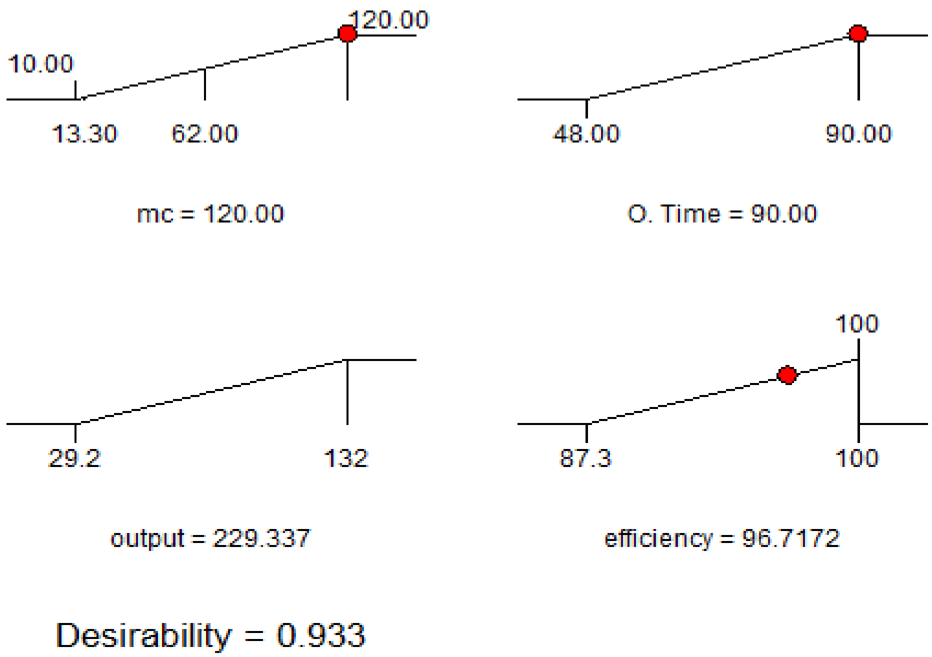

Figure 7: Throughput capacity and efficiency of a forage chopper at a predicted Mc of 120%.

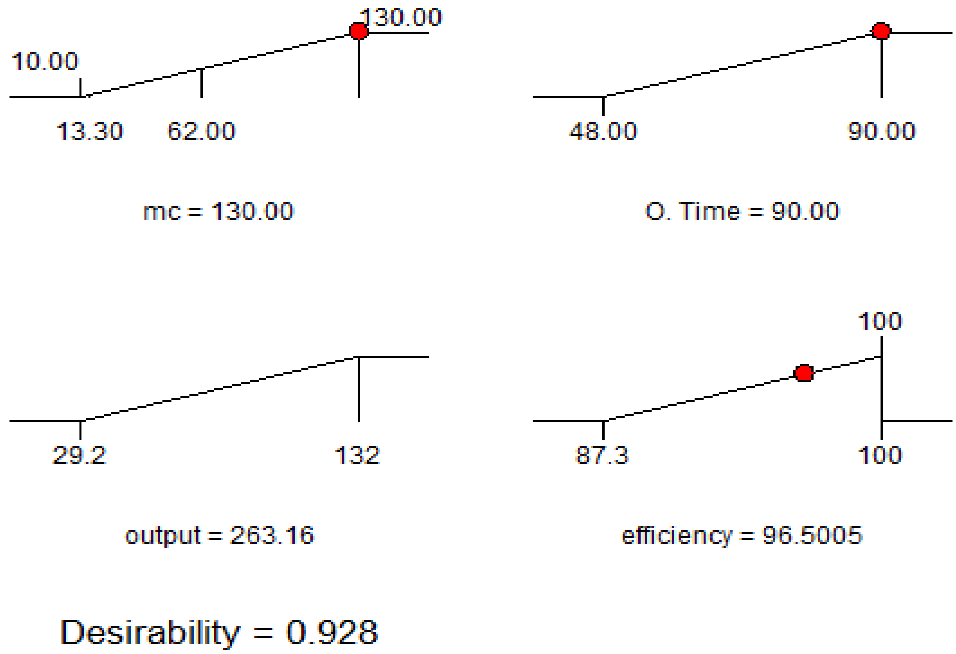

Figure 8: Throughput capacity and efficiency of a forage chopper at predicted Mc of 130%.

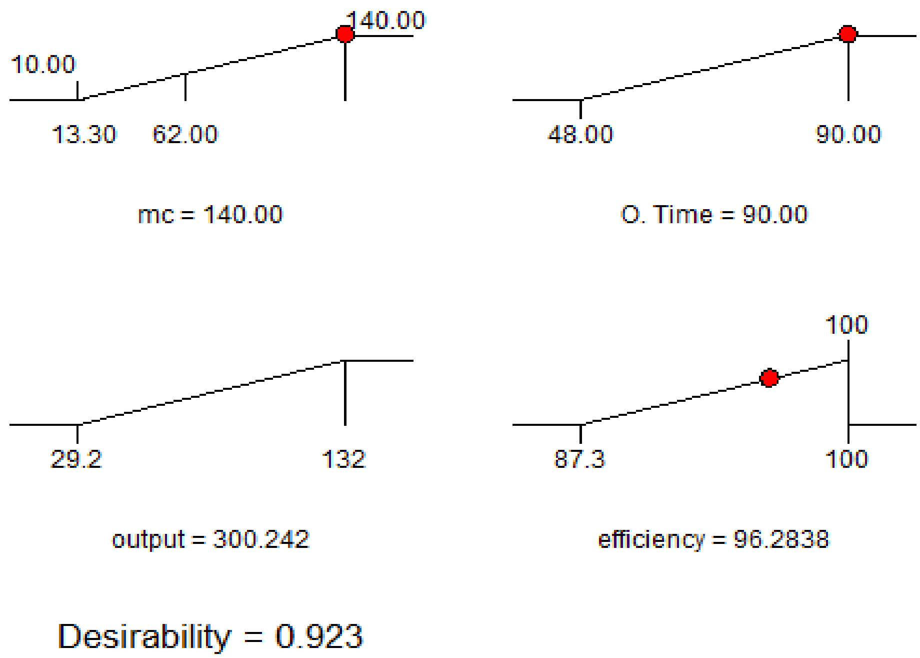

Figure 9: Throughput capacity and efficiency of a forage chopper at predicted Mc of 140%.

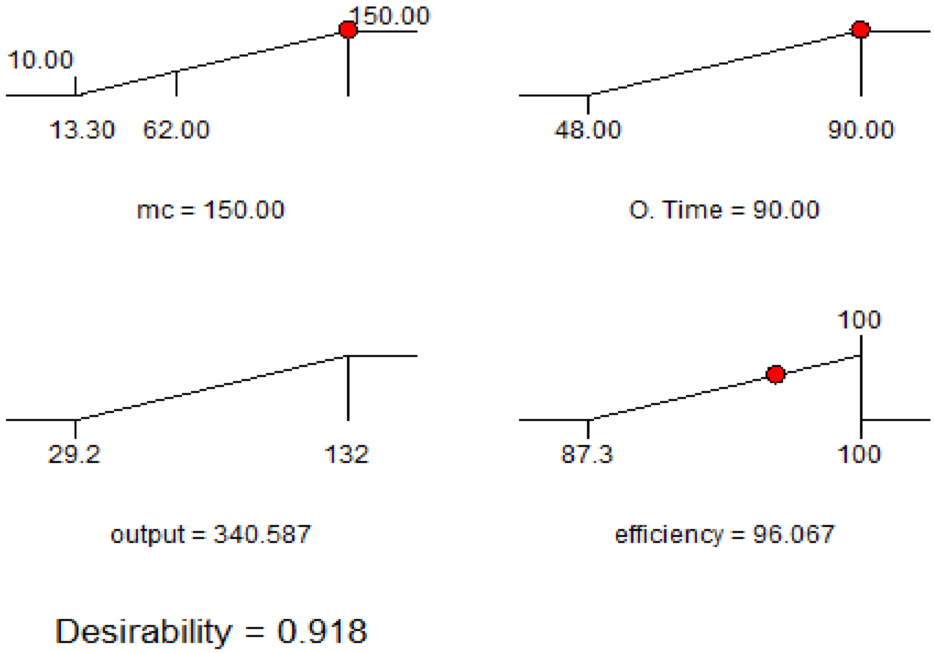

Figure 10: Throughput capacity and efficiency of a forage chopper at predicted Mc of 150%.

Development of a Charcoal Fired Fish Dryer for Micro and Small Scale Processors

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ABSTRACT

Fish is an important component of human and livestock diets worldwide. It has high nutritional values. Fish provides nourishing foods and it is often cheaper than meat, and it is available in large quantity. Conversely, fresh fish has a very short shelf life and the traditional method of its preservation is time consuming and unhygienic. This research was carried out to develop a charcoal fired fish dryer. The development of the fish dryer was based on some fundamental drying parameters and assumptions which were used in calculating some basic operational features of the dryer. The design of the dryer was done using catfish *Clarias gariepinus* with initial moisture contents of 75%, recommended final moisture content of 25% and maximum drying temperature of 55 ^{0}C. The dryer is a cabinet type made for micro and small scale processor. It has capacity of 10 kg per batch.The efficiency of the dryer was found to be 80.85 % at 70 rpm fan speed.The drying rate was found to vary significantly with the drying time ($p< 0.01$). The fish dries at falling rate at beginning and subsequently it dries at constant rate. The tray position and the fan speed have no significant effects on the drying rate of fish. This implies that there is even distribution of heat in the drying chamber.

Keywords: Design, construction, evaluation, charcoal, fish dryer, small-scale, processor, Nigeria

1. INTRODUCTION

Fish are vertebrate animals with gills that live inside water (aquatic). Fish is an essential source of food, income, employment, and recreation for people around the world and it is a very important source of animal protein for both man and livestock in developed and developing countries (Emmanuel *et al.*, 2014). There are several species of fish consumed as food in all region of the world. According to Ayyappan and Diwan (2003), fish supplies approximately 6% of global protein. In most developing countries where there is high rate of malnutrition, fish provides nutritious food which is often cheaper than meat and therefore available to a larger number of people (Ogunleye and Awogbemi, 2006). Fishes are known to be important sources of high quality protein, carbohydrate, lipid, ash, vitamins. In a proximate analysis of some fishes, Dhaneesh *et al*. (2012) found that major amino acids in the fish were lysine, leucine and methionine, ranging 2.84–4.56%, 2.67–

4.18% and 2.64–3.91%, respectively. Fatty acid compositions registered from 31.63% to 38.97% saturated fatty acids, 21.99–26.30% monounsaturated fatty acids, 30.32–35.11% polyunsaturated fatty acids and 2.86–7.79% branched fatty acids of the total fatty acids. The Omega-3 and Omega-6 were ranged 13.05–21.14% and 6.88–9.82% of the total fatty acids, respectively.

However, fresh fish has a very short shelf life (GERES, 1997). Spoilage begins as soon as the fish dies and processing should therefore be done quickly to prevent the growth of moulds and bacteria on it. Fish preservation methods/techniques according to Peter and Ann (1992) include: cooking (roasting, boiling or frying), salting, smoking and drying collectively known as curing (lowering the moisture content) and fermentation (lowering the pH). Fish smoking or drying is a primordial method of fish preservation against quick spoilage. The purpose of fish drying is to reduce the moisture content of the fish thereby retarding the growth of micro-organisms that are responsible for the spoilage. Drying can be achieved using different sources of energy inside a gadget (dryer). Some energy sources are solar, gas, charcoal, electricity and fire wood. Dryers are of different types and categories. They work on the same basic principles: energy generation, energy distribution, moisture migration and drying process. Common types of dryer are bin (silo) dryers, cabinet (tray) dryers, tunnel (truck) dryers, belt dryers, rotary dryers, fluidized bed dryers, pneumatic (flash) dryers, spray dryers, drum dryers, vacuum dryers, and freeze dryers. Drying process is a heat and mass transfer phenomenon where, due to application of heat energy, moisture migrates from the inner part of the product and moves to the surface from where it evaporates by diffusion.

Commercially, the major species of fish cultured in Nigeria include tilapias, salmon, catfish and carp. However, the African catfish species (*Clarias gariepinus* or *lazera*) are the most resistant and widely consumed in Nigeria (Emmanuel *et al.*, 2014). Fish farming involves raising fish commercially in ponds, fish cage in natural waterways, re-circulating aquaculture system (RAS), tanks or enclosures.The problem of postharvest processing and storage of fish has always been preventing the micro and small scale fish farmers from thriving well in their business. Presently in Nigeria, the mechanization level of fish processing is low (George *et al.*, 2014). This implies that majority of fish processing businesses in the country are in micro and small scale level using the traditional method. The national directorate of employment definition of small business enterprise is the one able to accommodate project with capital investment as low as N5,000 and employing as few as three persons (Francis, 2009). Balachandran (2001) observed that the traditional method of drying of fish is associated with some drawbacks as follows:

i. It usually takes longer time before it get dried thereby give room for mould and bacteria growth on the fish before fully dried.
ii. It is exposed to birds, animals and most likely rain and this may lead to a great loss.
iii. There is high possibility of contamination with dust, sand and infestation with insects (eggs and larvae).

iv. Shelf life of fish product is always not too long and poor quality final produced in most cases, resulting in losing significant amount of fish by the fish farmers.

In Nigeria, several efforts have been made by researchers to solve some of the drawbacks. Such efforts were: A multi-crop dryer developed by Omodara and Ade (2008) to dry crops has been used in recent time to dry cat fish. In operation a kerosene stove was placed in the heating chamber to supply the heat. Heat exchanger was used to prevent the smoke coming from the Stover from getting to the drying chamber. The fish dried in the dryer has a better quality and was to a greater extent free of smoke. However, there were cases of smoke contamination in some drying tests. Ilechie *et al.* (2010) developed an active solar dryer with adjustable air flow rates for agricultural products. Test results showed that a drying period of 8-11 hours was obtained by using the solar dryer in conjunction with the suction fan at 27.29 m^3/s suction rate. It was reported the dryer performed satisfactorily compared with drying period of 42-50 hours obtained from using open sun drying method. Akande and Adeyemi (2016) developed a detachable fish smoking kiln, Performance evaluation conducted on the equipment using fresh water catfish (*Clarias gariepinus*) (average live weight of 350 g ± 50 g per piece) as test organism showed that the kiln has a batch capacity for processing 50 kg live weight (average moisture content, 72 % w. b.) of *Clarias gariepinus* to smoked dried fish (average moisture content, 5.5 % w.b.) in 10 h when operated at 110 ^{0}C ± 10 ^{0}C. One major limitations of most of the existing fish dryers/smokers is that all the smoke generated from the combustions chamber are channeled to the product in the drying chamber. This could bring about food contamination with polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of chemicals that are harmful and are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances (Mumtaz and George, 1995). The present study is a complement of efforts of previous works to ameliorate the drawbacks associated with traditional methods. The objectives of this study are therefore to design and construct a portable charcoal fired fish dryer with less smoke contamination for micro and small scale processors and also to determine the effect of fan speed and tray position on the drying rate of catfish *Clarias gariepinus* in the fish dryer. The development of the fish dryer will assist the micro and small scale fish processors to produce qualitative fish quickly and under hygienic condition. These add value to the product and make it to attain international market standard.

2. MATERIALS AND METHODS

2.1 Design considerations

The following considerations were made for effective design of the fish dryer;

1. Quantity of fish to be dried per batch was assumed to be 10 kg. This is to suit the needs of micro and small-scale processor.
2. Use of locally available materials for easy maintenance.
3. Simplicity to ease construction, usage and maintenance.
4. Durability to withstand adverse weather condition and rough handling by the operator.

5. Low initial and operating costs because of the frequent nature of usage and low financial capability of the end users.
6. Initial moisture content of fresh fish and final moisture content were considered this is to determine the amount of energy needed to carry out the drying and also for safety of the dried product.
7. Wire gauze was selected for the dryer bed because it allows air movement through it freely.
8. Average ambient temperature and relative humidity for Kano Area was considered.

2.2 Materials

Material selection for the fish dryer was based on availability, suitability to the working conditions in service and cost.

Table 2.1: Materials Specification and Quantities

S/N	MATERIALS	SPECIFICATIONS	QUATITIES
1	Galvanized metal sheets	2mm thick	3
2	Square Pipes	Lengths	3
3	Wire mesh	1.0 x 0.5 m	3
4	Charcoal pot	1	1
5	Fan	50 Watts	2
6	Pair of hinges	40mm size	2
7	Lagging material	Wool fiber	Lump
8	Lock	50 mm size	1
9	Rivet nails	½ inches	1 pack
10	Handles		2

2.3 Drying parameters and standards

The criterion followed in the development of the fish dryer was based on some fundamental drying parameters and assumptions which were used in calculating some basic operational features of the dryer. The dryer was assumed to be a cabinet square shaped having a chimney on top. It was designed for small scale processor of dried fish with initial moisture content of the fish 75%, recommended final moisture content of the dried fish 25-30%, maximum temperature 55^{0}C (GERES, 1997).

2.4 Design Calculations

2.4.1 Determination of the amount of moisture to be removed from the fish

The amount of moisture to be removed was calculated using Equation (1) according to Ichsani and Dyah (2002):

$$Mw = \frac{\mathrm{W1}\ (Mi - Mf)}{100 - Mf} \tag{1}$$

Where,
Mw = weight of moisture to be removed (kg)
W_1 =weight of fish to be dried per batch (10 kg)
Mi = initial moisture content of fish (75%)
Mf =final moisture content of fish (25-30%) use the minimum value (25%)
Therefore,

$$Mw = 6.63\ \text{kg}$$

2.4.2 Energy required in evaporating the available moisture

In order to determine the quantity of charcoal needed for the dryer, the quantity of heat energy required was calculated from Equation (2) according to Axtell (2002):

$$Q = W_m Cpm(T_2 - T_1) + I_v M_w \tag{2}$$

Where,
Q is the amount of heat energy in kJ,
W_m= weight of the materials to be dried= 10 kg
Cpm = specific heat of fish = 3.6kJ/kg^{o}C (Radhakirshnan, 1997)
T_2 = temperature of air inside dryer =55^{o}C. (GERES, 1997)
T_1 = minimum ambient air temperature in Kano = 15^{o}C (WWCI, 2017)
I_v = heat of vaporization at 55^{o}C =2381.65 kJ/kg (Duffie and Becbman, 1980)
M_w = weight of moisture to be removed from the fish 6.625 kg
Q = 17218.43 kJ

2.4.3 Determination of the surface area of the drying cabinet

Volume occupied by fish to be dried can be determinedas:

$$V = \frac{Mf}{BDf} \tag{3}$$

Where,
V = volume of fish (m^3)
M_f = mass of fish (kg)
BD_f= bulk density of cat fish = 497.22kg/m^3 (determined)
Therefore, the volume occupied by 1 batch (10kg) catfish is estimated as: V = 0.0201 m^3
Area of the Drying Cabinet can be obtained from,

$$A = \frac{V}{A_f} \tag{4}$$

Where,
A = Area occupied by fish (m^2)
A_f= cross-sectional area of fish, A_f = 0.05 m (measured average of 20 fishes)
Therefore,A = 0.40224 m^2
Hence, area of each of the three trays of the dryer will be 0.13408 m^2
For square shaped cabinet dryer
$A_t = X^2$
Where,
A_t = area of a tray (m^2)
X = one side of the tray or tray dimension (m)
Therefore, X = $\sqrt{A_t}$
X = 0.3662m

2.4.4 Determination of the quantity of air needed for drying the fish.

The quantity of air required was determined according to Ajisegiri *et al.* (2006) as:

$$Qa \ \frac{Mw}{Hr2 - Hr1} \quad (5)$$

Where,
Qa = quantity of air needed for drying kg/s
H_{r1} = initial humidity ratios (kg/kg dry air)
H_{r2} = final humidity ratios (kg/kg dry air)
H_{r1} = 0.003268 kg/kg dry air, psychometricchart values at minimum ambient temperatures 15 ^{0}C for dry bulb, 7.36 ^{0}C for wet bulb and relative humidity of 30%
H_{r2} = 0.003268 kg/kg dry air psychometric chart values when the sensible heat has been supplied the dry bulb temperature increased to 55 ^{0}C.
Therefore, Q_a = 234.17 kg
Drying time was considered as 7h per batch
Therefore, $Q_a = \frac{234.17}{7}$
Q_a = 34.45 kg/h or 0.00929kg/s

2.4.5 Volume of air to effect drying in m^3 (V_a)

The volume of air to effect drying as determined as presented in Equation (6) (Ajisegiri *et. al.*, 2006).

$$M_v = Q_aV_s \quad (6)$$

Where,
M_v = volumetric flow rate of drying air in (m^3/s)
Q_a = mass of drying air is 0.00929 kg/s
V_s = specific volume of dry air (m^3/kg)
V_s= 0.82 m^3/kg psychometric chart value at 15^{0}C (T_1) and 30% relative humidity.
From equation (6)
M_v= 0.0076 m^3/s

2.4.6 Design for quantity of charcoal needed for combustion

The quantity of charcoal needed to be burned in the combustion chamber can be determined using:

$$Q_c = \frac{Q}{C_c} \tag{7}$$

Where,
Q_c = quantity of charcoal needed for combustion in kg;
Q = amount of heat energy required for drying = 17218.43 kJ;
C_c= 6552 kJ/kg calorific value of charcoal (Onomeaugustina, 2013)
Therefore, Q_c = 2.63 kg

2.4.7 Description of the Dryer

The dryer was designed to work on the principle of convective heat transfer. It is made of five units, namely combustion chamber, drying chamber, heat circulation unit, chimney and the frame (Figure 1). The combustion chamber consists of a rectangular ladle containing charcoal with perforation below it. A smoke vent is provided above the combustion chamber to reduce the amount of smoke that enters into the drying chamber. There is air blowing fan by the burner in the combustion chamber which helps in keeping the fire on and assisting complete combustion of the charcoal to minimize PAHs.The combustion chamber supplies the needed heat to remove the moisture from the products. The drying chamber is made up of three trays made from wire mesh on which the fish is arranged for drying.The heat circulation unit consists of a sucking fan and plenum. This is located between combustion chamber and the drying chamber. The fan sucks hot air from the combustion chamber and the plenum allows the even distribution of the hot air in the drying chamber. At the top of the dryer is a chimney which removes the moisture in the drying chamber to the surrounding.

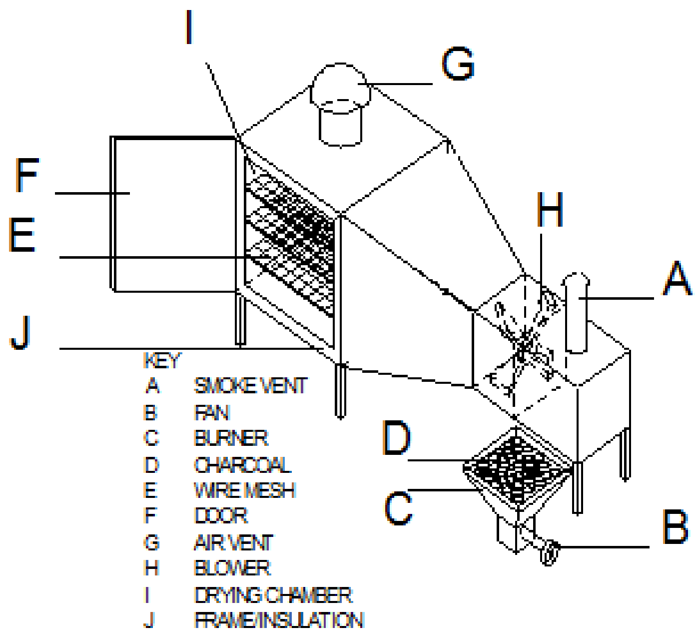

Figure 1: Isometric view of the Fish Dryer

2.4.8 Performance Evaluation of the Fish Dryer

i. Dryer efficiency (η)

In testing the dryer's performance, drying efficiency was determined using the formula given by Ikenweiwe *et al.,* (2010):

$$\eta = \frac{T1 - T2}{T1 - Ta} \times 100\ \% \qquad (8)$$

Where,

η= drying efficiency (%)

T_1= inlet air temperature into the dryer (°C)

T_2 = outlet air temperature from dryer (°C)

T_a= ambient air temperature 20°C

ii. Drying rate (DR)

The drying rate can be expressed mathematically as:

$$DR = \frac{M_{t+dt} - M_t}{dt} \qquad (9)$$

(Ceylan *et al.,* 2007)

Where,

M_t = moisture content at t (g water/g dry matter)

M_{t+dt} = moisture content at $t+dt$ (g water/g dry matter)

dt = time intervals (h)

2.4.9 Experimental Design

Dryer efficiencies were determined at three fan speeds levels (S1, S2 and S3) in three replications and average values for each speed levels were recorded. Using drying rate a performance index, treatments were randomly assigned in 7 × 3 × 3 factorial experiment in a randomized complete block design (RCBD) with the five drying time intervals (T1, T2, T3, T4, T5, T6, and T7), three trays positions (P1, P2 and P3) and three fan speeds (S1, S2 and S3). Data collected were subjected to analyses of variance using the SAS 9.2 Software package. Post hoc analysis were carried out using the least significance difference (LSD) for further comparison of the factors of the independent variables that have significant effect.

3. RESULTS AND DISCUSSION

3.1 Efficiency of the fish dryer

The effect of fan speed on the efficiency of the fish dryer is shown in Table 1. The efficiencies of dryer were calculated to be 61.36, 70.73 and 75.68 % for the fan speeds of 30, 50 and 70 rpm respectively. The results show that efficiency of the fish dryer increase with fan speed. This is probably because the disparities between inlet and out let temperatures were higher at the high speed fan than lower speeds. Similar results were obtained in a parabolic trough solar collector used for dehydration of apricots by Hanif *et al.* (2013). The author reported that air mass flow rates significantly ($P< 0.000$) affected drying efficiency of apricot. The results also corroborate with Kaplan and Celik, (2012) who found that the increase in the flow rate of drying air increased the performance of drying of Turkish Pine woodchip. Though, the study revealed that the drying air flow rate should not exceed 30 m^3/h as higher flow rates create operational problems such as woodchip blowing out from the chimney and the material feed inlet.

Table 1: Effect of Fan Speed on the Efficiency of the Fish Dryer

Speed (rpm)	Mean inlet Temperature (°C)	Mean outlet Temperature (°C)	Ambient Temperature (°C)	Efficiency (%)
30	64	37	20	61.36
50	61	32	20	70.73
70	67	29	20	80.85

3.2 Drying rate of fish

The analysis of variance for the effect of tray position and the fan speed on the drying rate of fish is shown in Table 2. From the results obtained, it can be deduced that only drying time was statically significant ($p< 0.01$). However, tray position and fan speed and interactions of both were not significant. These results implies that there is even distribution of heat in the drying chamber hence tray position at which the fish is kept does not affect the drying rate and physically, there was no smoke contamination observed on the dried fish.

Table 2: ANOVA showing the effect of drying time interval, tray position and fan speed on drying rate of fish.

Source of Variation (Sv)	Degrees of freedom (DF)	Sum of Squares	Mean Square	F-value	Pr>F
Time (TM)	6	27723.573	4620.59542	$1.279E8^{**}$	<0.0001
Block					
Tray (TRY)	2	0.00003	0.00001	0.39^{NS}	0.6778
Speed (SPD)	2	0.00002	0.00001	0.21^{NS}	0.8123
TRY x SPD	4	0.00007	0.00002	0.50^{NS}	0.7324
ERROR	48				
Total	62				

** Significant at 1% ^{NS} Not significant

Least square difference showing the effect of drying time on drying rate of fish is presented in Table 3. It can be seen that the drying rate decreases with increase in drying time. The results show that drying rate was significant ($p< 0.01$) in the first 60 minutes (T1) of drying and subsequently there is no significant difference between the drying rates at T2 through T6. These could be attributed to free water present in the fresh fish at the beginning of drying. This implies that the fish dries at falling rate at beginning and subsequently it dries at constant rate (Fellow, 2000). Average drying rate of the catfish is 8.62 g/h. This is higher than 2.4 g/h obtained for catfish by Omodara and Ade (2008) but lower than drying rate of 40 g/h for tomatoes by Ehiem (2009).

Table 3: LSD Showing the Effect of Drying Time on Drying Rate of Fish.

Drying Time	Mean Values	LSD
T1	60.000	A
T2	0.063	B
T3	0.061	B
T4	0.060	B
T5	0.059	B
T6	0.059	B
T7	0.008	C

4. CONCLUSION

A charcoal fired fish dryer was successfully designed, constructed and evaluated. Dryer efficiency was found to increased with fan speed. Drying time has significant effect on the drying rate ($p< 0.01$) but, tray position and fan speed were not significant on the drying rate. Drying rate decreased with increase in drying time. The fish dries at falling rate at beginning and subsequently it dries at constant rate. Physically, there was no smoke contamination observed on the dried fish. The following recommendations were made for further improvement of the fish dryer.

1. During testing of the dryer, it was observed that there was heat loss in the combustion chamber due to lack of lagging. In subsequent works, the combustion chamber of the dryer should be lagged to minimize the heat loss.
2. Quality of fish dried from the gadget should be compared with the traditional smoked fish.

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Assessment of Heavy Metals Uptake by Vegetables Cultivated on Soil Receiving Industrial Wastewater in Minna, Nigeria.

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ABSTRACT

Consumption of vegetable crops grown on soil irrigated with industrial wastewater has been the order of the day in most urban towns and cities of Nigeria, despite reports of its serious health impact. This study assessed the possibility of uptake of heavy metals by crops grown on soil receiving industrial wastewater during rainy and dry seasons. The crops investigated are Spinach, Cayenne Pepper, Jute mallow, roselle and lady's fingers okra. The initial composition of the wastewater was analyzed to contain 0.89 mg/l of chromium, 0.74 mg/l of cadmium, 1.04 mg/l of copper and 2.81 mg/l of iron. Control water used for this experiment contain no trace of any of these heavy metals. The experimental soil was also analyzed and contained 0.10 mg/kg of chromium, 0.06 mg/kg of iron before irrigation in dry season. After irrigation at the wastewater plots, the heavy metal concentrations in soil had increased to 6.24 mg/kg of chromium and 7.50 mg/kg of iron. In wet season, the concentrations of heavy metals in the soil were 0.00 mg/kg of chromium and 2.32 mg/kg of iron before irrigation. After irrigation in wet season, the concentrations increased to 6.01 mg/kg of iron. Mean difference of heavy metal concentrations were significantly high in vegetables in dry season, with values ranging from 0.03 mg/kg to 211mg/kg in wastewater plots, 0.20 mg/kg to 215 mg/kg in wet seasons wastewater plots, 0.00 mg/kg to 157 mg/kg in dry season. It is however recommended that consumption of vegetables irrigated with domestic/industrial wastewater be strongly discouraged because of its serious health implications.
Keywords: Wastewater, heavy metals, uptake, health risk index, daily intake rate and hazard index.

1. INTRODUCTION

Irrigation is the application of water to soil for the purpose of supplying moisture essential for plant growth (Egharevba, 2009). Irrigation depends basically on the availability of water and water rights. Irrigation leads to accumulation of heavy metals in the soil if wastewater and sewage water are use (Queirolo *et al.*, 2000). Using wastewater to irrigate agricultural land is one of the ways to reuse the wastewater from urban and industrial areas (Zegi, 2018). Heavy metals implicated as a result of sewage water includes Cu, Cd, Zn, Pb, Ni, Cr, in food items. Even at low concentrations of heavy metals in sewage effluents, long term uses of sewage often result in built up of these metals in the soil and consequently taken up by plants. Other sources of heavy metals in the soils include industrial and domestic effluents in addition to agricultural applications of fertilizer and pesticides (Singh *et al.*, 2009; Kalaskar, 2012).

The reuse of domestic and industrial waste water for plant growth is one of the options during water scarcity, and remain the common sources of water for irrigation of vegetables in most urban towns and cities of Nigeria. It contains an appreciable quantity of plant requirement though are a chief contributor to metal load in irrigated land from wastewater (Rattan *et al.,* 2005; Mahmood and Malik, 2013). This leads to environmental pollution which brings food safety issues and potential health risks due to the accumulation of heavy metals in agricultural soil and plants. It also possess potential barriers for international trading of food stuff (Cui *et al.*, 2004). Most crops irrigated with wastewater are vegetables. Vegetables accumulate heavy metals existing in the environment in their edible and non-edible parts. Intake of vegetables that is contaminated is an important path of heavy metal toxicity to humans (Wang *et al.,* 2005; Rattan *et al.,* 2005 and Osma *et al.,* 2012). A plant that is contaminated with high concentrations of heavy metals does not have visible changes in their appearance or yield but exceed animal and human tolerance. During the last twenty years, environmental problems have started to be a part of daily life in several countries. Their impact is clearly on the Manifest on the terrestrial and aquatic flora fauna, and keeps on increasing (Osma *et al.,* 2012). Knowledge of metal-plant interaction is important for the safety of the environment and for reducing risk of introduction of trace metals into the food chain.

The anthropogenic sources of environmental pollution by heavy metals include traffic emissions (vehicle exhaust particles, tire wear particles, weathered street surface particles, brake lining wear particles), industrial emissions (power plants, coal combustion, metallurgical industry, auto repair shops, chemical plants, etc.), domestic emissions, and weathering of building and pavement surfaces (Rattan *et al.,* 2005). Human activities in most cases have introduced potentially hazardous metals to the environment. This is as a result of the industrial revolution and urban development promoting a major threat to ecology and human well-being (Mahmood and Malik 2013). Contaminated air, soil, and water by human activities are associated with disease burden and this could be reasons for the current shorter life expectancy in developing countries when compared with developed nations. Heavy metal toxicity adversely disrupts growth and other physiological processes of plant, specifically leading to great economic and ecological trauma. If heavy metals move too rapidly in a particular soil, they can pollute ground and surface water supplies while it has generally been assumed that these metals are retained in agricultural soils (Bichi and Bello, 2013).

Despite all the glaring negative effects domestic and industrial wastewater causes to human health when used for irrigation, the trend of using wastewater for irrigation is at increase as most people lack adequate knowledge of the health risk that is involved. This paper therefore seek to investigate the heavy metals uptake and accumulation in some selected vegetables leaves, stems and roots in Minna; as well as bringing forth useful recommendations for the farmers, the consumers and the policy makers.

2. MATERIALS AND METHODS

2.1 Background and description of the Study Area

Niger state is one of the North-central states in the Guinea Savannah Zone of Nigeria. It is at sometimes called the food basket of the nation owing to the abundant potentials for all year round farming. Geographically, it is located on Longitude 6^{o} 00’ 00’’ E and Latitude 10^{o} 00’ 00’’ N as presented in figure 1. It is characterized by two distinct seasons; rainy and dry seasons. Short grasses and scattered trees in its extreme north and dense forest towards the south are features of its vegetation with mean maximum and minimum temperatures of 37 ^{o}C and 20 ^{o}C respectively.

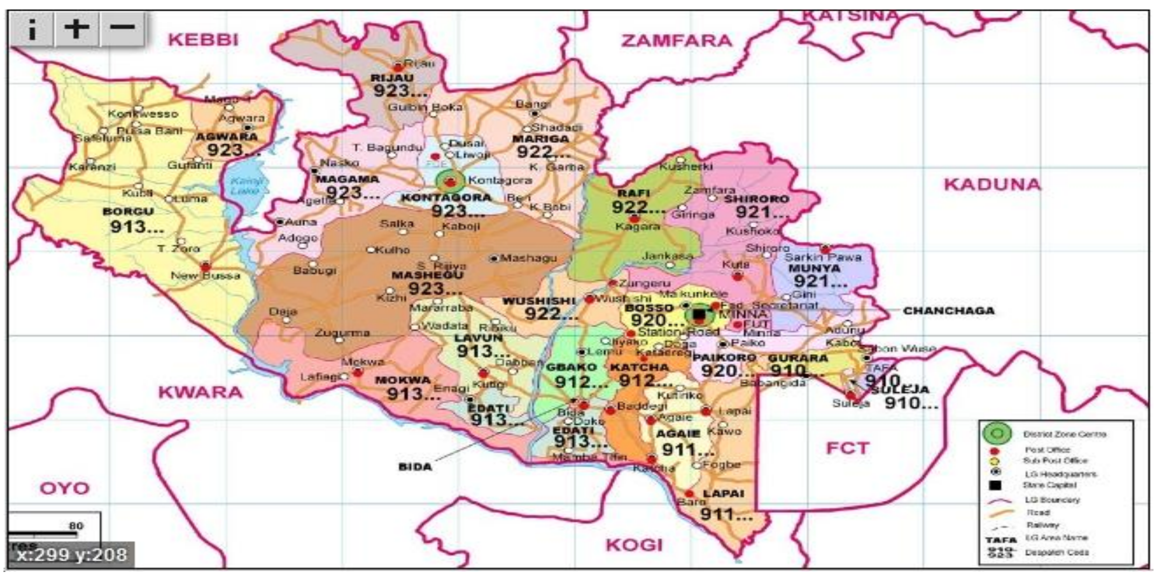

Fig. 1: Map of Niger State showing its boundary with other states of Nigeria

2.2 Experimental Set-up/Arrangements

A piece of land measuring 9m x 9m situated at Dutsen Kura along Minna western by-pass in Minna, Niger State was selected as a plot area. Wastewater from an urban drain (industrial/municipal) passing through Keterin-Gwari area was used as source of irrigation water at the wastewater irrigation plot, while water from a closed well at Dutsen-kuran Gwari, down Police Secondary School Avenue was used for irrigation at control plot. The entire experimental set-up is as presented in figure 2.

2.3 Soil and Water Samples collection and Analysis

Samples of water used for irrigation were collected in plastic bottles washed with detergent and distilled water and finally rinsed with the samples were stored at 4°C before taken to the Chemistry laboratory of Sheda Science and Technology Complex (SHESTCO) Abuja, Nigeria. Soil samples from the selected plots were collected by digging a hole of 15 cm and a representative samples were made by the cone and quarter method after removing unwanted debris. The collected soil samples were then dried in an oven and then sieved, store in a labeled polyethylene bags.

Fig. 2: Experimental Plot Design

2.4 Vegetable Samples Collection

Three hundred grams of edible portion of different vegetables grown at the study area were collected and washed with distilled water to remove soil particles, separated into three parts, chopped into small pieces using a knife and kept air-dried for approximately 70 hours at 105°C. These samples were grinded into fine powder before use for heavy metals extractions by acid digestion. Powdered samples (15g each) were placed in a silica crucible and few drops of concentrated nitric acid were added. Dry-ashing process was carried out in a muffle furnace (Swastik Scientific Co.Mumbai, P.14, Se.No 1021) by stepwise increase of the temperature up to 550°C and then left to ash at this temperature for 6 hours. The ash was kept in desiccators and then rinsed with 3N hydrochloric acid.

2.5 Sample Digestion and Heavy Metal Determination

Concentrations of heavy metals in the acidic solution were estimated using Atomic Absorption Spectrophotometer (Spectrometer Ice 3000 AA 02134 Dell, Thermo Scientific

Pvt. Ltd., India). Soil to plant metal transfer was carried out as transfer factor using equation 1:

$TF = C_{plant}/C_{soil}$

Where, C_{plant} is the concentration of heavy metals in plants and

C_{Soil} is the concentration of heavy metal in the soil (Mahmood and Malik, 2013).

Health risk index of heavy metals was calculated by knowing the exposure levels of these metals on humans. The statistical package used for analyzing the collected data was SPSS software 22.0, 2006 version. One-way ANOVA was used for evaluating the significant difference between heavy metal concentrations in vegetables cultivated on the plots in dry and wet seasons.

3. RESULT AND DISCUSSIONS

3.1 Result of heavy metal concentration in both irrigation water

The concentration of heavy metals in the wastewater samples used for irrigation were higher than their concentration in well water used for irrigation at the control plots, Cadmium (Cd) and chromium (Cr) higher above standard as mentioned in WHO/FAO (2007) and USEPA (2010). However, the Iron (Fe) and copper (Cu) concentrations are within the permissible level set by WHO/FAO (2007). The results are as presented in tables 1 and 2.

Table 1: Results of Wastewater Samples Analysis

	Cr(mg/l)	Cd(mg/l)	Mn(mg/l)	Cu(mg/l)	Fe(mg/l)
Sample1	0.19	0.04	0.71	0.04	2.81
Sample 2	0.19	0.04	0.71	0.04	2.81
Sample 3	0.19	0.04	0.71	0.04	2.81

Table 2: Results of well water Samples Analysis

	Cr(mg/l)	Cd(mg/l)	Mn (mg/l)	Cu(mg/l)	Fe(mg/l)
Sample 1	0	0	0.02	0	0
sample 2	0	0	0.02	0	0
Sample 3	0	0	0.02	0	0.01

3.2 Heavy Metals Concentrations in the Soil

Concentrations of heavy metals in the soil before and after irrigation are as presented in Tables 3 and 4. Wastewater and well water plots (control plots) in dry season show higher concentrations of iron in both plots while wet season show less sign of heavy metal concentration. However the concentration was even less on the control plots as indicated in table 5. It could be deduced that the availability of these metals in the soil at its original state might have contributed to the uptake of some of these metals before the wastewater application.

Table 3: Mean of Metals (mg/kg) in Dry Season for Soil Samples at Wastewater Plots

	Cr^m	Fe^m	Cu^m	Cd^m
Before Irrigation	26.10*	730.06**	0.26*	0.00*
After Irrigation	76.24*	777.50**	0.00*	0.02*

Results are mean difference *Not significant < 1** significant = 1.

Table 4: Mean of Metals (mg/kg) in Wet season for Soil Samples at Wastewater Plots

	Fe^m	Cr^m	Cu^m	Cd^m
Before Irrigation	557.32	0.00*	0.00*	0.00*
After Irrigation	496.01	0.00*	0.00*	0.00*

Results are mean difference *Not significant < 1 **significant = 1.

Table 5: Mean of Metals (mg/kg) in Dry Season for Soil Samples at well water Plots (Control plots)

	Cr^m	Fe^m	Cu^m	Cd^m
Before Irrigation	25.10*	730.24*	0.26*	0.00*
After Irrigation	20.10*	71.24**	0.00*	0.00*

Results are mean difference *Not significant < 1 **significant = 1.

3.3 Heavy Metals Concentrations in Vegetables Parts

The ANOVA test shows that concentration of heavy metals are significant while some are not with respect to season's interactions. The availability of heavy metals in plant parts may be due to the ability of the plant parts to store metals in their tissues, which is in line with the works of Chauhan and Chauhan (2014). The differences in the concentration of heavy metals in plant parts may also be due to their physiology and ability of the individual plants to take up, remove and store the metals in their various parts. This results also conforms to the results obtained by Arora *et al.*, (2008), Kalaskar, (2012) and Akan *et al.*, (2013) who had a similar work and found out those different concentrations in vegetables grown using different sources of water. The concentration of heavy metals like Fe, Cu, Cr and Cd varies with the plant parts, but all are below the tolerable limit as stated by FAO/WHO, (2010) and USEPA, (2010) standards. Rainy season's accumulations were the list compared to the dry season analyzed. This might be due to the rain water that washes the heavy metals in the soil and wastewater below the root zone. Okra leaves, pepper leaves and fruits irrigated with wastewater are seen to have accumulated higher concentrations of metals investigated. This is also in line with the works of Bichi and Bello (2013) in Kano, Nigeria and Singh *et al.*, (2010) in India which confirmed that vegetables have different accumulation capacity.

3.4 Transfer Factor of Metals

Transfer factors of metals in vegetables grown using industrial/municipal wastewater is the ratio of concentration in plant tissues to the concentration of pollutant in the soil. As shown in figures 3 – 6, transfer factors of metals from soil to plant were found to be higher in dry season at wastewater plots with the values greater than 1, indicating that bioaccumulation has taken place while the values less than 1 indicates that bioaccumulation has not taken place (Akpofure, 2012).

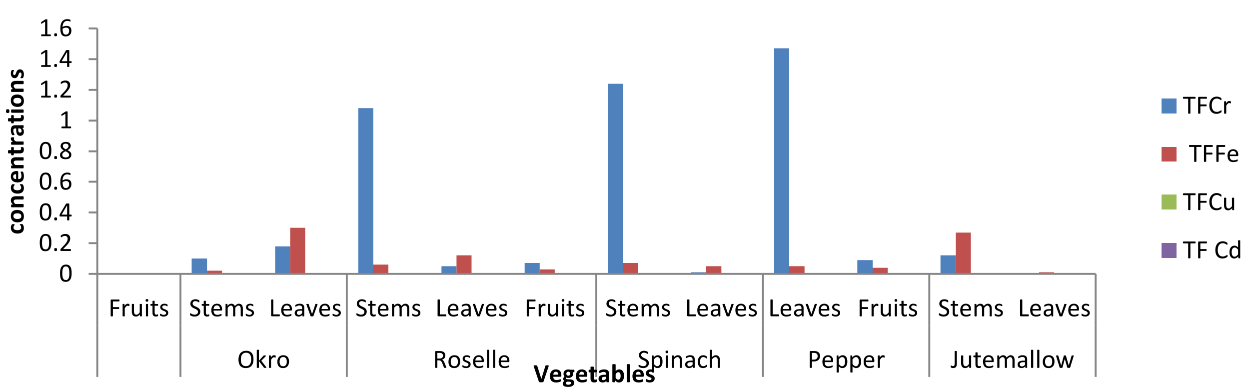

Fig 3: Transfer Factor (TF) of Metals (mg/kg) in Dry Season for Wastewater Plots

Chromium was found to be highly transferred with values that ranges from 0.01mg/kg to 1.47mg/kg with non-edible parts having the highest except for Roselle fruits that has a value of 0.07mg/kg. Iron was found to be present in all the vegetable parts analyzed with a range of 0.01mg/kg – 0.27mg/kg. The transfer value of Copper and Cadmium were negligible, and could be due to the inability of the crops to absorb the element in dry season due to the soil pH. In comparing the transfer factors of the studied elements in vegetables parts, the transfer factor for leaves was higher than the other parts signifying that bioaccumulation will occur first in leaves before other parts. This outcome is in accordance with that of Akpofure (2012). From the wastewater plots in which irrigation was supplementary during the wet season, iron were found to have higher transfer factor with a value that ranges from 0.01mg/kg to 0.43 mg/kg with leaves of Okra been the highest; however, the transfer factors of chromium, copper and cadmium were negligible. Consequently, in dry season iron has the highest transfer factor in the control plots with a value that ranges from 0.00 mg/kg to 2.21mg/kg, while chromium, copper and cadmium were also negligible. This might be due to the important of iron in chlorophyll of vegetables. Result also showed that iron has the highest transferred factor with a range of 0.02 mg/kg to 1.63 mg/kg in the leaves of okra in the well water plot during the rainy season, while copper, chromium and cadmium were negligible. Plots of transfer factors are as shown in figures 3, 4, 5 and 6 in the appendix pages. On metal toxicity in all the seasons for all the plots considered, wet seasons and dry season well water plots (Control plots) were found to be the safest.

4. CONCLUSIONS

The assessment of heavy metals uptake by vegetables cultivated on soil receiving industrial wastewater in Minna, Nigeria was successfully carried out during the 2016/2017 wet and dry seasons. Concentration of heavy metals were found to increase after the application of the domestic/industrial wastewater for irrigation on the plots. Uptake of heavy of heavy metals like iron, chromium and cadmium by vegetables was also identified, most especially on the leaves of the plant. This is an indication that the population who consume such vegetables might have health related problems since such metals are harmful to human season. It is however recommended that in as much as vegetables are very vital to human health, the growing processes must be done with a qualitative and quantitative water.

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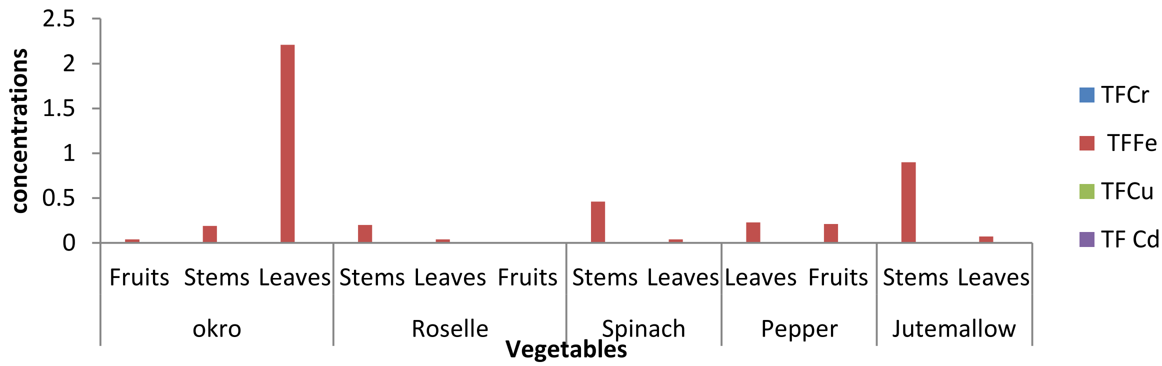

Fig 4: Transfer Factor of Metals (mg/kg) in Wet Season for Wastewater Plots

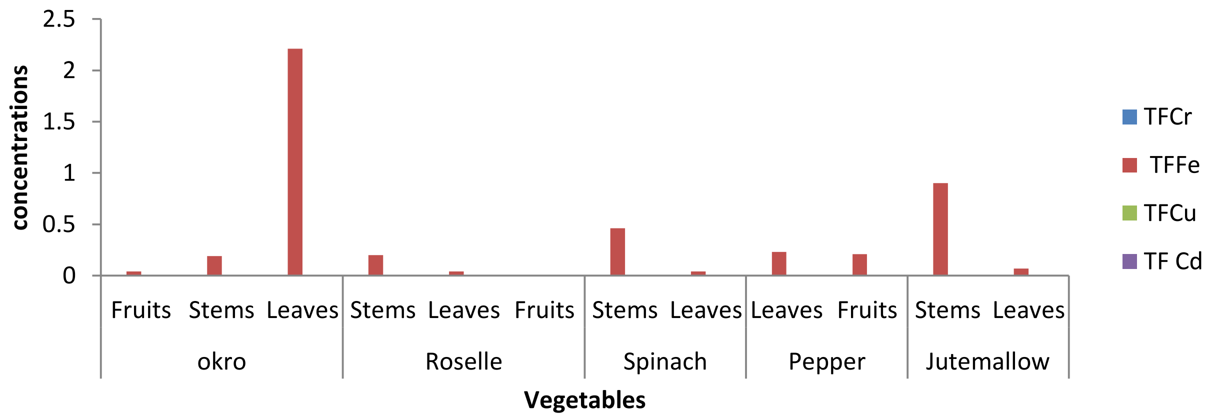

Fig 5: Transfer factor of Metals (mg/kg) in Dry Season for well water Plots (Control plots)

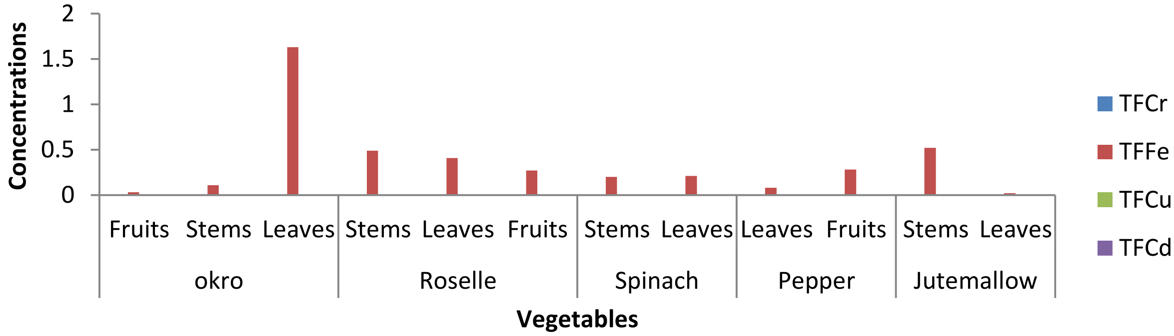

Fig 6: Transfer factors of Metals (mg/kg) in Wet Season for well water Plots (Control Plots).

Determination of Combustion Characteristics of some Agricultural Wastes in Niger State, Nigeria.

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ABSTRACT

Agricultural wastes cannot generally be called so because if they are properly managed,they can be sources of income generation. This paper intends to determine the combustion characteristics, combustion rate, ignition point, highest heating value, peak temperature, percentage weight loss, and proximate analysis of some agricultural biomass using Thermo Gravimetric Analysis (TGA). Forty milligram (40mg) of each samples of pre-determined moisture content are reduced to particles size of 25mm using an electric powered blending machine before transferred into muffle furnace. The temperature was raised from ambient to 850k with a linear heating rate of 25^{0}C/ min. Results showed that the energy generated by the rice husk, cowpea shell and corn cob were 20.88KJ/g, 18.68KJ/g and 19.51KJ/g respectively when combusted separately. Peak burning profile varied from 630k to 780k while the combustion rate varied from 0.5 mg/min to 2.75 mg/min and ignition temperature also varied from 385k to 600k. These results are useful to design of incinerator, briquette production and production of biofuels from the studied biomass.

Keywords: Thermo-gravimetric analysis, Agricultural biomass, Burning profile and Combustion characteristics.

1. INTRODUCTION

Several literatures have described agricultural wastes resources to include wood and wood wastes, agricultural crops and their waste by-products, municipal and solid wastes, waste from food processing and aquatic plants and algae (Brems *et al,* 2011; Miljkovil 2015). Although the chemical constituents and moisture content of agricultural wastes materials vary, they all contain low amounts of polluting elements and ash, which is the major difference between the agricultural waste fuels. Agricultural wastes cannot be denoted as wastes because of substantial benefits that can be explored from them. These benefits have been reported to include their use as fuel, its conversion into biofuel use as feeds, compost fertilizer and use in production of particle board. (Demirbas, 2008).

Combustion is one of the most important thermal treatment methods for agricultural wastes. Although the fundamental combustion behaviour of agricultural wastes fuels has received increasing attention of late, there remains no comprehensive compilation of their combustion (Demirbas 2000). Although burning agricultural wastes in order to produce heat energy is as old as mankind, though this kind of fuel is different from coal in its combustion characteristics and, due to its high volatile content and alkali content of ash, it can cause various problems (Miljkovi, 2015). The heating value of a fuel indicates the energy available in the fuel per unit mass while the net heating value is the actual energy available for heat transfer. The difference in available energy is explained by the fuel's chemical composition, moisture and ash content. For the purpose of properly designing and operating straw fired power plant, it is important to have detailed knowledge of the characteristics of fuel combustion and the effects of varying operating conditions. Considering the role of Niger State in agricultural activities, volume of agricultural waste generated annually in each local government area of the state and of course, the nuisance it causes, this research intends to determine the thermal properties of selected agricultural waste with a view to suggesting better ways of managing them to prevent environmental pollution.

2. MATERIALS AND METHOD

Niger State is one of the North-central states in the Guinea Savannah Zone of Nigeria. It is at sometimes called the food basket of the nation owing to the abundant potentials for all year round farming. Geographically, it is located on Latitude 10^{o} 00’ 00’’ N, 06^{o} 00’ 00’’ E, occupying a total area of 76,363 km^2. It is characterized by two distinct seasons; rainy and dry seasons. Short grasses and scattered trees in its extreme north and dense forest towards the south are features of its vegetation with mean maximum and minimum temperatures of 37^{o}C and 20^{o}C respectively. Politically, the state is sub-divided into three (3) zones viz: A, B and C., with a total of 25 Local Government Areas in all as indicated in figure 1. Records were obtained from the Niger State Ministry of Agricultural and Rural Development as well as Agricultural Development Project (ADP) on the annual food production in (tonnes/hectare) by each political zone of the state.

The sample of the biomass, maize cob, cowpea and rice husks were collected from milling points in Minna, Niger state capital and their grain/husk ratio determined. With the aid of a Muffin furnace, blender and in accordance with ASTM 2395 standards. A non-isothermal thermo-gravimetric analysis was performed using a furnace analyser. The samples were reduced to < 25mm particle size and 40mg each of the sample was spread on the bottom of the crucible before subjected to constant heat in an oxygenated furnace from a temperature of 400K through 1200K. With constant measurements of weight using the digital weighing balance, proper timing using stop watch and their respective temperatures change in the pace of 50k, and finally held for 30 minutes at constant weight. After every marked temperature each sample was put into the desiccator to allow to cool to temperature of zero kelvin before reweighing, which is in accordance with the ASTM 2395 standard. Burning profile was plotted using the Microsoft excel and behaviours of the different waste matter compared.

Fig. 1: GIS map of Niger State showing Local Government Areas.

3. RESULTS AND DISCUSSIONS

3.1 Annual waste generated in from each political zone of the state

The production of maize among the Zones has little difference based on the data obtained from ADP and the state ministry for agriculture and rural development, though Zone C is slightly higher with the value of 3,937 tonnes/year followed by Zone B with 2,619 tonnes/year. Zone A is the highest in rice production with the estimated value of 5,453 tonnes/year followed by Zone C with 3,032 tonnes/year and Zone B with 2,031 tonnes/year. Zone C is the centre known for cowpea production because of moderate weather condition. Records shows it has an estimated cowpea production of 4,746 tonnes/year followed by Zone A with 2,612 tonnes/year and zone B with 2,440 tonnes/year. The explanations above is clearly shown in figure 2 below. Meanwhile, the waste generated in each political zone for each of the crops under study was determined using grain/husk ratio. The result obtained indicated that Zone C is slightly higher with an estimated value of 2,619 tonnes/year, Zone B with 2,297 tonnes/year and Zone A with 2,054 tonnes/year. Zone A has the highest in rice production with an estimated value of 1,818 tonnes/year followed by Zone C with 1,010 tonnes/year and Zone B with 677 tonnes/year. Zone C as the centre for cowpea production has an estimated value of waste generation as 1,438 tonnes/year followed by Zone A with 792 tonnes/year and Zone B with 739 tonnes/year.

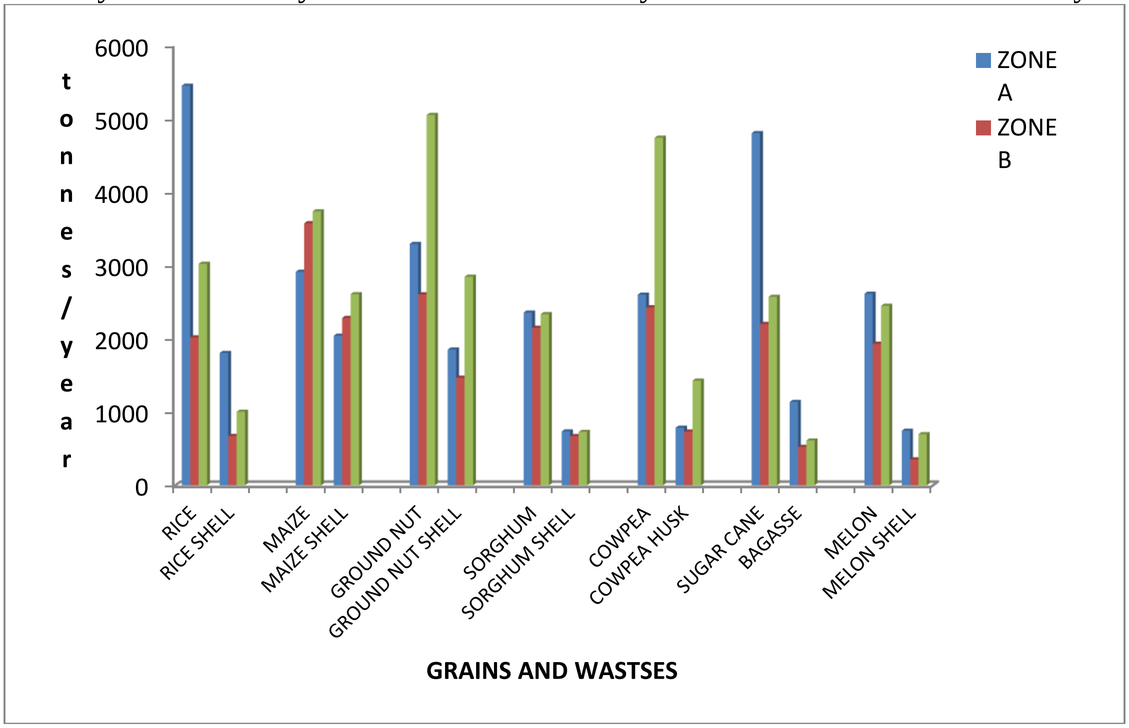

Fig. 2: Annual food production in tonnes/year – (ADP, 2018)

3.2 Result of Proximate Analysis of the Different Agricultural Wastes under Study

The result of the proximate analysis of the agricultural wastes under study at moisture content of 5 % after the non-isothermal thermo-gravimetric test is presented in figure 3. The volatile matter for the agricultural wastes ranges averagely from $80.275 \pm 1.525\ \%\ to\ 26.82 \pm 0.3\ \%$. After the volatile phase come the fixed carbon (FC) phase. This is the part that is quantified as the part of materials that is used to estimate the heat values or energy content in calories or KJ. From the study, the FC ranges from $35\%\ to\ 11.725\ \pm 1.525\%$ and the value of the energy Higher Heat Value (HHV) of $16.42\ \pm 0.3 KJ/g\ to\ 20.98\ KJ/g$.

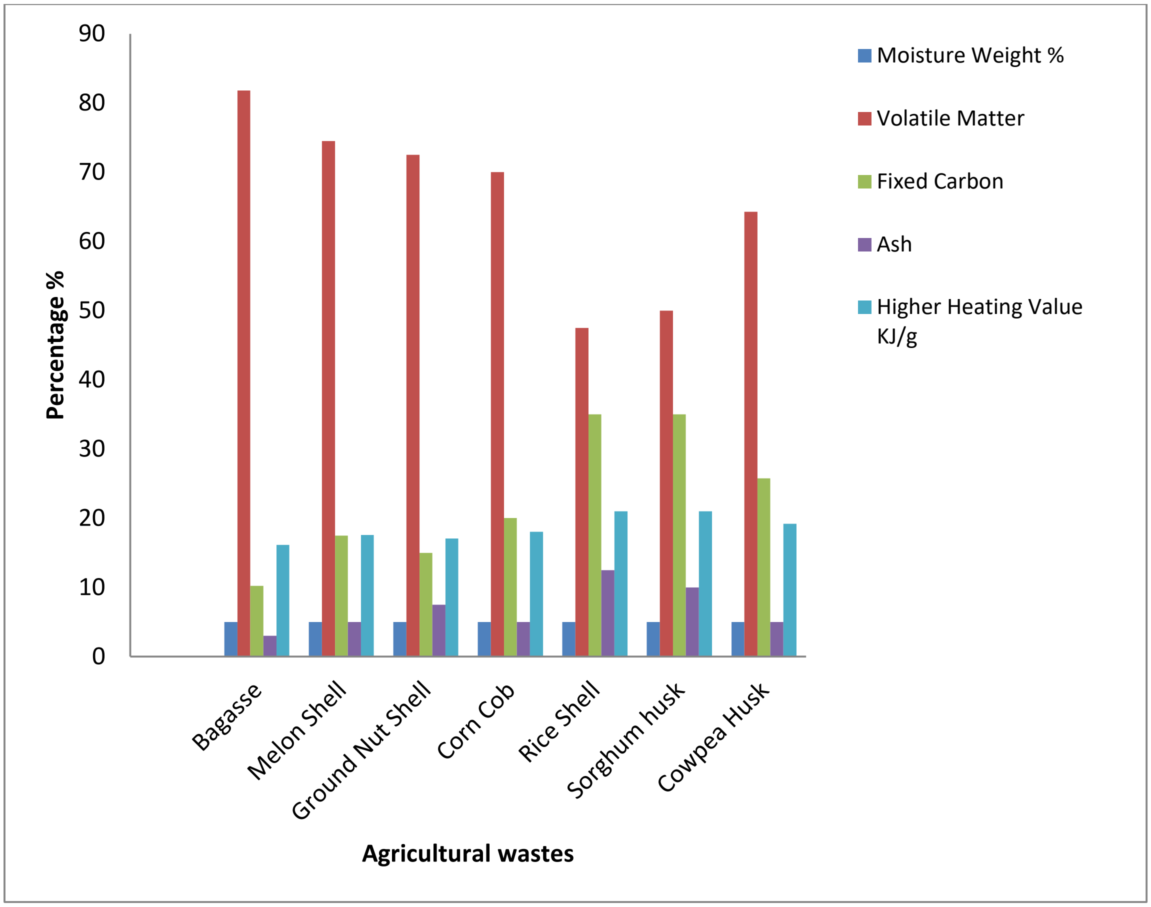

Fig. 3: Result of proximate analysis of the different agricultural wastes under study

The ash phase, the final phase is assumed as harmless to the environment and useful as soil nutrient. The ash content ranged from 12% to 3% from rice shell > cowpea husk > corn cob. The energy content of corn cob was 19.51KJ/g which is slightly higher than the standard which is 17.0KJ/g. The energy generated by the rice husk was 20.88KJ/g while the cowpea shell gives 18.68KJ/g. This cowpea energy value is close to 19KJ/g which is the standard. Mixture of rice shell and that of cowpea gives 18.68KJ/g which is slightly less than the energy generated by the two different agricultural wastes when treated individually.

3.4 Result of burning profile of the various agricultural waste

A plot of the rate of weight loss against temperature while burning a sample under an oxidizing atmosphere is referred to as the ‘‘burning profile’’ (Haykırı *et al.*, 2000). Figure 4 is the burning profile of corn cob, cowpea husks and their combinations. It can be seen from the profile that the ignition temperature of their combination is 200K compared to that of just corn cob and cowpea only which are 400K and 300K respectively. This indicates that the mixture has a combustive advantage over their individual component. The characterization of the carbon content shows a mass loss of 2 mg/min which is also faster than that of corn cob and cowpea husks which are 1.6mg/min and 1.7 mg/min respectively.

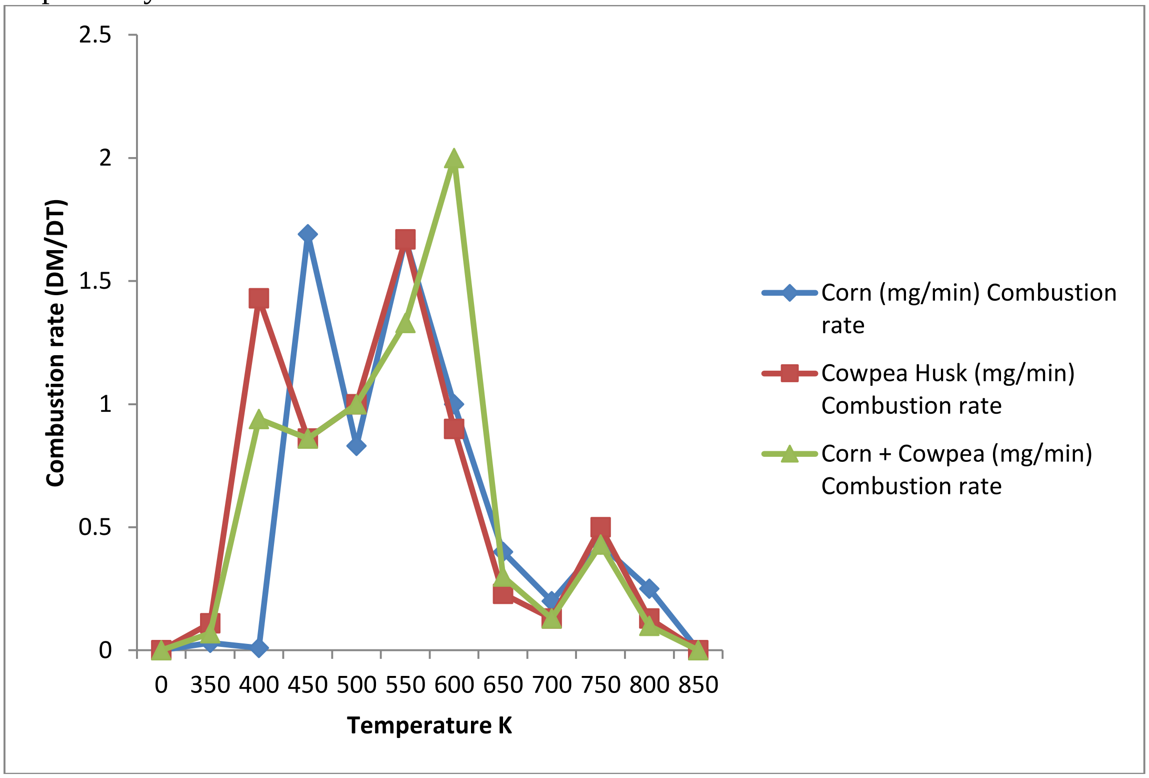

Fig. 4: Burning profile of corn cob, cowpea husk and their combination

The burning profile of cowpea husks, rice shell and their combination took a different behaviour as can be seen in figure 5. The burning temperature for their combine form starts at 100K, which is faster than that of rice shell alone which is 395K and cowpea husk which is 300K. The rate of combustion was 2.6mg/min at 300K which is faster than cowpea husk (i.e. 1.7mg/min at 500K), but slightly slower than rice shell (2.75mg/min at 600K). With a very low peak temperature of 300K and burning rate when compared with the individual components, it is very plausible to mix rice and cowpea for faster incineration of the waste.

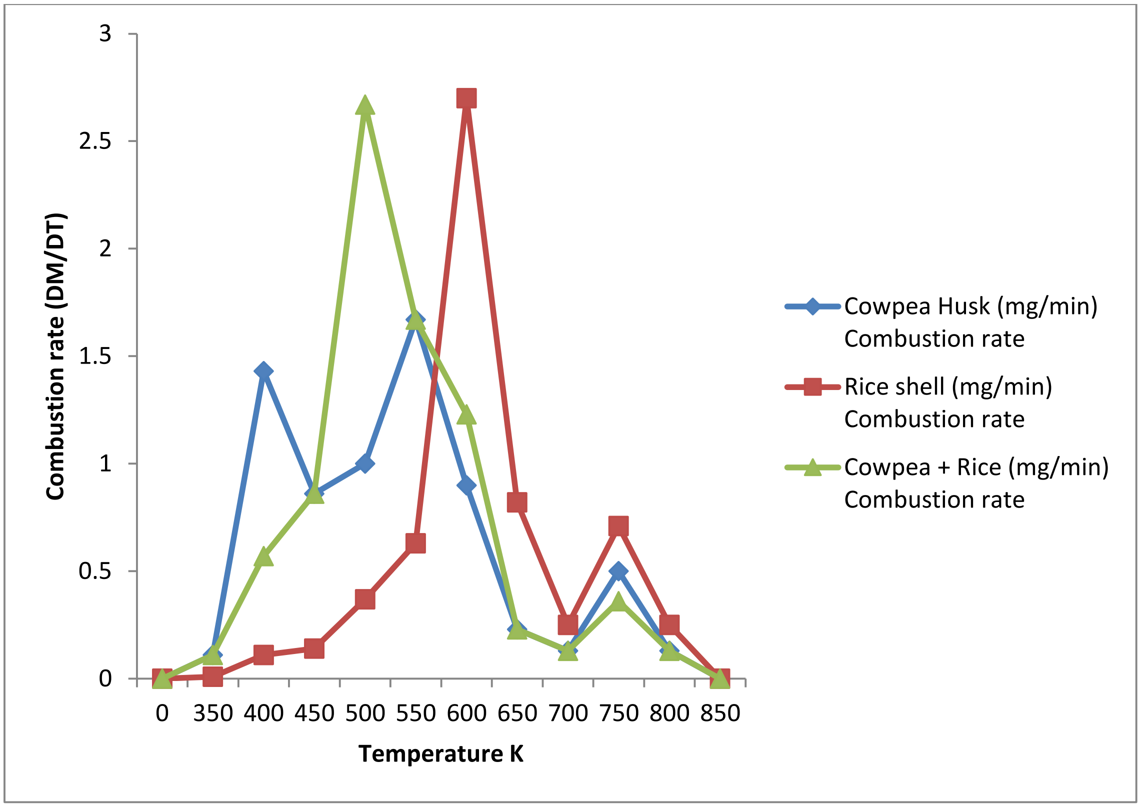

Fig. 5: Burning profile of cowpea husk, rice shell and their combination

The burning characteristics for rice shell and corn cob gave a different pattern as shown in figure 6. From the profile, the ignition temperature for the combine was at 200K compared to that of just corn cob alone that was 400K and rice which was 375K. This result also point out that the mixture has a combustive advantage over their single. The temperature of 600K is almost similar to the separate peak of the individual samples. The characterization of the carbon content show the mass loss of 2 mg/min which is also faster than that of only corn cob which was 1.6mg/min but not as fast as that of rice shell which is 2.75 mg/min.

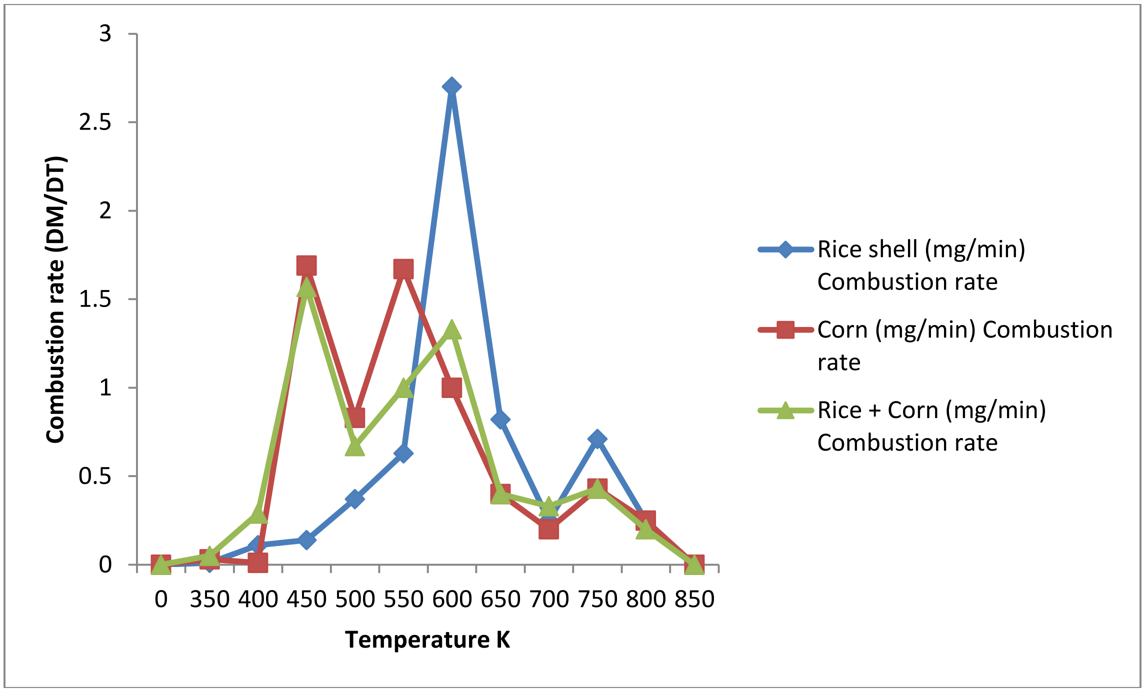

Fig. 6: Burning profile of corn cob, rice shell and their combination

4. CONCLUSION

The analysis of combustion characteristics of corn cob, rice husk, groundnut shell and melon husk in Niger state was successfully carried out. The results indicated that waste generation are not the same throughout the political zones of the state with cowpea production highest in zone C while zones A is leading in rice production and its waste generation. Proximate analysis of the various waste matter was also conducted and individual component fractions determined. Most importantly, the burning profiles for both the individual waste and their combinations were also plotted and studied. It is however recommended that more agricultural waste be looked into, and the analysis be done with more than two agricultural biomasses combined as this may give a better result.

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Development of Crop Water Production Model in a Rainfed Tropical Maize Crop Cultivation.

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ABSTRACT

Crop production, which is one of the sources of food for human and animal sustenance is a function of the availability of adequate quantity of water. The rainfall being seasonal is the main source of water for agricultural production in Nigeria. This has restricted production of crop to only raining season during which the intensity of the events will still affect yield of crop production to some extent. The vast potential of rainfed agriculture needs to be unlocked through knowledge-based management of natural resources for increasing productivity and income to achieve food security in the developing world. Maize production is majorly through rainfed agriculture in Nigeria and the irregularity of which affect the yield. This research work was to develop crop-water production model in tropical rain fed maize crop cultivation using maize yield and rainfall data from Oyo state. One of the major problems of food production in attempting to determine the relative future roles of irrigated and rain-fed agriculture is the lack of sufficient ground and accurate tool on a localized basis. Hence, the essence of this research works. Using correlation and full quadratic regression analysis, the effects of some rainfall indices (monthly and annual rainfall, raindays, rainfall onset and rainfall cessation) on maize yield in Oyo State were examined. The results of the correlation statistics showed that cessation has the strongest association ($r = -0.284$) with maize yield. The analysis also showed that early maize and late maize suffer moisture deficiency in March and November respectively while excessive rainfall of June/July and September also have implication for maize yield. It was also observed that the rainfall characteristics jointly contributed 96.7% in explaining the variations in the yield of maize per hectare. Conclusively, a model was development for predicting maize yield in Oyo State. The study also recommends the use of state own yield so as to harmonize with state rainfall data, application of appropriate moisture conservation management practices that ensured efficient use of water and use of drought resistance crop species with shorter growing periods as adaptive measures to the changing rainfall pattern within the study area.

Keywords: Rain-fed, Maize, Water, Yield, Secondary data, Regression`, Oyo state, Nigeria

1. INTRODUCTION

Crop production, which is one of the sources of food for human and animal sustenance is a function of the availability of adequate quantity of water. The water, natural is to be gotten directly from rainfall, but this source of water is also climatic dependent. This water is the main factor for any crop production on which other factors may depend. The rainfall being seasonal is the main source of water for agricultural production in Nigeria. This has restricted production of crop to only raining season during which the intensity of the events will still affect yield of crop production to some extent. In an interview with the director general of NIMET, Prof Anthony Anforom held on an NTA program ”INSIGHT” in August, 2015, the director made it known that as the date, the production of crop in Nigeria is limited to only rain-fed agriculture. That this has affected the crop production for the year, because of the late onset of rainfall and low rainfall as forecasted in the previous year. This, in general, limits the production of food in some areas that depended on rainfall for production and with limited amount of total rainfall per year.
The vast potential of rain-fed agriculture needs to be unlocked through knowledge-based management of natural resources for increasing productivity and income to achieve food security in the developing world. Soil and water management play a very critical role in increasing agricultural productivity in rain-fed areas in the fragile SAT (Semi-arid Tropics) systems (Wani *et al.,* 2009).

Maize crop is one of the generally grown cereal crop in the world. Maize, the main source of food in the tropical region, is grown in different varieties. The grains are rich in vitamins A, C and E, carbohydrates, and essential minerals, and contain 9% protein. They are also rich in dietary fiber and calories, which is a good source of energy (IITA, 2015). Crop production as stated earlier is limited to rainfall in some developing country and maize production is not an exception. Maize production is majorly through rain-fed agriculture in Nigeria and the irregularity of which affect the yield. International Institute of Tropical Agriculture and other research institute scientists have developed high yielding, drought-resistant and disease-resistant varieties that are adaptable to sub-Saharan Africa's various agro-ecological zones but many of which have not been adopted by the local farmers.

Therefor this research work aimed at developing crop-water production model in tropical rain fed maize crop cultivation, with focus on rainfall dataset for Oyo state between 1990 and 2013 periods and maize yield for the same period to determine rainfall indices for the years. One of the major problems of food production in attempting to determine the relative future roles of irrigated and rain-fed agriculture is the lack of sufficient ground and accurate tool on a localized basis. The variability and uncertainty of the climatic condition have drastic effect (low yield) on the crop production, the study of this variability and effect on the production will help for future planning to avert the effect of climatic change, hence the essence of this research work.

(a) (b)

Fig 1. (a) Photograph of maize plantation, and (b) Harvested maize

2. MATERIAL AND METHODS

2.1 The Location of the Study Area

Nigeria is located between latitudes 4° and 14°North of the equator and longitudes 3° and 14° East of Greenwich Meridian, and in West African region. The country is of area of 923768 sq kilometer, with tropical climatic condition and annual precipitation on the average ranging from 1800mm in the west to 4300mm in the east and 1300mm inland. The country experiences double rainfall maxima from March to July and September to October. Ibadan city where Nigeria Meteorological agency (NIMET) resides is located in coordinates of 7°23’47”N and 3°55’0” E and with mean total rainfall of 1420.06mm, falling in approximately 109 days and mean maximum temperature of 26.46°C (Wikipedia, 2015)

2.2 Sources of Climatic and Crop Yield Data

In order to develop the crop-water production model for productivity of water for rain-fed maize crop, weather data comprising of rainfall indices like dates of onset and end of rainy season, annual amount, temperature, duration and rain days, and crop yield are needed.

Data on daily rainfall (from which monthly and annual values were derived) was collected over 24 years (1990- 2013) from the official records of the Meteorological Centre of NIMET, Iseyin. The choice of this length of time is in line with the available data for the study, which is in accordance with numbers years for weather data in characterizing the climate of an area, as adopted by the World Meteorological Organization. The data used for this study were archival data on rainfall (in millimeters) and maize yield (in kilograms/hectare). The data on annual maize yield (kg) was collected from the official FAO database for Nigeria and for the same number of years 24 (1990 - 2013)

2.3 Derivation of Other Parameters

From the rainfall data collected, the following parameters were determined:

Date(s) of onset of the rainy season (in days); Date(s) of end of the rainy season (in days);Duration of the rainy season (in days);Annual number of rain days (in days); and, Annual rainfall amounts (in mm).

There are several methods of computing onset, end and duration of the rains such as used by Ilesanmi (1972) and Benoit (1977). However, Walter's formulation as modified by Olaniran (1983) was adopted in this study because of its high prediction reliability among other methods as used by Ifabiyi and Omoyosoye, (2011); Emmanuel and Fanan, (2013). The method was expressed as:

$$Date\ of\ Onset/End\ = DM\ \frac{51-A}{TM} \qquad \ldots\ldots\ldots\ldots(1)$$

where;

DM = the number of days in the month containing the date of Onset/End;

A = the accumulated total rainfall of the previous months;

TM = the total rainfall for the month in which 51 mm or more is reached and

51 mm = the threshold of rainfall for both Onset/End month.

Where such onset date was followed by dry spells of up to 14 days, the next rain day date that is not followed by such dry spells was chosen. For computing Cessation or End dates, the formula was applied in reverse order by cumulating the total rainfall backwards from December. Duration of the rainy season was derived by counting the number of rain days between the onset-date and the end-date of the rains in a given year. A rain day is a period of 24 hours (10:00 am - 10:00 am local time) with at least 0.3 mm of recorded rainfall amount. Annual rainfall total is the amount recorded for an entire year at a particular place (Emmanuel and Fannan, 2013).

2.4 Suitability of study area for maize production

The monthly water consumptive use of maize within its growing season as given by Lema (1978) were compared with average monthly rainfall obtainable in the study area during the growing season to bring out the suitability of the study area for maize production. This is as shown in the Table .1.

Table 1: Monthly water consumptive use of maize within the growing season month

	1st	2nd	3th	4th	5th	Total
Consumptive use (mm)	100	90	96	75	65	426

2.5 Model Formulation

The study employed the mean, standard deviation and coefficient of variability in analyzing the variations in the study variables. Partial correlation and multiple linear regression analysis were the statistical tools used to establish the relationship and effect of rainfall characteristics on maize yield.

The regression model (as used by Emmanuel and Fannan, 2013) for the study was computed as:

$$YIELD(HG/HA) = b0 + b1*X1 + b2*X2 + b3*X3 + b4*X4 + b5*X5 + b6*X1^2 + b7*X1*X2 + b8*X1*X3 + b9*X1*X4 + b10*X1*X5 + b11*X2^2 + b12*X2*X3 + b13*X2*X4 + b14*X2*X5 + b15*X3^2 + b16*X3*X4 + b17*X3*X5 + b18*X4^2 + b19*X4*X5 + b20*X5^2$$

Where;

Y = the value of the dependent variable (maize yield/ ha);

b_0= Y intercept

$b_1, b_2, b_3, b_4, \cdots b_n$= regression coefficients (each b represents the amount of change in Y (Maize yield/ha) for one unit of change in the corresponding x-value when the other x values are held constant;

$x_1, x_2, x_3, x_4, \cdots x_n$= the independent variables (*i.e.* rainfall onset, cessation, duration, annual totals and annual number of rain days respectively); and,

e = the error of estimate or residuals of the regression.

Apart from the coefficients of the independent variables (rainfall characteristics), coefficient of multiple determinations (R^2) was used to determine the percentage explanation achieved jointly by the rainfall characteristics. This method is preferred since it gives the best linear and unbiased estimates among other estimators. Several authors to effectively study the impact of climate on crop yield (Emmanuel and Fannan, 2013) have used this.

3. RESULTS AND DISSCUSSION

3.1 Variability in Rainfall Characteristics

The descriptive statistics of the rainfall characteristics are shown in the tables below. Table 2 shows the limit statistics of rainfall indices of the area of study and this indicates earliest onset of rainfall as 27th January 1997, latest onset of rainfall as 11th April 2007. Mean onset of Rainfall as 18th March and earliest cessation of rainfall as 5th October 2001, while latest cessation of rainfall as 25th December 1999 and mean ceasation of rainfall as 28th October 1999. Table 3 shows the limit statistics of other rainfall indices of the study area. Table 3 shows minimum annual amount of rainfall, number of rain-days, annual duration of rainfall, and maize yield as 909 mm (in 2001), 78 days (in 2006), 82 days (in 2006) and 11181.31

Hg/ha (in 1992) respectively. From table 3, the maximum annual amount of rainfall, number of rain-days, annual duration of rainfall, and maize yield as 1596.4 mm (in 1991), 119 days (in 1993), 122 days (in 1999) and 21961.28 Hg/ha (in 2009) respectively. The mean annual amount of rainfall, number of rain-days, annual duration of rainfall, and maize yield as 1212.72 mm, 94 days, 99 days and 14612.25 Hg/ha respectively.

The result indicated that there was a delay in the dates of onset accompanied by early cessation dates of the rainy season, shortening duration of the growing season and number of rain days, consequently declining maize yield per hectare even though high rainfall amount was received.

It was also be observed that the lowest rain-days was 78 days in 2006 and lowest annual rain-days (82 days) in the same year which might due to the late onset (12th march) and earlier cessation (25th October) of rainfall in the year. However, maize was not the lowest due to high rainfall (1169 mm) in the year. It can also be observed that 1992 recorded the lowest yield of maize per hectare (11181.30 Hg/ha), probably due to the latest onset date (12th April), earliest cessation date (30th October), short duration (92 days), low number of rain-days (88 days) and annual rainfall amount (1047.5 mm) that occurred in the same year. The lowest annual amount of rainfall (909 mm) in 2001 and shorter annual duration (91 days) might be due to earliest cessation (5th October) of rainfall in the year. The highest amount of rain-days (119 days) and maximum annual duration (122 days) of rainfall and higher annual amount of rainfall (1447 mm) were recorded in 1993 which might be as result of latest cessation (25th December) in the same year but lower maize yield (11847.81 Hg/ha).

Table 2. Limit statistics of onset and cessation of rainfall at the study area

INDICES	Mean	Earliest Day	Year	Latest Day	Year
Onset	79	27	1997	103	2007
Date/Days	18-Mar	27-Jan	_	11-Apr	_
Ceasation	303	280	2001	361	1993
Date/Days	28-Oct	5-Oct	_	25-Dec	_

Table 3. Limit statistics of rainfall indices and maize yield at the study area

INDICES	Mean	Minimum	Year	Maximum	Year
Annual Amount	1212.72	909	2001	1596.4	1991
Rain-days	94	78	2006	119	1993
Annual Duration	99	82	2006	122	1993/99
Maize Yield	14612.25	11181.31	1992	21961.28	2009

3.2 **The Coefficient of Variability**

Table 4 shows the descriptive statistics of rainfall indices and maize yield. The coefficient of variability of the rainfall characteristics shows that cessation dates of the rainy season has the highest coefficient of variability (56.1%), followed by dates of onset (29.11%), annual rainfall amount (13.82%), duration of the rainy season (12.77%) and the least variability of 12.12% was found in annual rain-days of the rainy season.

Table 4. Descriptive statistics of rainfall indices and maize yield at the study area

INDICES	Mean	Standard Deviation	Coefficient of variance (%)	Sample Variance
Maize Yield(Hg/Ha)	15825.33	2730.03	17.25	7453088.84
Onset(Days)	79	23	29.11	539
Cessation(Days)	303	17	56.10	290
Annual Amount(Mm)	1212.72	167.69	13.82	28116.81
Rain-days(Days)	94	12	12.77	142
Annual Duration(Days)	99	12	12.12	140

On a general note however, the coefficient of variability of (17.25%) was recorded in maize yield per hectare (Table 4). This result means that the annual rainfall durations were more reliable and predictable whereas the dates of cessation were more unreliable and un-predictable in the study area. The highest coefficient of variability of Maize could be as a result of the joint effect of the variability in all the rainfall characteristics studied and other climatic and non-climatic factors not directly considered in this study.

3.3 Suitability of the study area for maize production

The analysis of maize consumptive water use is also presented in Table 5. The mean rainfall amount obtainable in March according to Table 5 is 52.0mm. This amount fell short of the 100 mm that is required at the first set of planting. Thus, early maize plants in March may experience inadequate watering due to the nature of onset.

3.4 Relationship between Rainfall Characteristics and Maize Yield

A critical period during the planting season of maize is the month of November; as the minimum required (65mm) looks almost impossible to be met. In November the obtainable rainfall is only 21.5mm. This indicates a need of irrigation for the period for the purpose of preventing drought to the planted crop. The total consumptive use of 426mm of rainfall for maize production can be met in Oyo state as both rainfall obtainable for early maize and late maize were 627.7 mm and 710.7 mm respectively are more higher than the water consumption of maize production. However, it should be noted that the pattern of rainfall distribution is also relevant to the agronomy of any crop.

Table 5. Mean monthly pattern of rainfall for Oyo State (1990 – 2013)

Months	Rainfall(mm)
Jan	10
Feb	18.2
Mar	52
Apr	106.3
May	150.8
Jun	165.8
Jul	152.8
Aug	147.8
Sep	198.9
Oct	170.2
Nov	21.5
Dec	19.5
Mean(x)	101.2

Table 6. Monthly water consumptive use of maize within the growing season

Month	1st	2nd	3th	4th	5th	Total
Consumptive use (mm)	100	90	96	75	65	426
Rainfall obtainable for early maize (mm)	52 (March)	106.3 (April)	150.8 (May)	165.8 (June)	152.8 (July)	627.7
Rainfall obtainable for late Maize (mm)	152.8 (July)	147.8 (August)	198.9 (September)	170.2 (October)	21.5 (November)	710.7

Table 7. correlation coefficients analysis of rainfall indices and maize yield at the study area

	Yield	Onset	Cessation	Rain-Days	Annual Amount	Annual Rain-Days
	(Hg/Ha)	Date	Date	Day	Mm	Day
Yield (Hg/Ha)	1					
Onset	.263	1				
Cessation	-.284	-.016	1			
Rain-Days	-.174	-.405	.481*	1		
Annual Amount	-.241	-.418	.408	.710**	1	
Annual Rain-Days	-.088	-.287	.415	.975**	.660**	1

*Coefficient is significant at 0.10 confidence level (2-tailed).
**Coefficient is significant at 0.05 confidence level (2-tailed).

The correlations between rainfall characteristics and maize yield shows that dates of onset (0.263) had weak (significant) positive correlation with maize yield; dates of cessation (-0.284), annual rainfall amounts (-0.241), and rain days (-0.174) had weak negative correlations with maize yield; while annual rain days (−0.088) had very weak negative correlations with maize yield (Table 7). The dates of onset have greatest effect on the annual variation in yield. This implies that the area of study is prone to early onset of rainfall that has effect on the yield of early maize. Annual rain-days have the lowest influence on maize yield. This reveals that only the rain days during production season has effect on the yield of maize significantly.

3.5 Model for Predicting Maize Yield

3.5.1 Coefficient of prediction

The model for predicting maize in relation with rainfall indices is presented in coefficients as shown in table 8.

From the regression coefficients shown in Table 8, the regression equation or predictor model of the study was stated thus:

$$YIELD\left(\frac{HG}{HA}\right) = 656575 - 4309.2 * X1 + 356.20 * X2 + 19851.6 * X3 + 503.65 * X4 - 35940.4 * X5 + 0.469 * X1^2 + 11.99 * X1 * X2 + 167.61 * X1 * X3 + 0.07657 * X1 * X4 - 155.42 * X1 * X5 - 7.256 * X2^2 - 221.88 * X2 * X3 - 1.202 * X2 * X4 + 258.64 * X2 * X5 + 859.51 * X3^2 + 25.49 * X3 * X4 - 1613.6 * X3 * X5 - 0.161 * X4^2 - 22.04 * X4 * X5 + 756.40 * X5^2$$

Where;

Y = Predicted yield of maize in the area.

X_1, X_2, X_3, X_4, and X_5 are Onset date, cessation date, rain-days duration, annual amount and annual rain-days respectively.

From this model, it can be inferred, that, given a unit change in any of the rainfall characteristics while holding others constant, the highest variation in yield of maize in the area will be accounted for, by Rain days (19851.6 kg/ha), followed by interaction of Rain days (859.51 kg/ha), interaction of Annual rain days (756.40 kg/ha), Annual amount (503.65kg/ha), Cessation (356.20 kg/ha), interaction of Cessation and Annual rain days (258.64 kg/ha), interaction Onset and Rain days (167.61 kg/ha) and interaction Annual amount and Annual rain days (25.49kg/ha). Also followed by interaction of Onset and Cessation (11.99 kg/ha), interaction of Onset (0.469 kg/ha), interaction of Onset and Annual amount (0.07657 kg/ha), interaction of Annual amount (-0.161 kg/ha),interaction of Cessation and Annual amount (-1.202 kg/ha), interaction of Cessation (-7.256 kg/ha), interaction of Annual rain days and Annual amount (-22.04 kg/ha), interaction of Onset and Annual rain days (-155.42 kg/ha), interaction of Cessation and Rain days (-221.88 kg/ha), interaction of Rain days and Annual rain days (-1613.6 kg/ha), Onset (- 4309.2 kg/ha), and the least change in yield will be from annual Rain days (-35940.4 kg/ha).

These showed that among the rainfall characteristics, number of Rain days (X_3) is the most valuable variable for the variation in maize yield in the study area indicating that the yield of maize increases as number of rain-days increases. This is followed by interaction of Rain days (X_1^2), meaning that there was higher yield of maize under years with high number of Rain days than those with low rain days. The Rain-days and Annual amount over rainfall period has been the major determinant of maize yield in the area. The contributions of Rain

Table 8. Coefficient of prediction for full quadratic multiple regressions

		P value	Std Error	-95%	95%	t Stat	VIF
b0	656575	0.308	536247	-1050000.761	2363150.624	1.224	
b1	-4309.2	0.270	3196.2	-14481.1	5862.6	-1.348	29474.7
b2	356.20	0.918	3167.9	-9725.3	10437.7	0.112	13324.1
b3	19851.6	0.547	29320.2	-73458.5	113162	0.677	629446
b4	503.65	0.177	286.27	-407.38	1414.7	1.759	13607.9
b5	-35940.4	0.290	28040.0	-125176	53295.4	-1.282	558065
b6	0.469	0.933	5.153	-15.93	16.87	0.09104	1440.2
b7	11.99	0.481	14.94	-35.56	59.54	0.802	60003.0
b8	167.61	0.332	145.03	-293.95	629.17	1.156	466521
b9	0.07657	0.888	0.499	-1.511	1.664	0.154	1026.5
b10	-155.42	0.313	128.48	-564.29	253.45	-1.210	445507
b11	-7.256	0.399	7.399	-30.80	16.29	-0.981	29698.7
b12	-221.88	0.316	184.83	-810.09	366.34	-1.200	3888302.362
b13	-1.202	0.302	0.966	-4.277	1.873	-1.244	20737.7
b14	258.64	0.237	175.30	-299.26	816.54	1.475	3405930.095
b15	859.51	0.203	530.27	-828.03	2547.1	1.621	7949715.86
b16	25.49	0.126	12.11	-13.06	64.04	2.105	687535
b17	-1613.6	0.184	937.33	-4596.5	1369.4	-1.721	25375258.58
b18	-0.161	0.188	0.09466	-0.462	0.140	-1.699	9044.2
b19	-22.04	0.127	10.50	-55.45	11.36	-2.100	526325
b20	756.40	0.164	412.74	-557.12	2069.9	1.833	5132571.28

days and Annual amount are followed by those of Annual rain days, dates of cessation and date of onset but with insignificant coefficients.
The coefficient of multiple determinations (R^2) of 0.936 which was computed as 93.6% was observed. This means that 93.6% of the variations in the yield of maize per hectare for the past 25 years in the study area can be explained jointly by the variations in the five identified rainfall characteristics. The remaining 6.4% of the variations in the yield of maize can be attributed to other unexplained factors such as farming practices, soil properties, planting dates, weeds, fertilizer application seed varieties, pest and diseases, harvesting and other rainfall characteristics/climatic factors and technological involvement.

3.6 Validation of the Regression

The Figure 1 shows the scatter diagram of predicted yield and the original yield. The figure shows a good correlation between predicted yield and the yield, hence, the ability of the regression equation to predict yield, when all included rainfall indices are available.

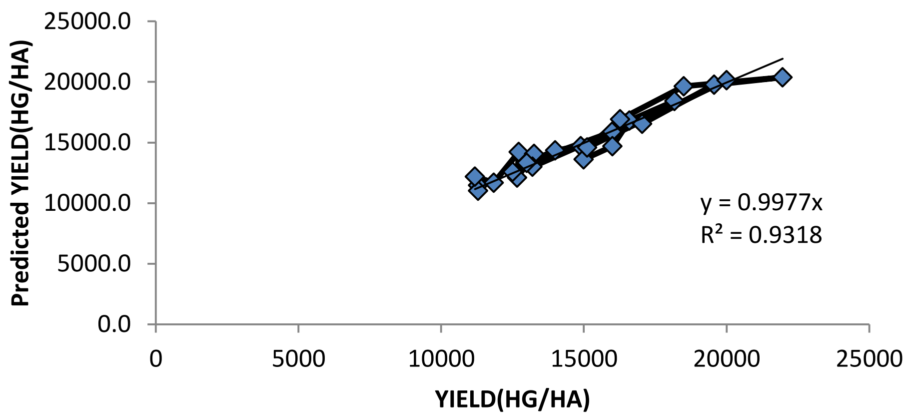

Fig 1**.** Scatter diagram of predicted yield versus yield

3.7 CONCLUSIONS

The study employed the mean, standard deviation and coefficient of variability in analyzing the variations in the study variables. Partial correlation and multiple linear regression analysis were the statistical tools used to establish the relationship and effect of rainfall characteristics on maize yield. This study established high variability in rainfall characteristics, which indicates high variability in Maize yield per hectare. Additionally, the study showed the suitability of the area for maize production.
The study shows that maize experiences moisture deficiency at the early stages (especially early maize) and at the last month of the growing season (late maize) in the study area. In the months of June, July and September rainfall is in excess of the total amount required and that there is relative response of variability in onset/cessation date to variability in rain days. This results in variability in amount of rainfall per rain period. The results also reveal that number of rain days and annual rainfall amount have the strongest influence on maize

yield per hectare in the study area. Conclusively, a predictive model was established for maize yield in the area.

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Modeling and Optimization of Electrical Properties of Bulk Sorghum Grains for Automation Sensing Operations.

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ABSTRACT

Automation of sorghum production will increase world food production and improve the economy of producing countries. Electrical properties of sorghum are used to select sensors and actuators used to automate their production operations like handling, separation and sorting. The objective of this study was to model and optimize some electrical properties of bulk sorghum grains for automation of harvesting, processing and storage operations of sorghum production. Electrical properties of three major varieties (NGB 01907: Red sorghum; NGB 01589: White sorghum; and NGB 01227: yellow sorghum) determined include resistance, conductance, resistivity, conductivity, capacitance, dielectric constant, inductance and capacitance reactance (impedance). The grains were conditioned to four moisture levels (10, 13, 16, 19 and 22% db). These properties were determined by forming different circuits with functional generator, oscilloscope, resistors, capacitors, connecting wires and grains sample holder by passing current frequencies of 1, 500,1000,1500 2000 kHz. Response surface central composite experimental design (CCD) was used for modeling and optimization. Reduced cubic, reduced linear and linear models were chosen, transformed and used to generate polynomial equations. All generated model equations were confirmed (validated) by the use of both mathematical and experimental methods. These generated polynomial equations were used to optimize the electrical properties. Optimized ranges for designing or selecting electrical sensors and actuators for automating harvesting, processing and storage operations, using these electrical properties for sensing was developed. Among the three farm operations studied only processing operation like handling, separation and sorting require values that fall at the middle of all optimized ranges of the electrical properties.

Keywords: Electrical properties, Modeling, Optimization, Sorghum, Operations, Response surface, Central composite design

1. INTRODUCTION

Sorghum (*Sorghum bicolour* (L.) Moench] is one of the stable foods in Africa and the rest of the developing countries. It has many commercial and local usages. According to Jean 2008 and Kimber, 2000, Sorghum is of the family *Graminea*. Early account suggested that it was first cultivated along the Nile River in northern Africa in 1000 BC. In world cereal grains importance, sorghum rank fifth after wheat, maize, rice and barley (FAO, 2003: FAO, 2014: FAOSTAT 2015). Adebayo and Ibraheem, (2015) reported that the highest producer of sorghum USA produces 10.400,000 metric tonnes alone while Nigeria produces 6,300,000 metric tonnes making it the highest in Africa and the third highest in the world. They also reported that the USA exports 5,800,000 metric tonnes while Nigeria exports none. They are also of the opinion that sorghum is second most important cereal grain in Africa after maize, therefore making it very crucial to food security in Africa. The study of the engineering properties of sorghum is crucial to its production.

Barbosa-Cánovas et al, 2006 explained the importance and essential of engineering properties of foods, in the process design and manufacture of food products. An electrical property of grain was first measured by Briggs, 1908. He discovered that there is a relationship between electrical resistance and grain moisture and temperature when direct current passes through them. Later other researchers now started using alternating current (AC) to measure electrical properties like Resistance, conductivity, capacitance, di-electric properties, impendence and inductance. At various, moisture contents with different range of current frequencies or wavelengths. These researchers includes: Burton and Pitt 1929: Nelson et al. 1953: Nelson 1973: Ahmed et al. 2007: Dejmek and Miywaki 2002: Jiao et al., 2011: Kardjilova 2012: Kardjilova 2013: Bhargava et al., 2013 Burubai , 2014: Hlaváčová et al.2015.

Modeling is defined as a process by which ideals and concepts of Scientists and Engineers about the natural environment are presented to each other and then make changes to these ideals and concepts over time in response to new evidence and understandings. A model can also be a mathematical representation of a physical, biological or information system. Mathematical modeling is a principled activity. (Ambitious science teaching, 2015; Cha et al 2000; Dym and ivey, 1980). Mathematical model equations are the first stages of optimization.

Mathematical optimization can be defined as selection of best factors or elements (with regard to some set goals or constrains before the beginning of the selection) among some group of factors and element considered. More generally, optimization includes finding "best available" values of some objective function given a defined domain (or input), including a variety of different types of objective functions and different types of domains. (The Nature of Mathematical Programming, 2014; *Battiti et al 2008). There are different mathematical approaches to achieved optimization. One of these approaches is* Response surface methodology.

Response surface methodology (RSM) can be described as a technique that involves complex calculation for optimization process. This approach develops a suitable experimental design that integrates all of the independent variables and uses the data input from the experiment to finally come up with a set of equations that can give theoretical value of an output. The outputs are obtained from a well-designed regression analysis that is based on the controlled values of independent variables. Thereafter, the dependent variable can be predicted based on the new values of independent variables. Response surface methodology (RSM) involves the use of the following experimental designs: Central Composite Design (CCD); Box-Behnken (BB); Optimal Designs (Khairul and Mohamed 2015; Giovanni, 1983;).

Central Composite designs (CCD) are based on 2-level factorial designs, augmented with center and axial points to fit quadratic models. Regular CCD's have 5 levels for each factor. This can be modified by choosing an axial distance of 1.0 creating a Face-Centered, Central Composite design which has only 3 levels per factor. The center points are replicated to provide excellent prediction capability near the center of the factor space. A central composite design is a common augment from the two-level factorial design. Categorical factors can be added to these designs; however, the design is duplicated for every categorical treatment combination (*Stat-Ease* 2017).

The objective of this study is to determine, model and optimize some electrical properties of bulk sorghum grains varieties to design or select electrical sensors and actuators suitable for automation of unit operations like sorting, and grading during harvesting, processing and storage operations.

2. MATERIALS AND METHODS

2.1 Sample

Sample seeds that was used in this study are; Sorghum (*Sorghum bicolour* (L.) Moench with three varieties namely: NGB 01907 (Red sorghum), NGB 01589 (White sorghum), NGB 01227 (yellow sorghum). Grains samples were procured from the National Center for Genetic Resources and Biotechnology (NACGRAB) research center, Ibadan, Nigeria. The samples were divided into their respective varieties and their initial moisture content determined according to ASAE standard S352.2 (ASAE 2002).The samples were conditioned according to the method describe by Audu *et al* (2017) and Audu *et al* (2018), to moisture contents of 10, 13, 16, 19 and 22%.

2.2 Determination of Electrical Properties of Sorghum

A sample holder was first constructed to hold the bulk sorghum grains. This holder consists of two circular copper plates and a circular body made of Teflon as shown in figure 1. The lower circular copper plate is permanently seal to the Teflon body, while the upper plate is threaded as a cover to the holder. Circuit arrangements with oscilloscopes display shown in figure 2 were used to measure resistance (R), capacitance (C) and inductance (L). Circuits' components include; signal generator, digital oscilloscope, resistors, sample holder, capacitors and connecting wires.

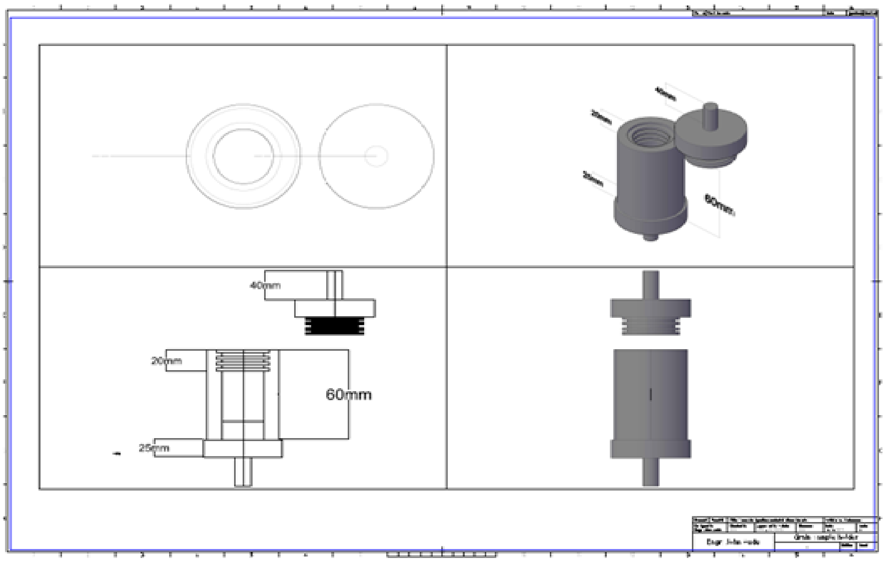


Figure 1: Grain sample holder

Conductance (G) was calculated using equation 1, Resistivity (ρ) using equation 2, Conductivity (σ) using equation 3, Impedance of the capacitor (Z_c) or Capacitance Reactance (X_c) using equation 4 and the relative permissively or dielectric constant (ε) using equation 5.

$$\boldsymbol{G = 1/R} \tag{1}$$

$$\boldsymbol{\rho = R\frac{A}{L}} \tag{2}$$

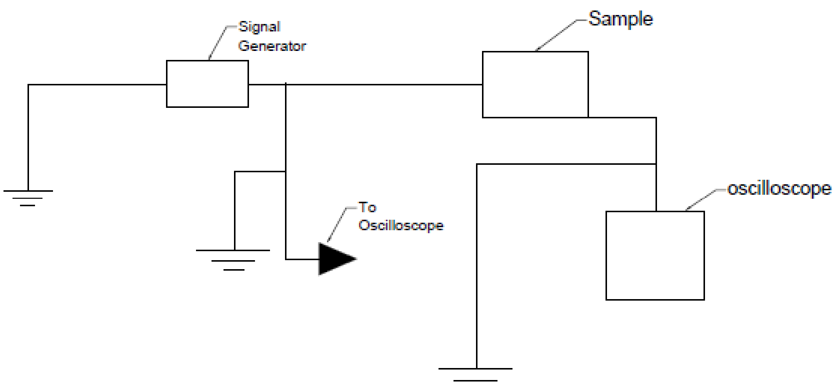
$$\boldsymbol{\sigma = \frac{1}{\rho}} \tag{3}$$

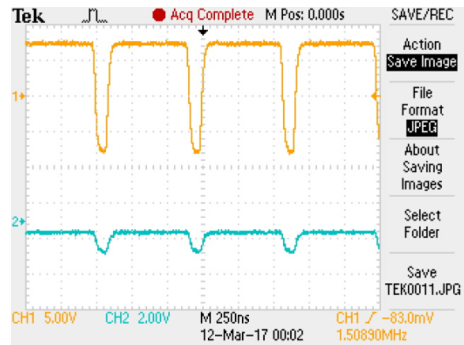
$$\boldsymbol{Z_c \text{ or } X_c = \frac{1}{2\pi f C}} \tag{4}$$

$$\boldsymbol{\varepsilon' = \frac{C}{C_o}} \tag{5}$$

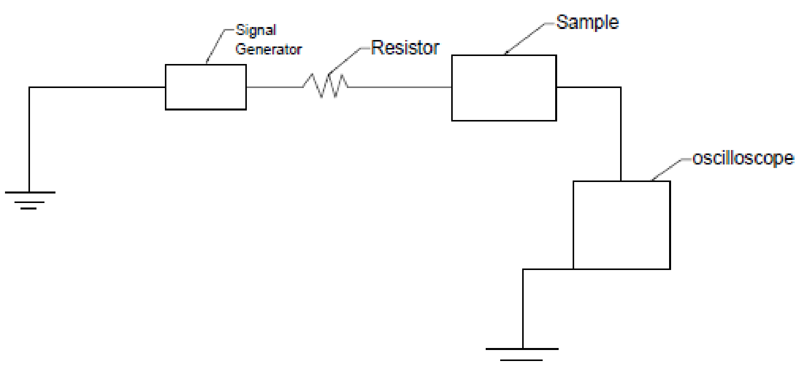
Where,

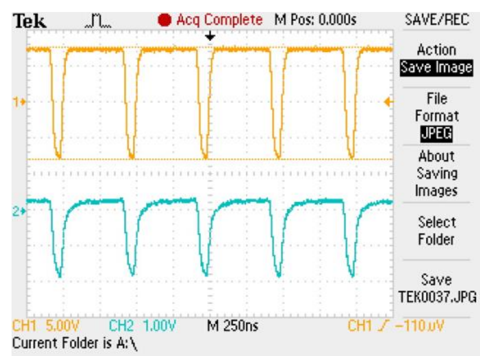
G is the Conductance (S), R is the Resistance (Ω), ρ is the Resistivity (Ωm), A is the Area (m^2), L is the Length (m), σ is the Conductivity (S/m), Zc or Xc is the Impedance or Capacitance reactance (Ω), f is the frequency of current (Hz), C is the capacitance of sample (F), C_o is the capacitance of empty capacitor (F). ε^l is the dielectric constant.



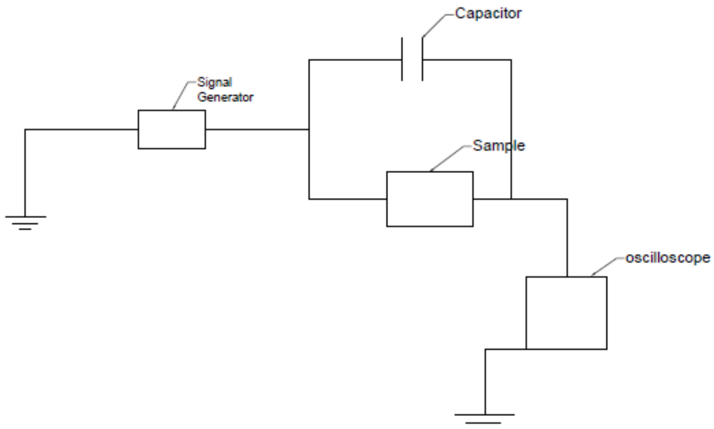


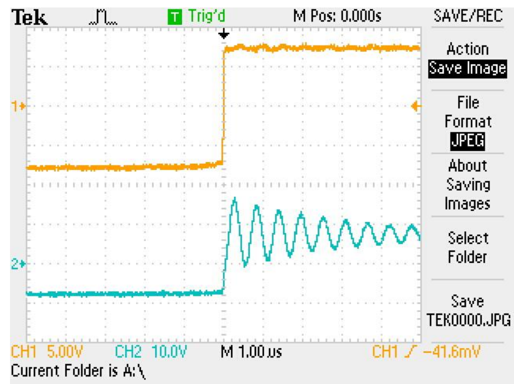
(a) Resistance measurement arrangement and its oscilloscope display





(b) Capacitance measurement arrangement and its oscilloscope display





(c) Inductance measurement arrangement and its oscilloscope display

Figure 2: Electrical properties circuit arrangements and their oscilloscopes display

All electrical properties were measured on current frequency ranges of 1, 500,1000,1500,2000 kHz.

2.3 Statistical Analysis

Experimental design used for modeling and optimizing the electrical properties was Responses surface central composite design (CCD). Statistical software used for analysis was Design Expert version 10, a product of *Stat-Ease Company.*

3. RESULTS AND DISCUSSION

3.1 Modeling

The result of electrical properties of sorghum is shown in table 1. The experimental results obtained for resistance, conductance, resistivity, conductivity, capacitance, dielectric constant, inductance and capacitance reactant; ranges from 1.08 – 190.53Ω, 0.01 – 0.22S, 0.15 – 12.85Ω/m. 0.04 – 6.52S/m, 1.4×10^{-11} – 1.28×10^{-4}F, 0.48 – 4571428.57, 8.4×10^{-9} – 1.7136×10^{-6}H and 1,243.24 – 22,733,472.77Ω respectively. The model recommended for modeling by the software was reduced cubic model for resistance, conductance, resistivity; conductivity and inductance due to low P-value (probability that the model error is high), highest Adjusted R-Squared (measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model) and also the highest Predicted R-Squared (measure of the amount of variation in new data explained by the model). Also recommended was reduced linear model for capacitance because of its lowest model P-value and high lack of fit P-value (the amount the model predictions miss the observations). Linear model was chosen for dielectric constant and capacitance reactant (impedance) because it has a low Model P-value and the highest lack of fit p-value (see Table 2).

Table 1: Experimental design table for presenting results of electrical properties of sorghum

Run	M	F	C:variety	R	G	ρ	σ	C	ε'	L	X
	%	Hz		ohms	S	ohms/m	S/m	F	ε'	H	ohms
1	16	1	NGB 01589	15.00	0.07	2.12	0.47	1.24E-07	4428.57	1.1508E-06	1,283,341.20
2	16	1000	NGB01907	6.90	0.15	0.98	1.03	2.16E-11	0.60	1.3734E-06	7,367,329.14
3	16	1	NGB01907	17.01	0.06	2.41	0.42	0.000128	4571428.57	1.4455E-06	1,243.24
4	10	1000	NGB01907	5.85	0.17	0.83	1.21	2.8E-08	777.78	5.3352E-09	5,683.37
5	16	2000	NGB 01227	5.27	0.19	0.75	1.34	3.2E-11	2.13	5.5592E-07	2,486,473.58
6	19	1500	NGB 01227	9.16	0.11	1.30	0.77	2.24E-11	1.07	1.039E-06	4,736,140.16
7	16	1000	NGB 01589	6.23	0.16	0.88	1.14	2.32E-11	0.64	1.1431E-06	6,859,237.47
8	16	2000	NGB01907	6.23	0.16	0.88	1.14	1.52E-11	1.01	5.5029E-07	5,234,681.23
9	13	500	NGB 01589	4.88	0.21	0.69	1.45	4.4E-11	1.52	1.1341E-06	7,233,377.70
10	16	1000	NGB 01227	6.35	0.16	0.90	1.11	3.8E-11	1.06	1.2503E-06	4,187,744.98
11	13	500	NGB 01227	4.64	0.22	0.66	1.52	1.4E-11	0.48	1.4639E-06	22,733,472.77
12	13	500	NGB01907	16.81	0.06	2.38	0.42	2.7E-11	0.93	1.3018E-06	11,787,726.62
13	16	1000	NGB01907	6.90	0.15	0.98	1.03	2.16E-11	0.60	1.3734E-06	7,367,329.14
14	16	1000	NGB 01589	6.23	0.16	0.88	1.14	2.32E-11	0.64	1.1431E-06	6,859,237.47
15	13	1500	NGB 01589	4.50	0.22	0.64	1.57	3.1E-11	1.48	1.5762E-06	3,422,243.21
16	16	1000	NGB 01589	6.23	0.16	0.88	1.14	2.32E-11	0.64	1.1431E-06	6,859,237.47
17	19	500	NGB01907	9.62	0.10	1.36	0.74	4.8E-11	1.66	1.0946E-06	6,630,596.22
18	16	1000	NGB 01589	6.23	0.16	0.88	1.14	2.32E-11	0.64	1.1431E-06	6,859,237.47
19	19	1500	NGB 01589	43.94	0.02	6.21	0.16	3.6E-11	1.71	1.5762E-06	2,946,931.65
20	16	1	NGB 01227	3.33	0.30	0.47	2.12	1.26E-07	4500.00	1.355E-06	1,262,970.71
21	16	1000	NGB01907	17.01	0.06	2.41	0.42	0.000128	4571428.57	1.4455E-06	1,243.24
22	16	1000	NGB 01589	6.23	0.16	0.88	1.14	2.32E-11	0.64	1.1431E-06	6,859,237.47
23	10	1000	NGB 01589	2.68	0.37	0.38	2.64	3.1667E-11	0.88	1.03936038	5,025,293.98
24	16	1000	NGB01907	6.90	0.15	0.98	1.03	2.16E-11	0.60	1.3734E-06	7,367,329.14
25	16	1000	NGB 01227	6.35	0.16	0.90	1.11	3.8E-11	1.06	1.2503E-06	4,187,744.98
26	19	1500	NGB01907	8.05	0.12	1.14	0.88	3.3E-11	1.57	1.4954E-06	3,214,834.53
27	22	1000	NGB 01589	190.63	0.01	26.95	0.04	4E-11	1.11	1.1341E-06	3,978,357.73
28	22	1000	NGB01907	9.67	0.10	1.37	0.73	2.7E-11	0.75	1.1341E-06	5,893,863.31
29	19	500	NGB 01589	90.91	0.01	12.85	0.08	3.6E-11	1.24	1.3192E-06	8,840,794.96
30	13	1500	NGB01907	15.79	0.06	2.23	0.45	3E-11	1.43	1.6538E-06	3,536,317.99
31	16	1000	NGB 01227	6.35	0.16	0.90	1.11	3.8E-11	1.06	1.2503E-06	4,187,744.98
32	22	1000	NGB 01227	8.87	0.11	1.25	0.80	2.5E-11	0.69	1.7136E-06	6,365,372.37
33	16	1000	NGB 01227	6.35	0.16	0.90	1.11	3.8E-11	1.06	1.2503E-06	4,187,744.98
34	13	1500	NGB 01227	4.55	0.22	0.64	1.56	2.6E-11	1.24	1.5195E-06	4,080,366.91
35	16	2000	NGB 01589	5.94	0.17	0.84	1.19	2.16E-11	1.44	5.7883E-07	3,683,664.57
36	16	1000	NGB01907	6.90	0.15	0.98	1.03	2.16E-11	0.60	1.3734E-06	7,367,329.14
37	10	1000	NGB 01227	1.08	0.92	0.15	6.52	3.0333E-11	0.84	1.7238E-08	5,246,186.02
38	19	500	NGB 01227	11.74	0.09	1.66	0.60	2.8E-11	0.97	1.1341E-06	11,366,736.38
39	16	1000	NGB 01227	6.35	0.16	0.90	1.11	3.8E-11	1.06	1.2503E-06	4,187,744.98

M=Moisture, F = frequency, R = Resistance, G = Conductance, ρ = Resistivity, σ = Conductivity, C = Capacitance, ε = Dielectric constant, L = Inductance, X = Capacitance reactance

Table 2: Summary design models used for Electrical properties of sorghum

Name	**Unit**	**Obs**	**Analysis**	**Minimum value**	**Maximum value**	**Mean**	**Std. Dev.**	**Transform**	**Model**
Resistance	ohms	39	Polynomial	1.08491	190.625	15.4784	32.4054	None	Reduce Cubic
Conductance	S	39	Polynomial	0.0052459	0.921736	0.161572	0.144315	Inverse	Reduce Cubic
Resistivity	ohms/m	39	Polynomial	0.153406	26.9544	2.18865	4.58212	None	Reduce Cubic
Conductivity	S/m	39	Polynomial	0.0370997	6.51864	1.14266	1.02062	Inverse	Reduce Cubic
Capacitance	F	39	Polynomial	1.4×10^{-11}	0.000128	6.571×10^{-6}	2.86×10^{-5}	Inverse Sqrt	Reduce Linear
Dielectric constant	ε’	39	Polynomial	0.482759	4.57143×10^{6}	234682	1.022×10^{6}	Natural Log	Linear
Inductance	H	39	Polynomial	5.36×10^{-9}	1.03936	0.0266514	0.166431	None	Reduce Cubic
Capacitance reactance	ohms	39	Polynomial	1243.24	2.274×10^{7}	5.531×10^{6}	3.917×10^{6}	Inverse Sqrt	Linear

No transformation of the response data was done for resistance, resistivity and inductance. Inverse transformation was used for conductance and conductivity. This was because data analysis without transformation shows that the difference between adjusted R-Squared and predicted R-Squared is greater than 0.2 (Usually this indicates there are too many insignificant terms in the model). Also a normal probability plotted shows an "S-shaped" curve, which indicates that a transformation of the response may provide a better analysis.

Since the conductance and conductivity is rate/time data an inverse transformation was used. An inverse square transformation was used for capacitance and capacitance reactance. This was because
analyzing the data gotten from the experiment directly shows that the different between adjusted R-Squared and predicted R-Squared is greater than 0.2 and a graph of residual vs predicted values plotted shows expanding variance ("megaphone pattern <") which indicates that transformation will improve the models. A natural log transformation was done to dielectric constant data. This was because analyses of the experimental data directly shows that the different between adjusted R-Squared and predicted R-Squared is greater than 0.2 and data exhibited a variance growth pattern.

All analysis was polynomials. Statistical data from the modeling analysis show that all models used were significant (at $p< 0.01$) which implies that there is only a 0.01% chance that an F-value this large to cause significant effect could occur due to noise. In the summary ANOVA table (table 3), values of "Prob > F" less than 0.05 indicate model terms are significant. All model generated in this study were significant except for capacitance reactance (Impedance). This could be because of the granular nature of sorghum. Current frequencies do not have effects on resistance, resistivity, conductance, conductivity capacitance reactance. This is due to the symmetric intra cellular arrangement of sorghum cells. Moisture content was also found not to be significant to the capacitance, dielectric constant and capacitance reactance of the grains. This could be because the moisture level of the sorghum cell was not large enough to alter its electrical storage capacity.

The R-Squared (A measure of the amount of variation around the mean explained by the model) and Standard deviation for resistance, conductance, resistivity, conductivity, capacitance, dielectric constant, inductance and capacitance reactant; were 0.9504 and 8.26, 0.9504 and 8.26,0.9504 and 1.17, 0.263 and 60860.12, 0.2469 and3.61, 0.7846 and 0.087, 0.2129 and $6x10^{-3}$ respectively. The "Pred R-Squared" of the entire electrical properties model except inductance and capacitance reactant model is in reasonable agreement with their "Adj R-Squared" (i.e. the difference is less than 0.2). The negative values on the inductance and capacitance reactant models shows that they will be poor predictive models (see table 4). These negative values could be because of sorghum seeds high resistive behaviour to electric current. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. All sorghum's electrical models ratio is greater than 4. Coefficients of variation (CV) for all models generated are all high (greater than 1), this is because all electrical properties do not have a natural zero point. So Coefficients of variation (CV) can't be used to determine the accuracy of these models. Rather the Standard deviation (Root MSE) (Square root of the residual mean square) can be used to determine accuracy of these models. The Standard deviation of all model generated are low for acceptance for accuracy. The PRESS (Predicted Residual Error Sum of Squares) which is a

Table 3: Summary of ANOVA for electrical properties modeling

Properties	**Source**	**Degree of freedom**	**F - value**	**P – value Prob. > F**	
Resistance	Model	9	61.73	< 0.0001	Significant
	A-Moisture	*1*	*110.60*	*< 0.0001*	Significant
	B-frequency	*1*	*3.18*	*0.0849*	Not significant
	C-variety	*2*	*30.79*	*< 0.0001*	Significant
	AC	*2*	*98.62*	*< 0.0001*	Significant
	A^2	*1*	*57.65*	*< 0.0001*	Significant
	A^2C	*2*	*62.65*	*< 0.0001*	Significant
Conductance	Model	9	61.73	< 0.0001	Significant
	A-Moisture	*1*	*110.60*	*< 0.0001*	Significant
	B-frequency	*1*	*3.18*	*0.0849*	Not significant
	C-variety	*2*	*30.79*	*< 0.0001*	Significant
	AC	*2*	*98.62*	*< 0.0001*	Significant
	A^2	*1*	*57.65*	*< 0.0001*	Significant
	A^2C	*2*	*62.65*	*< 0.0001*	Significant
Resistivity	Model	9	61.73	< 0.0001	Significant
	A-Moisture	*1*	*110.60*	*< 0.0001*	Significant
	B-frequency	*1*	*3.18*	*0.0849*	Not significant
	C-variety	*2*	*30.79*	*< 0.0001*	Significant
	AC	*2*	*98.62*	*< 0.0001*	Significant
	A^2	*1*	*57.65*	*< 0.0001*	Significant
	A^2C	*2*	*62.65*	*< 0.0001*	Significant
Conductivity	Model	9	61.73	< 0.0001	Significant
	A-Moisture	*1*	*110.60*	*< 0.0001*	Significant
	B-frequency	*1*	*3.18*	*0.0849*	Not significant
	C-variety	*2*	*30.79*	*< 0.0001*	Significant
	AC	*2*	*98.62*	*< 0.0001*	Significant
	A^2	*1*	*57.65*	*< 0.0001*	Significant
	A^2C	*2*	*62.65*	*< 0.0001*	Significant
Capacitance	Model	2	6.43	0.0041	Significant
	A-Moisture	*1*	*0.48*	*0.4913*	Not significant

	B-frequency	*1*	*12.38*	*0.0012*	Significant
Dielectric constant	Model	4	2.79	0.0419	Significant
	A-Moisture	*1*	*0.34*	*0.5636*	Not significant
	B-frequency	*1*	*7.73*	*0.0088*	Significant
	C-variety	*2*	*1.54*	*0.2292*	Not significant
Inductance	Model	8	13.66	< 0.0001	Significant
	A-Moisture	*1*	*15.88*	*0.0004*	Significant
	C-variety	*2*	*3.67*	*0.0377*	Significant
	AC	*2*	*15.88*	*< 0.0001*	Significant
	A^2	*1*	*18.10*	*0.0002*	Significant
	A^2C	*2*	*18.10*	*< 0.0001*	Significant
Capacitance reactance	Model	4	2.30	0.0789	Not significant
	A-Moisture	*1*	*0.49*	*0.4900*	Not significant
	B-frequency	*1*	*2.33*	*0.1360*	Not significant
	C-variety	*2*	*3.19*	*0.0538*	Significant

measure of how the models, fit each point in the design. All the models generated except inductance and capacitance reactant has high PRESS values. This means that predictions done by these models outside the design space (experimental range) are likely to contain high error. For inductance and capacitance reactant models because of their low PRESS, it can be used to predict values outside the design space with little error. -2 Log Likelihood (coefficient estimates for the chosen model to maximize the likelihood that the fitted model is the correct model) shows good values. These likelihood values was used to calculated the BIC (Bayesian Information Criterion) which is a large design penalized likelihood statistic used to choose the best model and AICc (Akaike information criterion for small size data) which is a small to medium design penalized likelihood statistic used to choose the best model. Value obtained for BIC and AICc are very close to each other showing that the data used for generating these models are large, meaning that they are large design. The electrical properties model equations generated for all sorghum varieties studied are shown in table 5. Both Mathematical and experimental confirmation (validation) of these models were done. These confirmations are shown in table 6. Confirmation is achieved if the value obtained for both the observed mean (mean obtained from validation experiments) and data mean (mean from numerical optimized values) lies between the 95% PI low (low prediction interval) and the 95% PI high (high prediction interval). All models were confirmed except conductance, conductivity and capacitance reactance. This was because of the transformation choices which did not allow validation (because it did not provide a 95% PI value). When any other transformation choices were used on these three models the models then looses all its prediction abilities which were the aim of the study. Other electrical properties outside these three were then confirmed experimentally by comparing their observed means with previous experimental values.

Table 4: Statistical Parameters Generated for Electrical Properties Models.

Statistical Parameters	**Electrical properties**							
	R	**G**	**ρ**	**σ**	**C**	**ε**	**L**	**X**
Std. Dev.	8.26	8.26	1.17	1.17	60860.12	3.61	0.087	6.088×10^{-3}
Mean	15.48	15.48	2.19	2.19	1.667×10^{5}	1.35	0.027	2.216×10^{-3}
C.V. %	53.38	53.38	53.38	53.38	36.51	267.01	326.19	274.72
PRESS	8282.51	8282.51	165.60	165.60	1.606×10^{11}	588.54	1.68	1.668×10^{-3}
-2 Log Likelihood	263.83	263.83	111.25	111.25	966.83	205.52	-90.08	-292.58
R-Squared	0.9504	0.9504	0.9504	0.9504	0.2632	0.2469	0.7846	0.2129
Adj R-Squared	0.9350	0.9350	0.9350	0.9350	0.2223	0.1583	0.7272	0.1203
Pred R-Squared	0.7924	0.7924	0.7924	0.7924	0.1127	0.0014	-0.5992	-0.0417
Adeq Precision	46.595	46.595	46.595	46.595	8.455	6.849	21.662	5.242
BIC	300.47	300.47	147.89	147.89	977.82	223.84	-57.11	-274.26
AICc	291.69	291.69	139.11	139.11	973.52	217.34	-65.87	-280.76

Std. Dev. = Standard Deviation, PRESS = Predicted Residual Error Sum of Squares, BIC = Bayesian information criterion, AICc = Akaike information criterion (small sample size corrected version), C.V = Coefficient of variation, R = Resistance, G = Conductance, ρ = Resistivity, σ = Conductivity, C = Capacitance, ε = Dielectric constant, L = Inductance, X = Capacitance reactance

3.2 Optimization

Numerical optimizations for the electrical properties of bulk sorghum were done and displayed in table 7, for harvesting, processing and storage sensing operations. This table can be used for either sensor designing or selection for the automation of harvesting, processing and storage operations. Sensing ranges of all properties considered in this study were displayed also in table 7. The three factors (moisture, frequency and variety) combination desirability (an objective function that ranges from zero outside of the limits to one at the goal) was 1.

Optimized values for Resistance and conductivity range from 5 - 33Ω and 0.03 – 0.5S respectively, with harvesting operation requiring the least resistance value and the highest conductance value. But storage operations require the least conductance and the highest resistance value. This is because of the high moisture of the grains during harvest. That causes partial covalency of water's hydrogen bonding which is capable of hindering current flow within grains. But allow it to flow between two different grains. Similar observation has been reported by Briggs (1908) and Kardjilova et al (2012). 0.8 – 4.7Ω/m and 0.2 – 3.5S/m were the optimized value range for resistivity and conductivity respectively. Among the operations, harvesting required the lowest resistivity while storage requires the highest. This is also because of the high moisture of grains during harvesting and low during storage. Storage operations require the lowest conductivity while harvest requires the highest. The reason being the same as that explained for conductance.

Optimized values range for capacitance and dielectric constant are 2.8 $x10^{-11}$ – 1.3 $x10^{-10}$ and 14 .9 – 942.6 respectively. Harvesting operations require the lowest capacitance and dielectric constant value, while storage operations require the highest value for both capacitance and dielectric constant. This could be because the high moisture of grains during harvest increases the size of the grains, therefore creating high porosity in the bulk grains. These pore spaces reduce the storage of electric current in the bulk sorghum. Similar observation was reported by Kardjilova et, al (2013) and Burubai (2014) for spelled grains and melon seeds at certain frequency. Range of 1.5 $x10^{-7}$ – 1H was the optimized range of inductance for all three farm operations. Both ranges are within storage operations. This is because at low grain moisture, electric current can easily change direction of flow without hindrances from partial covalency of water's hydrogen bonding formed during high grain moisture. For capacitance reactance (Impudence), optimized value ranges from 35494 – 21918794 Ω. Again, both the highest and the lowest values lie within storage operations. The reason for this phenomenon is the same as that explained for inductance.

Table 5: Model equations of electrical properties generated for sorghum varieties.

Electrical Properties	Sorghum Variety	Model Equations
Resistance	NGB 01589	$R = 428.00238 - 65.64882\ M - 4.91402x10^{-3}\ F + 2.48674\ M^2$
	NGB 01907	$R = 6.28465 + 1.36723M - 4.91402x10^{-3}F - 0.049062M^2$
	NGB 01227	$R = -5.81011 + 1.37620\ M - 4.91402x10^{-3}F - 0.019327\ M^2$
Conductance	NGB 01589	$1 / G = 428.00238 - 65.64882\ M - 4.91402x10^{-3}F + 2.48674\ M^2$
	NGB01907	$1 / G = 6.28465 + 1.36723\ M - 4.91402x10^{-3}F - 0.049062\ M^2$
	NGB 01227	$1 / G = - 5.81011 + 1.37620\ M - 4.91402x10\text{-}3F - 0.019327\ M^2$
Resistivity	NGB 01589	$\rho = 60.51954 - 9.28274\ M - 6.94843x10^{-4}\ F + 0.35162\ M^2$
	NGB01907	$\rho = 0.88865 + 0.19333\ M - 6.94843x10^{-4}\ F - 6.93734x10^{-3}\ M^2$
	NGB 0122	$\rho = - 0.82155 + 0.19459\ M - 6.94843x10^{-4}\ F - 2.73288x10^{-3}M^2$
Conductivity	NGB 01589	$1 / \sigma = 60.51954 - 9.28274\ M - 6.94843x10^{-4}\ F + 0.35162\ M^2$
	NGB01907	$1 / \sigma = 0.88865 + 0.19333M - 6.94843x10\text{-}4\ F - 6.93734x10^{-3}\ M^2$
	NGB 01227	$1 / \sigma = - 0.82155 + 0.19459M - 6.94843x10^{-4}\ F - 2.73288x10^{-3}M^2$
Capacitance		$1 / Sqrt\ (C) = 57670.52209 + 2350.80132\ M + 71.39589\ F$
Dielectric constant	NGB 01589	$\ln \varepsilon = 5.84593 - 0.11708\ M - 3.34921x10^{-3}\ F$
	NGB01907	$\ln \varepsilon = 8.01117 - 0.11708\ M - 3.34921x10\text{-}3F$
	NGB 01227	$\ln \varepsilon = 5.87027 - 0.11708\ M - 3.34921E\text{-}003F$
Inductance	NGB 01589	$L = 4.53526 - 0.51398\ M + 0.014257\ M^2$
	NGB01907	$L = - 4.40400x10^{-6} + 6.68116x10^{-7}\ M - 1.92364x10^{-8}\ M^2$
	NGB 01227	$L = - 1.99138x10^{-6} + 3.30291x10^{-7}\ M - 8.08001x10^{-9}M^2$
Capacitance Reactance	NGB 01589	$1 / Sqrt\ (X) = 7.34580x10^{-3} - 2.36062x10^{-4}M - 3.1x10^{-6}\ F$
	NGB01907	$1 / Sqrt\ (X) = 0.012576 - 2.36062x10^{-4}\ M - 3.1x10^{-6}\ F$

NGB 01227	*1 / Sqrt (X) = + 7.35885x10^{-3} - 2.36062x10^{-4} M - 3.1x10^{-6} F*

R = Resistance (Ω), G = Conductance (S), ρ = Resistivity (Ω/m), σ = (S/m) Conductivity, C = Capacitance (F), ε = Dielectric constant, L = Inductance (H), X = Capacitance reactance (Ω), Moisture content (%), F = Frequency (Hz*)*

Optimized current frequency range for using these electrical properties for sorghum automation operations lie between 500 – 1500 kHz. Among the three farm operations studied only processing operation require values that fall at the middle of all optimized ranges of the electrical properties.

Table 6: Confirmation (Validation) of the electrical properties models

Response	**Mean**	**Median**	**Std Dev**	**n**	**SE Pred**	**95% PI low**	**Observed Mean**	**Data Mean**	**95% PI high**
Resistance	9.312	9.312	8.262	1	8.71	-8.50	8.2	10.399	27.12
Conductance	0.192	0.107	0.153	1	N/A	0.0368681	0.07		*No confirmation*
Resistivity	1.317	1.317	1.168	1	1.23	-1.20	0.1	0.18	3.84
Conductivity	1.358	0.76	1.081	1	N/A	0.260736	2.51		*No confirmation*
Capacitance	5.039×10^{-11}	3.599×10^{-11}	3.324×10^{-11}	1	N/A	1.175×10^{-11}	2.4×10^{-11}	6.55×10^{-11}	5.757×10^{-10}
Dielectric constant	14.0411	1.866	18.491	1	N/A	0.000915	154.22	225.242	3801.54
Inductance	-0.038	-0.038	0.087	1	0.092	-0.23	3.4×10^{-2}	1.24×10^{-6}	0.15
Capacitance reactance	2.306×10^{9}	4.549×10^{6}	3.257×10^{9}	1	N/A	5645.54	7.1×10^{5}		*No confirmation*

Table 7: Optimized values of electrical properties for bulk sorghum sensing Operations

Harvest Operation		
Properties	Lower Limit	Upper Limit
Moisture (%)	19	22
Frequency (Hz)	500	I500
Resistance (Ω)	5.902	12.094
Conductance (S)	0.121	0.501
Resistivity (Ω/m)	0.835	1.71

Conductivity (S/m)	0.858	3.545
Capacitance (F)	2.81×10^{-11}	8.31×10^{-11}
Dielectric constant	14.9	459.718
Inductance (H)	9.84×10^{-7}	1.35×10^{-6}
Capacitance reactance (Ω)	84150.06	1321071
Processing Operation		
Moisture (%)	13	16
Frequency (Hz)	500	1500
Resistance (Ω)	6.357	13.31
Conductance (S)	0.104	0.423
Resistivity (Ω/m)	0.899	1.882
Conductivity (S/m)	0.736	2.991
Capacitance (F)	3.25×10^{-11}	1.12×10^{-10}
Dielectric constant	27.5	928.03
Inductance (H)	9.37×10^{-7}	1.36×10^{-6}
Capacitance reactance (Ω)	43539.98	11232255
Storage Operation		
Moisture (%)	8.5	10
Frequency (Hz)	520	1304
Resistance (Ω)	8.338	33.277
Conductance (S)	0.032	0.238
Resistivity (Ω/m)	1.18	4.705
Conductivity (S/m)	0.226	1.681
Capacitance (F)	$4.61x^{-11}$	$1.29x^{-10}$
Dielectric constant	16.924	942.599
Inductance (H)	-1.5×10^{-7}	1.036736
Capacitance reactance (Ω)	35494.16	21918794

4. CONCLUSION

The following conclusions were drawn from this study

- Electrical properties of bulk sorghum grains were determined for three varieties at five moisture levels by passing five different current frequencies.
- Reduced cubic, reduced linear and linear models were chosen and transformed then used to generate polynomial equations for optimizing electrical properties of bulk sorghum

- Optimized ranges for designing or selecting sensors and actuators for automating harvesting, processing and storage operations, using these electrical properties for sensing was developed.

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Effects of Soil Moisture Stress on Growth and Yield of Okra (*Abelmoschus Esculentus*) Under Drip Irrigation

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ABSTRACT

The growth and yield responses of okra (*Abemoscus esculentus*) to water stress under four water regimes of 100%, 80%, 60% and 40% field capacity were examined under drip irrigation for two varieties of okra; Clemson's spineless variety and B35 variety at Federal College of Agricultural Research Farm Ibadan. A Latin Square Design was used for the test plot of 10m by 6m (60m^2). The water requirements of Clemson's spineless and B35 varieties were determined from field capacity of the soil. Tensiometer and soil moisture meter were used to determine the amount of moisture present in the soil. Irrigation was applied at an interval of three days, and the analysis of variance at a level of significance of 5 % indicated significant differences in yield with level of irrigation, and also with growth.

Results indicated that, moisture stress had significant influence on growth and yield components of okra. Numbers of leaves, plant height, stem girth, and yield were affected by water deficit. For Clemson's spineless, the yield followed in the order; 100%FC (2.04t/ha) > 80%FC (1.44t/ha) > 60%FC (1.31t/ha) > 40FC% (1.0t/ha). For B35 variety, the yield followed in the order; 100%FC (1.77t/ha) > 80%FC (1.35t/ha) > 60%FC (1.13t/ha) > 40%FC (0.99t/ha). The variation observed in the yield of the two might be due to their different degree of tolerance to drought level. The results of the study could be useful in designing effective water scheduling for irrigation system for okra production.

Keywords: Okra, Drip, Irrigation, Tensiometer, Field capacity, Moisture stress.

1. INTRODUCTION

Okra *(Abelmoschus esculentum L)* is an annual herb and vegetable crop grown throughout the tropical and subtropical parts of the world either as the sole crop or intercrop with maize or another (Emuh *et al.,* 2006). The nutritional importance of okra pod has reawakened interest in bringing the crop into commercial production. The fruits are used in making soup, salad and for flavoring when dried and powdered. The tender fruits contain minerals especially calcium, magnesium, iron and phosphorus, protein, vitamin A and C including riboflavin as well as high mucilage (Ndaeyo *et al.,* 2005). Mature okra seeds are good sources of protein and oil (Oyelade *et al*., 2003) and it has been known to be very important in nutritional quality. Its ripe fruit and stems contain crude fiber, which is used in the paper industry. Despite the nutritional value of okra, its optimum yields (2-3 t /ha) and quality have not been attained in the tropical countries partly because of a continued decline in soil fertility and soil moisture (Pettigrew, 2004).

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Water deficits and insufficient water are the main limiting factors affecting worldwide crop production (Nuruddin, 2001). Plants growing under suboptimal water levels are associated with slow growth and, in severe cases, dieback of stems; such plants are more susceptible to disease and less tolerant of insect feeding (Wilson, 2009). In crops, water stress has been associated with reduced yields and possible crop failure. The effects of water stress however vary between plant species. As the plant undergoes water stress, the water pressure inside the leaves decreases and the plant wilts. The main consequence of moisture stress is decreased growth and development caused by reduced photosynthesis, a process in which plants combine water, carbon dioxide and light to make carbohydrates for energy. Water deficit inhibits photosynthesis by causing stomata closure and metabolic damage. Stomata of the leaves that are slightly deficient in water opened more slowly in light and close more quickly in the dark (Nuruddin, 2001). Soil moisture stress reduces leaf water potential which in turn may reduce transpiration (Shibairo *et al.,* 1998). Kirnak *et al*. (2001) have found that water stress results in significant decreases in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress have less fruit yield and quality.

Okra plants need a controlled supply of water throughout the growing period for optimal quality and higher yield. Drip irrigation with its ability of small and frequent water applications have created interest in view of decreased water requirements, possible increased production, and better product quality (Connor *et al.,*1981; Mohammed *et al.,*2006). Edoga and Edoga (2006) also reported that with drip irrigation, the soil is maintained continuously in a condition which is highly favorable to the crop growth. Controlled irrigation is essential for high yields because the crop is sensitive to both over and under irrigation (Al-Harbi *et al.,* 2008). Therefore, this research aims at studying the possible impacts of soil moisture stress using drip irrigation on the growth and yield of Okra.

2. MATERIALS AND METHOD

2.1 Experimental Design

This experiment was conducted at the Agricultural Research farm of the Federal College of Agriculture, Moor Plantation, Ibadan. The experimental site is located between **7.365° N** and **3.859° E** with an altitude of **400meters** above sea level. The experiment was conducted on sandy- loam soil having a pH of 5.99. The average annual maximum and minimum temperatures are 36.70^{o}C and 22.3^{o}C, respectively.

Two varieties of okra were used as planting materials. These were Clemson’s spineless and B35 varieties. These varieties were collected from the Institute of Agricultural Research and Training (IAR&T). The cultivar has been used by farmers in the region and it takes 45-60 days to mature under field condition.

The experimental field was laid in a latin square block design. Four moisture levels of 100%FC, 80%FC, 60%FC and 40%FC (Field Capacity) irrigation were applied**.** The treatments were replicated twice for the two varieties. The 100%FC was used as control. A simple drip irrigation technology was adopted for the experiment. Each water regime has two rows. Drip laterals were laid out at 1.0m spacing between the rows. The drippers/emitters were placed at 0.75m apart along the lateral line with a discharge capacity of 4.0 l/hr each.

The gross plot size of the experimental field was measured to be 10m by 6m (60m^2). Each bed was placed at 1m apart. The soil was ploughed and the beds were constructed. For sowing, three seeds were planted per hole with a spacing of 0.75m.

2.2 Field Capacity Determination

The field capacity of the soil was determined using the core method (Mbah, 2012). 100 cm^3 soil cores were used to take sample from the plot. The sample was wetted to saturation and leave to dry for 24hours. The weight of the wetted core was measured. The sample was oven dried to a constant weight at 105^{o}C (ASTM, 1987). The field capacity was calculated as follows:

$$F.C = \frac{W_{WC}-W_{OS}}{W_{OS}-W_{C}} \times Bulk\ density \qquad \text{……………………..} (1)$$

Where: W_{wc} = Weight of wetted core after 24hrs

W_{OS} = Weight of oven dry sample

W_C = Weight of core sampler.

The planting was carried out on 8th of November, 2016. For sowing, three seeds were planted per hole with a depth of 3cm and a spacing of 75cm. The number of stands per bed was 8. Weeding was carried out weekly which was done with bare hand by uprooting the weeds.

2.3 Irrigation Scheduling

The goal of irrigation scheduling was to make the most efficient use of water and energy by applying the right amount of water to cropland at the right time and in the right place. Proper irrigation scheduling requires a sound basis for making irrigation decisions. Methods of irrigation scheduling are based on soil water measurements, meteorological data or monitoring plant stress. Tensiometers measure the soil water tension that can be related to the soil water content. The tensiometer gauge reads the tension between soil and water particles. Soil moisture tension increases when there is less water in the soil. As a result, the tensiometer gauge reads high for dry soils and low for wet soils.

For most soil types, readings under 10 cbars indicate a wet soil, and above 50 cbars indicate a dry soil (Fabura and Nkakini 2015). The following steps were considered when determining a watering schedule for a drip irrigation system

1. Determination of the crop root zone depth (RD)
2. Determination of the soil type

3. Determination of the Available soil water storage capacity (AWSC) or Field capacity(FC)
4. Determination of the total available water storage capacity (TAWSC)

   TAWSC = Rooting depth x AWSC
5. Determination of 80% FC, 60%FC and 40%FC respectively,

80% FC of moisture depletion = Total AWSC x 80%

60% FC of moisture depletion = Total AWSC x 60%

40% FC of moisture depletion = Total AWSC x 40%

Once the percentage depletion of moisture content was noticed through the use of soil moisture meter and tensiometer for each regime, the amount of missing water was replaced by drip irrigation

2.4 Data Collection

Seedling emergence:

The number of seedlings that emerged per treatment was obtained through daily counts of shoots showing above the soil surface at 5-14 days after planting.

Plant height:

Plant height was determined by measuring the height of the plant. A 30-cm ruler was used to take measurements from the soil surface to the topmost stretched leaf of each plant. Measurements were taken every week, starting from nine days after planting (DAP).

Stem diameter:

A vernier caliper was used to measure seedling diameter at 5-cm height above the soil. Measurements of stem diameter started when all plants from the different treatments had grown above 5-cm height.

Number of leaves

This was done by physical counting of leaves on a plant. Growth parameters mentioned above are monitored and recorded on weekly basis after first two weeks of emergence.

Yield

Five plants were randomly selected from the middle area of each replicate of the treatments in order to eliminate border effects. The fruits from these plants were harvested manually in five pickings at two day intervals. These fruits were weighed and the yield was determined.

Data Analysis

Data obtained were subjected to statistical analysis using Analysis of Variance (ANOVA) to determine if the treatments have any significant effect on parameters measured at 5% confidence level. Regression analysis was also done using Analysis of Variance (ANOVA).

3. RESULTS AND DISCUSSION

3.1 Soil Sample Analysis

The results of the soil physical analysis showed that the textural class of the soil used for the experiment was sandyloam, with a pH that indicates that it is acidic. The soil is low in almost all the essential nutrients. Apart from exchangeable Ca and Mg, all the other essential elements such as total N, available P, exchangeable K and Na are below the critical levels recommended for crop production. The soil moisture content is also low, thus resulting in low available water.

Table 1: Soil Test Analysis

Parameters	Values
pH(H_2O)	5.99
% of Sand	47.52
% of Clay	13.56
% of Silt	38.92
Textural class	Sandy-loam
B.Density g/cm^3	1.57
Ca (cmol/kg)	2.04
Mg (cmol/kg)	1.34
CEC (cmol/kg)	4.51
H+	0.11
Average P (ppm)	14.95
Total Nitrogen %	0.15
Organic carbon %	1.86
Organic matter %	3.20
Electrical conductivity	138.80

3.2 Plant Height of Clemson's Spineless and B35 Varieties

Height of clemson's spineless and B35 okra varieties planted on the four water regimes (100%FC Regime, 80%FC Regime, 60%FC Regime, and 40%FC Regime) were being recorded on weekly basis, the result is represented in Figure 1 and 2. The figure shows that there is a uniform increase in height of clemsom's spineless okra planted on all the four regimes until 42 DAP after which there was an increase in the rate at which the heights were increasing. 60%FC regime produced the highest plant height value of 45cm and 40cm at 70 DAP respectively, 100%FC regime have the second highest value of 42cm and 37cm at 70 DAP respectively, 40%FC regime have the third highest value of 35cm and 30cm at 70 DAP respectively, and 80%FC regime produces the least plant height at 32cm and 35cm. The increase in Clemson's variety plant height with days of planting was in line with Puneet *et al.,* (2016) who reported that plant height increases with time. The result obtained below shows that the variations on the effects of soil moisture stress was insignificant on the plant height.

Comparing the plant height of the two varieties, 100%FC of Clemson spineless gives 42cm while B35 variety gives 37cm, 80%FC of Clemson spineless gives 32cm while B35 variety gives 35cm, 60%FC of Clemson spineless gives 45cm while B35 variety gives 40cm, 40%FC of Clemson spineless gives 35cm while B35 variety gives 30cm.

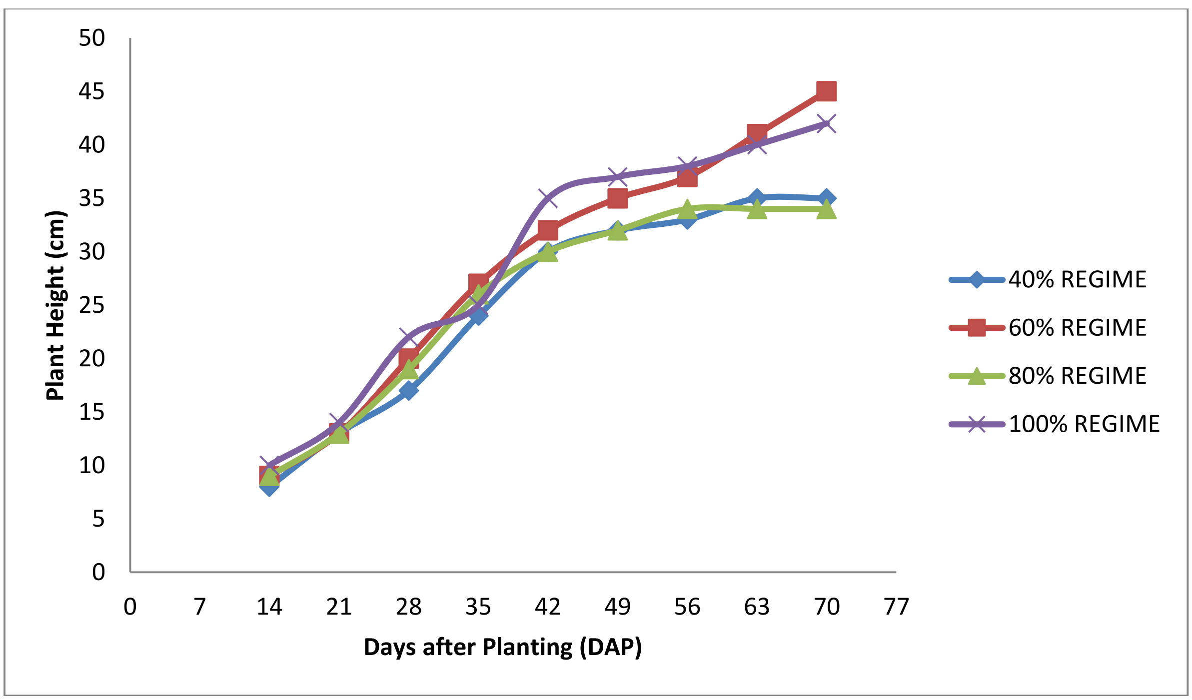

Figure 1: Changes in Heights of Clemson's spineless Variety with Days after Planting (DAP)

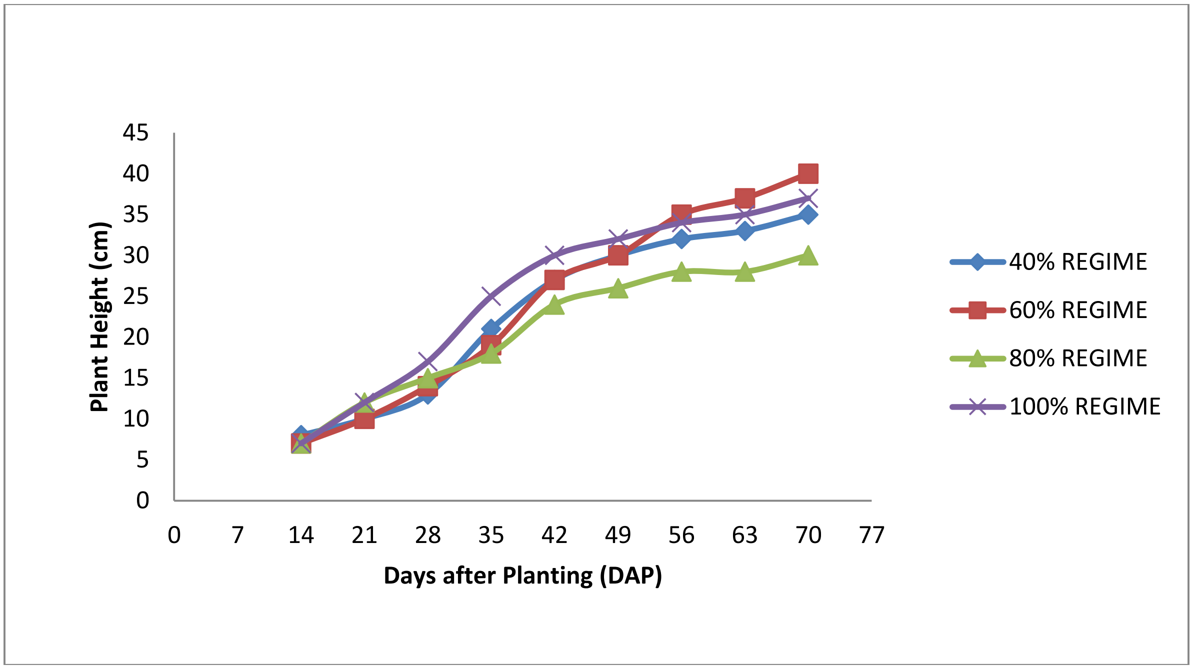

Figure 2: Changes in Heights of B35 Variety with Days after Planting (DAP)

3.3 Stem Girth of Clemson's Spineless Variety

The stem girth of Clemson's spineless okra planted on the four water regimes (100%FC Regime, 80%FC Regime, 60%FC Regime, and 40%FC Regime) were recorded on weekly basis, the result is represented in Figure 3.The figure shows that there was a uniform increase in stem girth of clemsom's spineless okra planted on all the four regimes until week 7 after which there was an increase in the rate at which the stem girth were increasing. 60%FC regime produced the highest stem girth value of 12.12mm at 70 DAP, 100%FC regime produced the second highest value of 10.12mm at 70 DAP, 80%FC regime produced the third highest value of 8.23mm at 70 DAP, followed by 40%FC which produced the least value of 7.84mm.

3.4 Stem Girth of B35 Variety

The stem girth of B35 okra planted on the four water regimes (100% Regime, 80% Regime, 60% Regime, and 40% Regime) were recorded on weekly basis, the result is represented in Figure 4. The figure shows that there was a uniform increase in stem girth of B35 okra planted on all the four regimes until week 6 after which there was an increase in the rate at which the stem girth were increasing. 80%FC regime produced the highest stem girth value of 8.78mm at 70 DAP, 100%FC regime produced the second highest value of 8.61mm at 70 DAP, 60%FC regime gave the third highest value of 8.43mm at 70 DAP, followed by 40%FC which produced the least stem girth of 8.01mm.

Comparing the stem girth of the two varieties, 100%FC of Clemson's spineless gives 10.12mm while B35 variety gives 8.61mm, 80%FC of Clemson's spineless gives 8.23mm while B35 variety gives 8.78mm, 60%FC of Clemson's spineless gives 12.12mm while B35 variety gives 8.43mm, 40%FC of Clemson's spineless gives 7.84mm while B35 variety gives 8.01mm. Hence Clemson spineless produces greater value in stem girth in all the regimes except in 80%FC regime.

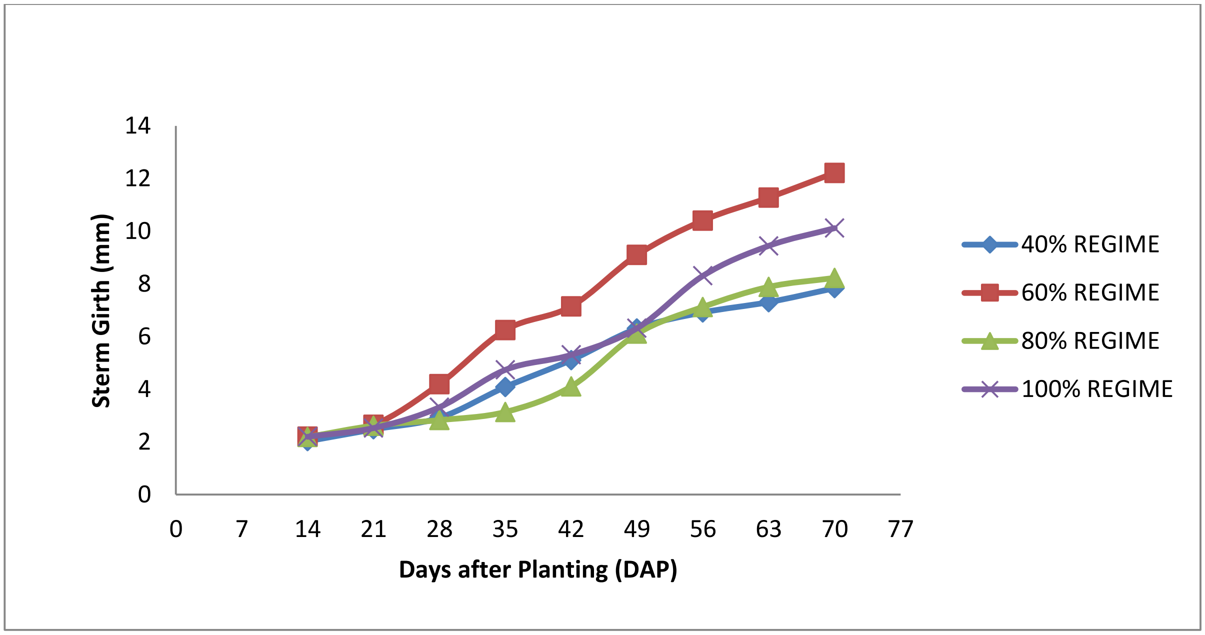

Figure 3: Changes in Stem Girth of Clemson's spineless Variety with Days after Planting (DAP)

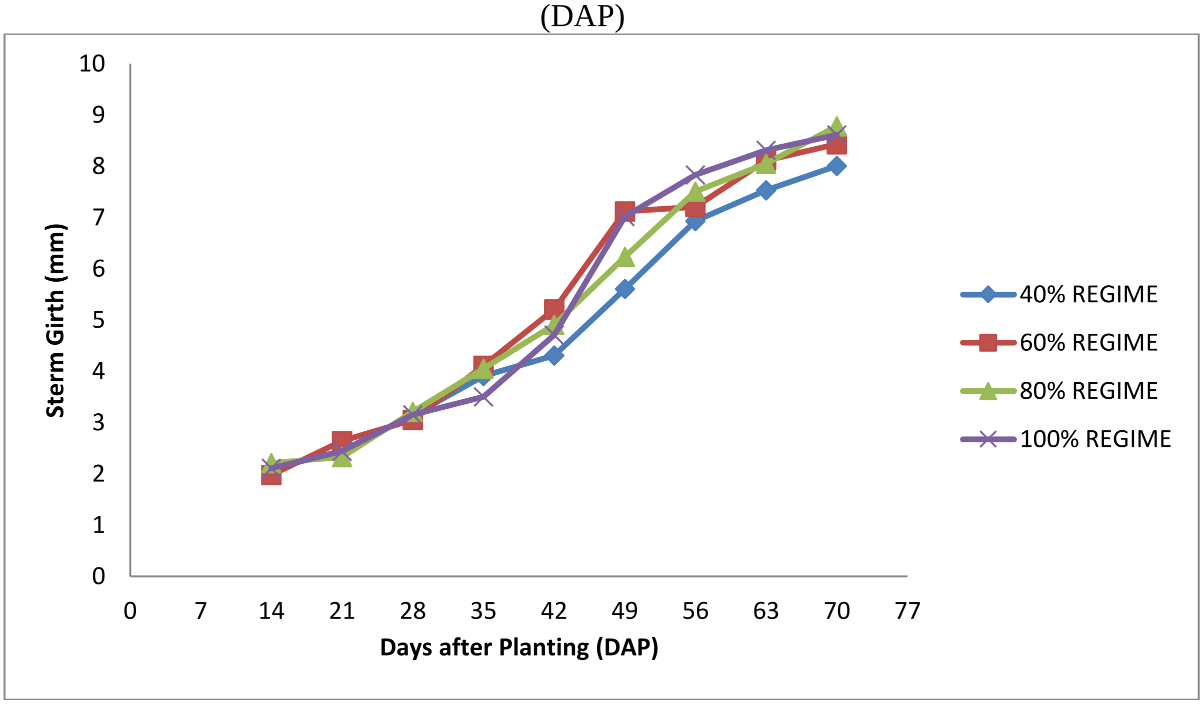

Figure 4: Changes in Stem Girth of B35 Variety with Days after Planting (DAP)

3.5 Plant Leaves of Clemson's Spineless Variety

The plant leaves of Clemson's spineless okra planted on the four water regimes (100%FC Regime, 80%FC Regime, 60%FC Regime, and 40%FC Regime) were recorded on weekly basis, the result is represented in Figure 5.The figure shows that there was a uniform increase in plant leaves of Clemson's spineless okra variety planted on all the four regimes until week 7 after which there was an increase in the rate at which the plant leaves were increasing. 100%FC regime produced the highest plant leaves number of 26 at 70 DAP, 60%FC regime produced the second highest number of 23 at 70 DAP, 80%FC regime produced the third highest number of 20 at 70 DAP, followed by 40%FC regime which produced the least number of 17 at 70 DAP.

3.6 Number of Leaves of B35 Variety

The plant leaves of B35 okra planted on the four water regimes (100%FC Regime, 80%FC Regime, and 60% FC Regime, and 40% FC Regime) was recorded on weekly basis, the result is represented in Figure 6. The figure shows that there is a uniform increase in plant leaves of B35 okra planted on all the four regimes until week 7 after which there was an increase in the rate at which the plant leaves were increasing. 100%FC regime produced the highest plant leaves number of 24 at 70 DAP, 80%FC regime produced the second highest value of 20 at 70 DAP, 60%FC regime produced the third highest number of 16 at 70 DAP, followed by 40%FC regime which produced the least number of 14 at 70 DAP. The result obtained shows that the variations on the effects of soil moisture stress is not much felt on the plant leaves.

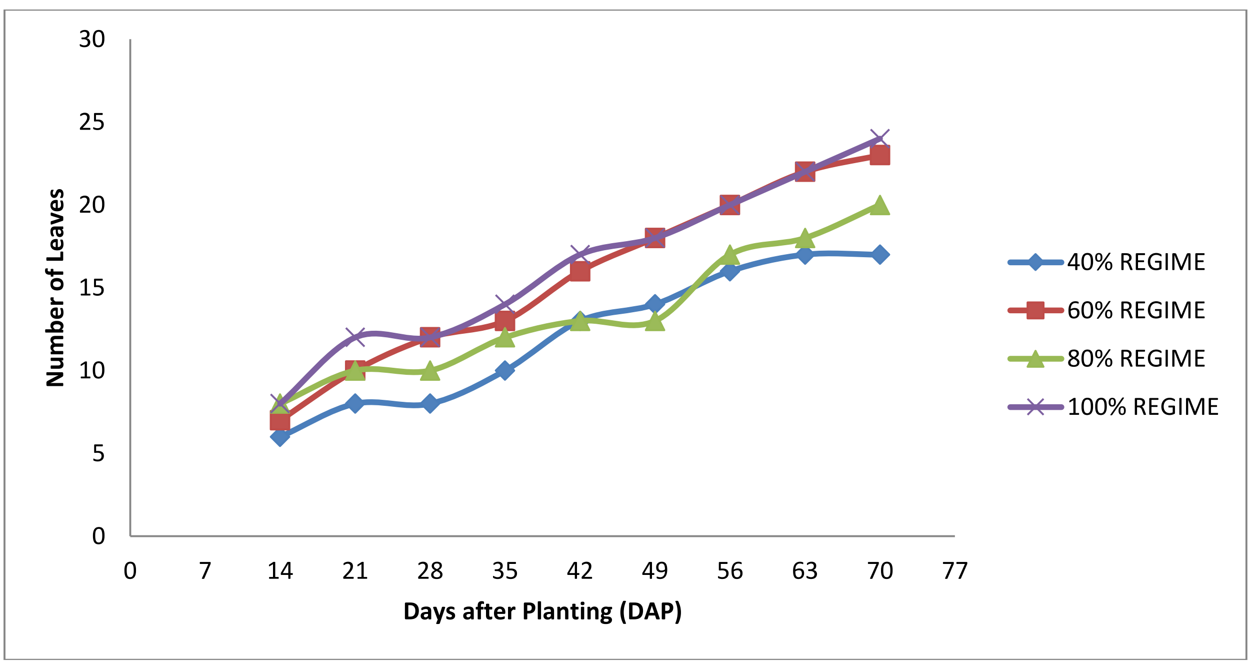

Figure 5: Changes in Number of Leaves of Clemson's spineless Variety with Days after Planting (DAP)

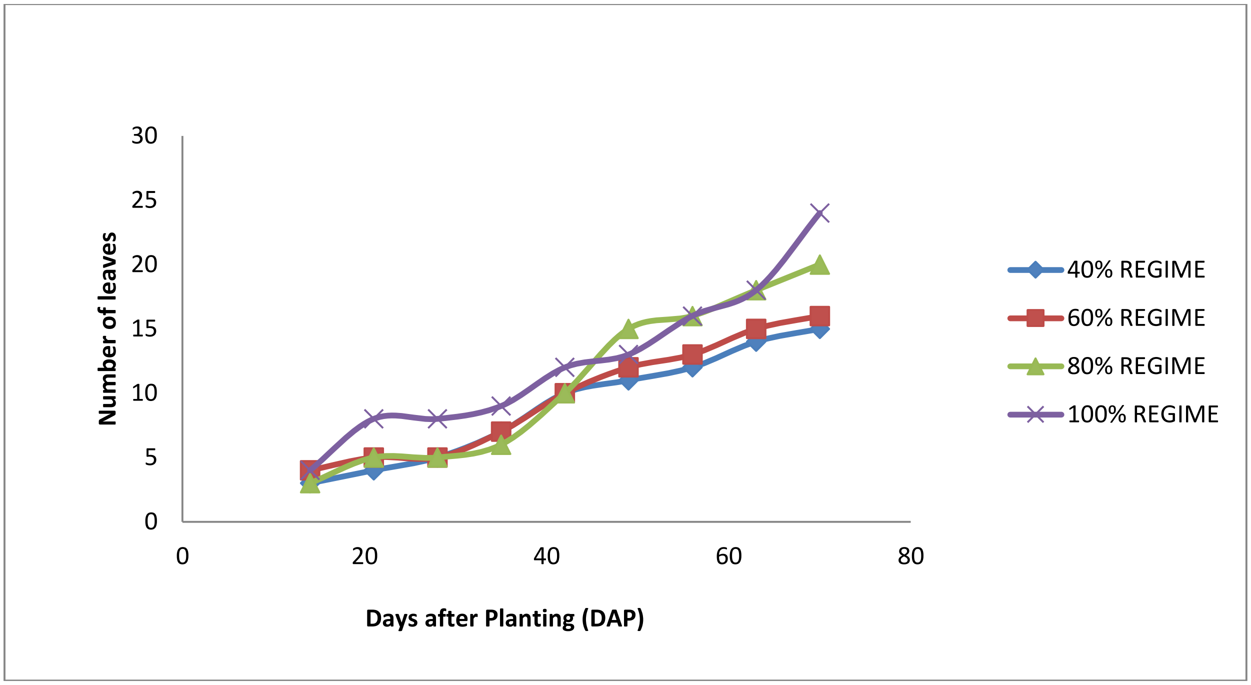

Figure 6: Changes in Number of Leaves of B35 Variety with Days after Planting (DAP)

3.7 Okra Yield

The variations of yields in the four treatments for the two varieties are shown in Figures 7 and 8. Okra fruits of Clemson spineless and B35 varieties were harvested at 70DAP. The yield of each regime were harvested and recorded.

For Clemson's spineless variety, the 100%FC gave the highest yield value of 2.04tons/ha, 80%FC regime gave the second highest value of 1.44tons/ha, 60%FC regime gave the third highest value of 1.31tons/ha, and 40%FC regime gave the least value of 1.0tons/ha.

For B35 variety, the 100%FC regime gave the highest yield value of 1.77tons/ha, 80%FC regime gave the second highest value of 1.35tons/ha, 60%FC regime gave the third highest value of 1.13tons/ha, and 40%FC regime gave the least value of 0.99tons/ha.

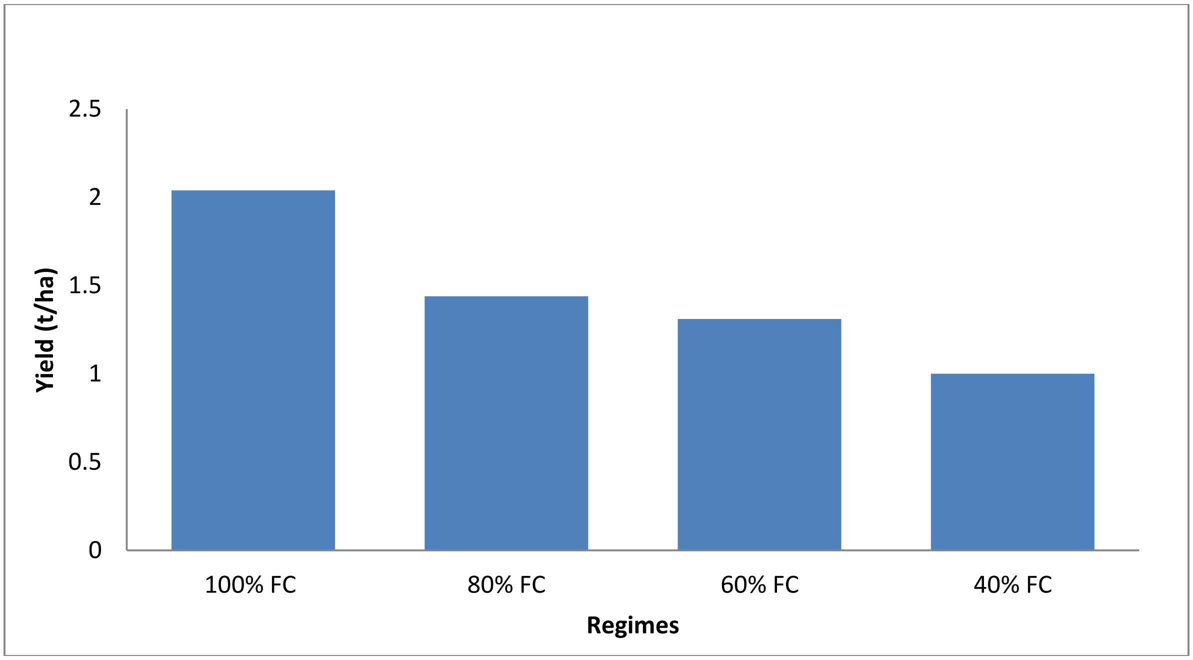

Figure 7: Trend in Yield of Clemson's spineless variety for different Irrigation Regimes

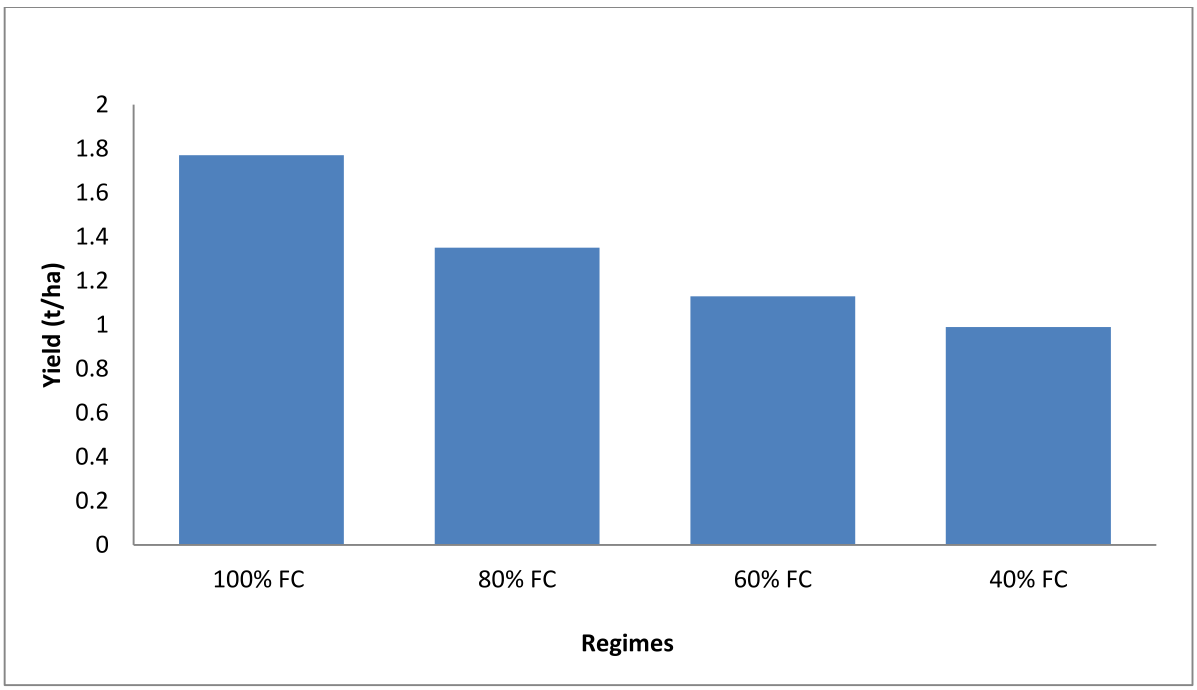

Figure 8: Trend in Yield of B35 Variety for different Irrigation Regimes

3.8 Discussion

The variation in the yield value of both Clemson's spineless and B35 varieties shows that at high regime of water application, high yield can be obtained and vice versa. This also implies that the more the moisture stresses on okra plant, the more the reduction in yield. Also from the result obtained, Clemson's spineless variety gave high yield as compared to B35 variety. The results obtained corroborated the findings of Al-Harbi *et al.,* (2008) and Abdul Naveed *et al.,* (2009) that increase in the amount of water use leads to increase in okra yield. This result is also in agreement with the findings of Kurunç and Ünlükara, (2009) who reported increased yield of okra with increasing irrigation water application. According to Calvache and Reichardt (1999), water deficit during vegetative growth leads to decline in yield. This was evident from the results obtained from the two varieties at different application regime of water.

4. CONCLUSION

The two different okra varieties obtained from IAR&T was planted and monitored under drip irrigation condition. From the analyzed data, there was a uniform increase in the stem diameter, plant height and number of leaves in the two varieties of okra planted and also there was a slightly significant difference across the four regimes at 5% significance difference. The effect of soil moisture stress on plant height, plant leaves and stem girth was insignificant. Clemson's spineless had the best result value in terms of okra yield, okra productivity, plant height, plant leaves and stem girth as compared to B35 variety. It can be concluded that, okra plant are tolerant to drought even though they produce better when they get the sufficient amount water as recorded in the 100%FC.

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Design, construction and performance evaluation of a rice destoner

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ABSTRACT

The market price of local rice in the market is significantly determined by its quality which is dependent on the level of cleaning and some other processing operations. Hence, the need to improve the quality of rice, increase production and reduce human labour has brought about the development of rice destoning machine. Therefore, this study aimed at designing, fabricating and evaluating the performance of a rice destoner. The design was based on the principle of material separation and was constructed from locally-available materials. The machine was powered by a 2hp electric motor and three vibrating screens of varying apertures were used for the upper, middle and lower screens. The machine had an average capacity of 130 kg/h. The performance of the machine was evaluated with 10 kg of *Ofada* rice at 11, 21 and 25% moisture content (dry basis) and 10 kg of Faro 55 rice at 14, 22 and 27% moisture content (dry basis). The results showed that separation efficiency decreased as the moisture content of rice decreased for both varieties. Cleaning of rice at low moisture content is recommended for optimum performance of the destoner.

Keywords: Rice, Cleaning, Quality, Destoner, Separation efficiency, Moisture content, Performance evaluation.

1. INTRODUCTION

Rice (*Oryza spp.*) is a staple food for more than half of the human race of a hundred million and is very competitive in the world trade. It belongs to the grass family, *Gramineae* (Sweeney and Mccouch, 2007) and has become the second most important cereal in the world after wheat in terms of production due to a decline in maize production (Selbut, 2003). It is highly nutritious with high calorie constituents thus providing more than one-fifth of the calories consumed worldwide by humans (Smith, 1998).

In Nigeria, rice is grown on 1.77 million ha and ranks sixth after sorghum, millet, cowpea, cassava and yam. On a social scale, it can be ranked first because it is no longer just a mere festival meal, but the staple food of most homes both in urban and rural areas (Selbut, 2003).

Locally produced rice in Nigeria has been found to contain some stones, sand particles, debris, chaffs and other impurities which have contributed to its low quality and poor consumer acceptance. The low quality of local rice is one of the factors militating against its demand and prospect of being exported to generate foreign exchange for the country. These foreign materials or impurities in locally-produced rice are often introduced into rice during harvesting, threshing, handling, packaging etc (Selbut, 2003). Ogunlowo and Adesuyi (1999) reported that the harvest and post-harvest operations of local rice encourage the introduction of contaminants. Mud usually is attached to the stem of rice when uprooted from the soil and thereafter, it dries up to become sand and stones which can only be removed by cleaning. Also, after parboiling, drying is usually carried out under the sun on bare floor, platforms or slabs which could also result in stones and other dry impurities being introduced into rice. Hence, cleaning, as a preliminary operation, must be carried out to remove the unwanted materials or impurities from rice to increase the quality of locally-produced rice and make it more attractive to the consumers.

Cleaning of harvested rice includes operations such as winnowing (for separation of chaff and other light impurities) and destoning (removal of stones and sand particles from rice) which can be done either manually or mechanically with the use of a cleaning machine. Manual or traditional methods of cleaning are time consuming and laborious (Mohammed *et al.*, 2017). These limitations necessitate the need for appropriate technologies for cleaning locally-produced rice. This study therefore, developed a motorised rice destoner with a view to improving the quality of local rice, increasing productivity and reducing the drudgery involved in rice cleaning.

1.1 Review of existing rice destoning machine

Efforts have been made by researchers to design and construct rice destoners with varying separating efficiencies (Henderson and Perry, 1976; Osueke, 1998; Simonyan *et al.,* 2010; Adejuyigbe and Bolaji, 2012; Agidi *et al.*, 2015). Henderson and Perry (1976) designed a grain destoner which uses gravity and floating characteristics between the rice grains and stones. The destoner was made of a triangular shaped perforated table which is subjected to reciprocating motion that moves any material on it in the direction of conveyance due to gravity. Osueke (1998) also designed a rice destoner which separated small stones, sand and metallic impurities from the cleaned rice. Simonyan *et al.* (2010) designed a rice destoning machine on mechanical principles of reciprocating and vibrating sieves. The mixture of rice and stones was fed onto the reciprocating sieve through the hopper where stones smaller than the rice pass through and stones larger than the sieve size fall with the rice onto the vibratory sieve. The vibratory sieve sends the stones in the opposite direction of the flow of clean rice. Average rice and stone separation efficiencies obtained were 74.2 and 70%, respectively. Adejuyigbe and Bolaji (2012) incorporated two vibrating sieves into a destoning machine. The average capacity of the machine was 31,800 kg/h and the average efficiency was found to be 90%. Agidi *et al.* (2015) designed a rice destoner locally powered by a 2 Hp electric motor. The separation of stone from rice was achieved by the horizontal oscillation of the reciprocating screens and the results showed that the machine had 69 and 87% for stone and rice separation efficiencies respectively.

This study therefore, developed a rice destoning machine that incorporates three vibrating sieves for separating rice from small-sized and large-sized stones and a blower (centrifugal fan) to separate chaff and other light impurities from the cleaned rice.

2. MATERIALS AND METHODS

2.1 Development of the rice destoner: description of the machine

The rice destoner was constructed using 2 mm by 2 mm angle iron, galvanized metal and stainless steel of thickness 2 mm and 1.5 mm respectively. It comprises a centrifugal fan which blows off chaffs and lighter impurities and three set of sieves for better separation efficiency. It has two screens (uppermost and bottom) with circular apertures and a middle screen with oblong holes to trap stones that escape the uppermost screen. The screens were tilted at angles between 15° to 20° to the horizontal and the angles could be varied with respect to the speed and efficiency required. The two screens were connected together and mounted on the frame work which connects them to the shaft. The shaft has an auger which conveys rice grains over the upper sieve as it is being fed into it from the hopper. The separation is achieved by an eccentric drive which effects the reciprocation of the middle and lower screens causing it to move to and fro thereby, ensuring the separation of impurities from the rice grains. The rice destoner was powered by a 2 hp electric motor and operates at a speed of 360 rpm. The 3-Dimensional view of the machine is shown in Fig. 1.

2.2 Design considerations and calculations

2.2.1 Belt and pulley design for shaker mechanism

The belt and pulley were designed in accordance with Fenner industrial belt drive manual. A 2 hp electric motor rotating at 1440 rpm was chosen. V-belt type of A-section was selected for the machine.

2.2.2 Design for shaft diameter

The shaft diameter was determined according to Equation 1 (Khurmi and Gupta, 2005).

$$D^3 = \frac{16}{\pi S_s\sqrt{(K_b M_b)^2 + (K_t M_t)^2}} \qquad (1)$$

Where: D = Diameter of shaft; $M_b = Maximum\ bending\ moment, Nm M_t = Torsional\ moment, NM$; $S_s = Allowableshearstress, MN/\mathrm{m}^2; K_b = Combined\ shock\ and\ fatigue\ factor\ applied\ to\ torsional\ moment\ on\ rotating\ shaft\ (Hall, 1988)$.

The torsional moment was calculated using Equation 2 while the angle of wrap, linear velocity, mass of belt, weight of the pulley and volume of pulley on shaft were determined using Equations 3 to 7, respectively.

$$M_t = (T_1 - T_2) \times r \qquad (2)$$

$T_1 = Tension\ on\ tighter\ side\ of\ the\ belt\ on\ pulley\ (N)$; r = Radius of pulley (m)

$T_2 \ = Tension\ on\ slack\ side\ of\ the\ belt\ on\ pulley\ (N)$;

The angle of wrap: $\cos(\frac{\theta}{2}) = \frac{r_{1-}r_2}{l}$ (3)

Linear velocity $(\mathrm{ms}-1)$: $V = \frac{2\pi Nr}{60}$ (4)

Mass of belt (kg), $\mathrm{m} = \rho bt$ (5)

Figure 1. Three-Dimensional view of the rice destoner

Weight of the pulley(kg), $W = V \times \rho$ (6)

Volume (V) of pulley on shaft $= \ \pi(R^2 - r^2) \times t$ (7)

$Where$: θ = angle of wrap (degrees); r1 = outer radius of the pulley (m);
= inner radius of the pulley (m); N = rotational speed (rpm); r
= radius of the driven pulley; ρ = density of steel (7800kg/m3).

The reactions on the shaft were determined using moment of forces and a maximum bending moment of 14.1 kNm was obtained. Hence, the diameter of shaft was obtained as 0.0299 m. Therefore, a shaft diameter of 30 mm was selected.

2.2.3 Design of shaft key for shaker mechanism

The shaft key size was determined using Equation 8**.**

$Ts = \frac{Ss}{N} \times W \times L \times r$ (8)

$Where$: Ts = shearing Stress; Ss
= Allowable shear stress of 100Mpa for mild steel; N
= Factor of safety; W = width of Key; L = Length of hub on pulley.

2.2.4 Torsional rigidity of shaft design

Torsional rigidity of solid shaft was determined based on the permissible angle of twist given in Equation 9 (Hall et al., 1988).

$$\theta = \frac{584Mt \times L}{Gd^4} \tag{9}$$

$Where$: Mt = Torsional moment on shaft; θ = angle of twist (0); L
= Length of the shaft between point and the applied load and resisting torque (mm); G
= Torsional modulus elasticity given as 80 × 104 N/m2 and d
= Shaft diameter (mm).

2.2.5 Critical speed of shaft

The critical speed of shaft was determined from Equation 10.

$$\mathrm{Wc} = \sqrt{5/4(g/\delta_{max})} \tag{10}$$

$Where$: Wc = Critical speed in rpm; g
= Acceleration due to gravity (9.8m/s); δ_{max}
= Maximum static deflection for a single attached mass.

2.2.6 Bearing Design

Equivalent load on the bearing was determined according to Equation 11(Hall *et al*, 1988)

Equivalent load, $P = X_o \times F_r + Y_o \times F_a$ (11)

Where: Fa = Thrust load (N); Y = Thrust = 1.48; X = Radial factor = 0.56; Equivalent load factor = 1; Fr = Radial force = 90N (determined).

A bearing corresponding to 145 kN dynamic load (No: P206) was therefore, selected from the bearing chart.

2.2.7 Sieve Design

Osueke (1998) classified the sand particles found in rice into two categories namely, sand and stones. He further classified the sands into fine and coarse, with particle size ranging from 0.2 to 2 mm and 0.02 to 0.2 mm, respectively. The stones ranged from 2.25 to 4.0 mm and the bulk density was given as 1.33 g/cm^3. These parameters were the basis on which the sieve sizes were selected.

The upper screen was chosen to be a round-hole sieve with a diameter of 4 mm based on the effective diameter of rice grains which was determined to be 3.8 mm. This would therefore, enable the separation of sand particles larger than 4 mm and permit the grains to fall onto the middle screen. The distance between the holes was determined using the coefficient of open area (Co) according to Equation 12.

$$C_o = \frac{D^2}{(D+d)^2} \tag{12}$$

$$Where: width\ of\ opening\ (mm);$$
$$d = distance\ between\ the\ elongated\ sides\ of\ the\ opening\ (mm)$$

The middle screen had oblong holes at distance of 3 mm between the adjacent lateral sides of the openings. This would enable the rice grains to pass through unto the lower sieve due to its shape and stones of particle sizes above 3mm were trapped. The coefficient of opening of this sieve was determined using Equation 13.

$$C_o = \frac{DL - 0.22D^2}{(D-d)(L+d_1)} \qquad (13)$$

$$Where: L = length\ of\ opening\ (mm);$$
$$d_1 = Distance\ between\ the\ adjacent\ lateral\ sides\ of\ the\ opening, mm.$$

A round hole sieve was selected for the lower screen with a diameter of 2 mm. This sieve is expected to trap the rice grains since the effective diameter of rice is 3.8 mm (Akintunde and Tunde-Akintunde, 2007) and allow the passage of the sand particles of sizes less than or equal to 2 mm. The coefficient of opening was also determined using Equation 12 as in the uppermost screen.

2.2.8 Fan Pulley and Belt drive design

The belt was designed in accordance to the Fenner standard industrial belt drives for a one step pulley. On the assumption that machine will run for less than 10 hrs per day, a service factor of 1 was chosen. Belt designed power was determined as 1.5 kW and the belt section of 80 mm. At 1:1.6 speed ratio, diameters of 100 and 160 mm were selected for the driving and driven pulleys, respectively. The center distance was calculated using Equation 14.

$$C = 2 \times \sqrt{(D+d) \times d} \qquad (14)$$

$$Using\ a\ correction\ factor = 0.87, V\ belt\ A1250\ was\ selected.$$

2.2.9 Auger design

The auger was designed using rapid screw conveyor design chart. The flight diameter, screw diameter, rubber pad diameter, shaft diameter and housing diameter were 78, 240, 5, 30 and 258mm respectively. The screw clearance of 13mm was chosen.

2.3 Performance Evaluation

The performance of the rice destoner was evaluated in terms of separation efficiency. The machine was operated at a speed of 360 rpm and its using 10 kg of the locally produced *Ofada* rice at 11, 21 and 25% moisture content (dry basis) and 10 kg of Faro 55 rice at 14, 22 and 27% moisture content (dry basis) to determine the influence of moisture content on the separation efficiency of the machine. The efficiency of the machine was calculated using the procedure used by Okunola *et al.* (2015).

2.3.1 Procedure for Evaluation

The initial moisture content of the rice grain was determined using oven drying method. This involved drying of a sample of known weight in the oven at a temperature of about 103^0C until three consecutive weights were constant. The moisture content was determined using Equation 15.

$$MC = \frac{W_w - W_d}{W_d} \times 100 \qquad (15)$$

$$Where: MC\ is\ the\ moisture\ content\ (\%\ dry\ basis;$$
$$W_w\ is\ the\ wet\ weight\ of\ the\ sample\ (g) and\ W_d\ is\ the\ dry\ weight\ of\ sample\ (g).$$

The initial moisture content of the two varieties of rice was varied by using Equation 16 (International Rice Research Institute, 2009).

$$Q = \frac{A(b-a)}{100-b} \qquad (16)$$

$$Where: Q = Mass\ of\ water\ to\ be\ added\ (kg); A = Initial\ mass\ of\ sample\ (kg);$$
$$a = Initial\ moisture\ content\ of\ sample\ (\%\ dry\ basis);$$
$$b = Final\ moisture\ content\ of\ samples\ (\%\ dry\ basis)$$

The required mass of water was mixed with the appropriate mass of rice available to obtain the desired moisture content. Separation Efficiency (SE) of the machine was calculated using Equation 17.

$$SE = \frac{Good\ Product}{Total\ Product} \times \frac{Bad\ reject}{Total\ reject} \qquad (17)$$

3. RESULTS AND DISCUSSION

3.1 Results of performance evaluation of the machine

The evaluation was carried out by destoning two different varieties of rice at three different moisture contents. The separation efficiency obtained for *Ofada* rice and Faro 55 rice at different moisture contents are presented in Tables1 and 2, respectively.

Table 1. Results obtained for *Ofada* rice

Moisture content (%)	**Efficiency (%)**	**Time taken (mins)**	**Capacity (kg/hr)**
11	81.16	4.42	135
21	77.41	4.98	120
25	68.72	5.17	116

Table 2. Results obtained for Faro 55 rice

Moisture content (%)	**Efficiency (%)**	**Time taken (mins)**	**Capacity (kg/hr)**
14	85.96	4.00	150
22	77.42	4.50	133
27	74.41	5.00	120

3.2 Effect of moisture content on machine efficiency separation

The separation efficiency of the machine decreased as the moisture content of the rice being destoned increased for both varieties of rice. Variations in separation efficiency with moisture content are presented in Fig. 2 and for Faro 55 and *Ofada* rice, respectively. It can thus be deduced that the machine performed better at lower moisture content of rice for both varieties of rice. The highest separation efficiencies of 85.96 and 81.16% were obtained for Faro 55 and *Ofada* rice, respectively. Reduced efficiencies as the moisture content of rice increased may be as a result of excessive clogging of the screens at higher moisture levels.

3.3 Effect of moisture content on capacity

An increase in the moisture content results in a longer destoning time which invariably decreased the capacity of the machine. There existed increased difficulty of the grains to slide on the sieve as the moisture content increased due to increasing coefficient of friction and angle of repose of both rice varieties on the surface of the screens (Aghajani, 2012). This increase in time taken can also be attributed to clogging of the screensin the machine which can also reduce the screening efficiency of the vibratory screens in the machine (Ortega-Rivas, 2012).

4. CONCLUSIONS

Rice destoner has been designed and constructed from locally-available materials. The machine was evaluated to determine its performance on rice at different moisture levels. Higher separation efficiencies and machine capacities were obtained at lower moisture contents for Faro 55 and Ofada rice varieties. The total cost of the machine was ₦200,000 which can be considered to be relatively more affordable for rice farmers when compared to the imported ones.

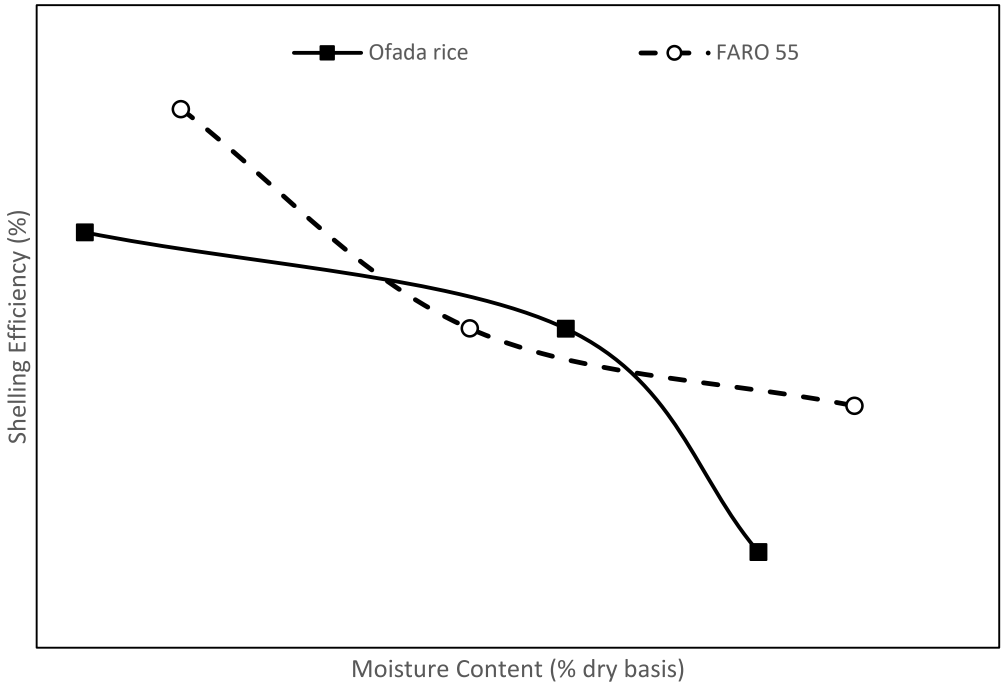

Figure 2: Separation Efficiency for Ofada and Faro 55 rice

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Non-destructive Online Real-time Milk Quality Determination in a Milking Robot using Near-infrared Spectroscopic Sensing System

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ABSTRACT

A near-infrared spectroscopic (NIRS) sensing system was developed on an experimental basis for the quality determination of three major milk constituents (fat, protein and lactose) and somatic cell count (SCC) of non-homogenized milk. The NIRS sensing system was used for acquiring NIR spectra of non-homogenized milk during milking in an automatic milking system (milking robot) over the wavelength range of 700 nm to 1050 nm. The three major milk constituents were analyzed for reference data using a MilkoScan instrument, while SCC was analyzed using a Fossomatic instrument. We developed calibration models using partial least square (PLS) regression analysis, and the precision and accuracy of the models was validated. The coefficients of determination (r^2), standard errors of prediction (SEP) and bias were 0.98, 0.23% and 0.00% for fat, 0.72, 0.25% and 0.00% for protein, 0.54, 0.15% and 0.00% for lactose, and 0.63, 0.48 Log SCC/mL and 0.00 Log SCC/mL for SCC respectively. These results show that the NIRS sensing system developed in this study could be used for online real-time determination of milk quality in a milking robot. The system can provide dairy farmers with information on milk quality and physiological status of each cow and therefore, give them feedback control for improving dairy farm management. By using the NIRS system, dairy farmers will be able to produce high-quality milk and precision dairy farming will be realized.

Keywords: Milk fat, protein, lactose, somatic cell count, dairy precision farming, japan

1. INTRODUCTION

Dairy farming involves a lot of work such as feeding, milking, livestock management, feed crop production and manure treatment. As usual, extensive dairy farmers manage their livestock in groups which is a system known as herd management (Svennersten-Sjaunja et al., 1997). However, a system known as individual cow management is essential for monitoring milk composition quality of each cow which is important for animal breeding, effective cow usage and feed management. Thus, this is the reason for the recent need for a technique that will enable dairy farmers to determine milk quality of individual cows during milking.

The non-destructive, rapid, easy to use, time saving and pre-treatment free nature of near-infrared spectroscopy (NIRS) makes it an effective tool for analyzing milk quality during milking process. NIRS has been used to obtain qualitative and quantitative information of food and agricultural commodity such as rice (Kawamura et al., 2003a; Natsuga and Kawamura, 2006), wheat (Natsuga et al., 2001), and fruits and vegetables (Lakshmi et al., 2017). NIRS has been practically used in automatic rice-quality assessment in Japan (Kawamura et al., 2002; Kawamura et al., 2003a). NIRS has also been use for milk quality determination (Sato et al., 1987; Tsenkova et al., 2001; Kawamura et al., 2003b; Tsenkova et al., 2006; Kawamura et al., 2007; Kawasaki et al., 2008; Tsenkova et al., 2009; Iweka et al., 2016). However, the application of NIRS for online real-time monitoring of milk quality of individual cow has not been achieved.

In this study, an experimental online near-infrared (NIR) spectroscopic sensing system was developed for milk quality determination. Iweka et al., (2016) reported that the NIR spectroscopic sensing system can be used for real-time determination of milk quality during milking with sufficient precision and accuracy. As a result of our findings, the NIR spectroscopic sensing system was installed in an automatic milking system.

The objective of this study was to examine the accuracy of the NIR spectroscopic sensing system for milk quality determination in an automatic milking system.

2. MATERIALS AND METHODS

2.1 Near-Infrared Spectroscopic Sensing System

An experimental online near-infrared (NIR) spectroscopic sensing system was designed for analyzing milk quality of each cow during milking. The system consisted of an NIR instrument (NIR spectrum sensor and NIR spectrometer), milk flow meter, milk sampler and a laptop computer (Fig. 1). The system was installed in a milking robot system (GEA Farm Technologies, Westfaliasurge, Germany). Non-homogenized milk from the milking robot flowed continuously across a bypass into the milk chamber of the NIR spectrum sensor. Excess raw milk flowed past the milk flow meter and was then released through a line tube into the bucket. The volume of a milk sample in the chamber was about 30 mL. The optical axes of halogen lamps A and B and the optical fiber were set at the same level, but the optical axis for halogen lamp C was set at 5 mm higher the optical fiber (Fig. 2). The NIR instrument acquired absorbance spectra through the milk. Spectra were obtained in the wavelength range from 700 nm to 1050 nm at 1 nm intervals every 20 s during milking (Table 1). The milk flow rate was simultaneously recorded in the laptop computer.

2.2 Cows and Milk Samples

Twenty six Holstein cows belonging to a dairy farm at Tochigi Prefecture, Japan were used for this study. These cows were at their different lactation stages. The experiment was conducted throughout the whole day for two consecutive days, that is; on the 22nd and 23rd of February 2018. Milking was automatically started as soon as a cow walked into the milking robot. Milk samples were collected from the milking sampler every 20 s during milking.

2.3 Reference Analyses

Three major milk constituents (fat, protein and lactose) and somatic cell count (SCC) of non-homogenized milk were measured as milk quality items in this study. The milk constituents were determined using a MilkoScan instrument (Foss Electric, Hillerod, Denmark) and SCC were determined using Fossomatic instrument (Foss Electric, Hillerod, Denmark). The total number of samples used for reference analyses were 377 for milk constituents and SCC.

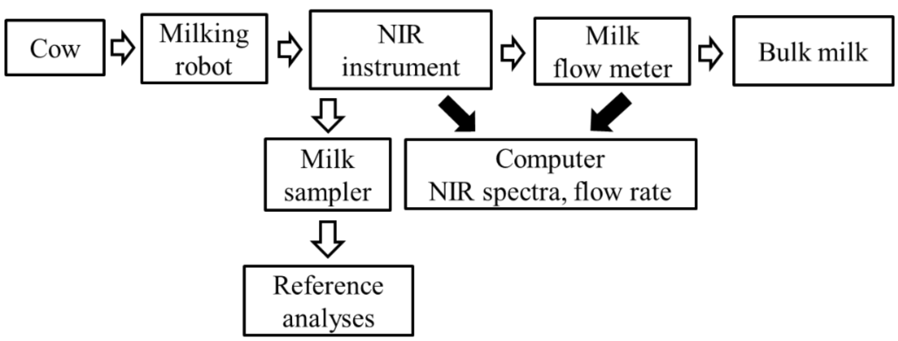

Figure 1. Flow chart of an on-line near-infrared spectroscopic sensing system for determining milk quality in an automatic milking system

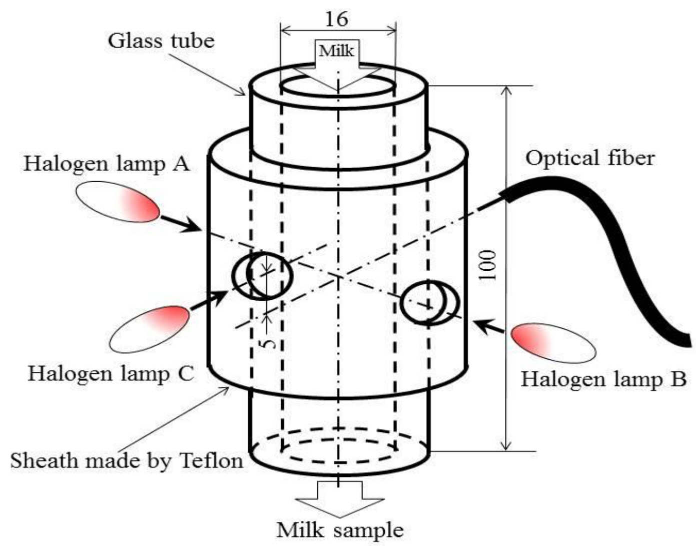

Figure 2. Schematic diagram of the optical system of milk chamber of the NIR spectrum sensor

Table 1. Specifications of the near-infrared spectroscopic instrument

Devices	Specifications
NIR spectrum sensor	Absorbance spectrum sensor
Light source	Three halogen lamps
Optical fiber	Quartz Fiber
Milk chamber surface	Glass
Volume of milk sample	Approx. 30 mL
Distance between optical axis and milk level	55 mm
NIR spectrometer	Diffraction grating spectrometer
Optical density	Absorbance
Wavelength range	700 - 1050 nm, 1-nm internal
Wavelength resolution	Approx. 6.4 nm
Photocell	CMOS linear array, 512 pixels
Thermal controller	Heater and cooling fan
Data processing computer	Windows 7
A/D converter	16 bit
Spectrum data acquisition	Every 20 s

2.4 Chemometric Analyses

Chemometric analyses were carried out to develop calibration models for milk quality parameters and to validate the precision and accuracy of the models. Spectra data analyses software (The Unscrambler ver. 10.3, Camo AS Trondheim, Norway) was used for the analyses. The total reference samples were used to develop calibration models. The calibration models were validated using full cross validation method. The statistical method of partial least squares (PLS) was used to develop calibration models from the absorbance spectra and reference data. The best model was obtained when we used the original spectra data thus, pretreatment techniques such as multiplicative scatter correction, 2nd derivative and smoothing was not used.

3. RESULTS AND DISCUSSION

3.1 Near-infrared Spectra

The original spectra of raw milk are shown in Fig. 3. The NIR spectra showed two bands peaks at around 740 nm and 840 nm indicate the overtone absorptions by C-H bands and C-C bands that are related to the distinctive absorption bands of milk constituents such as fat, protein and lactose. There was a strong absorption peak of O-H functional groups in water such that band around 960 nm were prominent spectra.

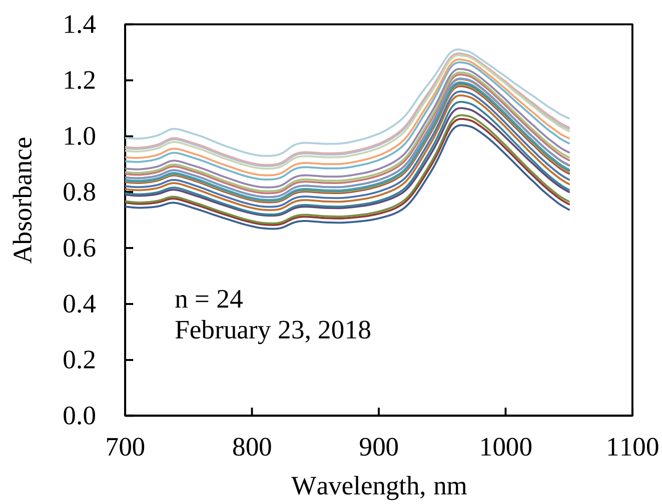

Figure 3. Original spectra of non-homogenized milk from cow number 1 during milking on February 23, 2018

3.2 Precision and Accuracy of Calibration Model

The validation statistics of the NIR sensing system for milk quality determination are summarized in Table 2. Correlations between reference and NIR-predicted values of milk fat, protein, lactose and SCC are shown in Figures 4 to 7 respectively.

The three major milk constituents are vital for milk quality determination. The quality of each milk constituents are influenced by the physiological condition of each cow and cow feed. Thus, monitoring of milk constituents during milking everyday can be used for individual cow and feed management. The coefficient of determination (r^2), standard error of prediction (SEP) and bias were 0.98, 0.23% and 0.00% for fat, 0.72, 0.25% and 0.00% for protein, and 0.54, 0.15% and 0.00% for lactose respectively. The high r^2 values, small SEP values and the negligible bias values (zero) indicated that there were sufficient levels of precision and accuracy for predicting the three major milk constituents. The performance of calibration models for fat was excellent. The high performance of calibration model for fat was due to the fact that milk spectra had much information on fat content, starting from the scattering of light by fat globules to the absorption by C-H bands and C-C bands of triacylglycerol. The results showed that the NIR spectroscopic sensing system designed in our study can be used for online real-time milk constituent quality determination during milking by a milking robot.

SCC is a recognized standard for mastitis diagnosis and it is a very important indicator for health and milk quality. Milk SCC can show the level of cow infection and it consequence on the mammary gland of dairy cows which is related to mastitis (Satu, 2003). Milk produced from the udder of a healthy cow contains less than 100,000 somatic cells per mL (i.e., 4logSCC/mL) while cows with subclinical mastitis produce milk containing more than 200,000 somatic cell per mL (i.e., 5.3logSCC/mL) (Satu, 2003). The values of r^2, SEP and bias for SCC were 0.63, 0.48 Log SCC/mL and 0.00 Log SCC/mL respectively. The results obtained for SCC indicated that the precision and accuracy for predicting SCC was sufficiently high. Thus, the calibration model could be used for the diagnosis of subclinical mastitis

3.3 Dairy Precision Farming

The installation of NIR spectroscopic sensing system developed in our study into a milking robot system would facilitate the monitoring of milk constituents and diagnosis of mastitis of individual cows in real-time during milking. The NIR sensing system could provide dairy farmers and veterinarians useful information on milk quality and physiological status of each cow and thus, give them assessment control for improving dairy farm management. The application of this NIR sensing system could take dairy farm management to the next level of dairy precision farming on the basis of individual cow information.

4. CONCLUSIONS

The NIR spectroscopic sensing system developed in this study can be used for online real-time monitoring of fat, protein, lactose and SCC during milking by a milking robot with sufficiently high levels of precision and accuracy. By application, the NIR sensing system would enable dairy farmers to be able to produce high-quality milk and dairy precision farming will be actualized.

5. ACKNOWLEDGEMENT

This study was supported by a grant from the Project of NARO (National Agriculture and Food Research Organization, Japan) Bio-oriented Technology Research Advancement Institution (The Project for Development of New Practical Technology). The authors are grateful to NARO for the grant.

Table 2. Validation statistics of the near-infrared sensing system for milk quality determination

Milk quality items	n	Range	r^2	SEP	Bias	Regression
Fat, %	377	0.98-8.54	0.98	0.23	0.00	y = 1.00 x + 0.00
Protein, %	377	2.73-4.46	0.72	0.25	0.00	y = 0.99 x + 0.04
Lactose, %	377	3.91-4.99	0.54	0.15	0.00	y = 0.98 x + 0.08
SCC, log SCC/mL	377	3.48-6.56	0.63	0.48	0.00	y = 0.98 x + 0.09

n: number of validation samples. r^2: coefficient of determination. SEP: standard error of prediction. Regression line: Regression line from predicted value (x) to reference value (y)

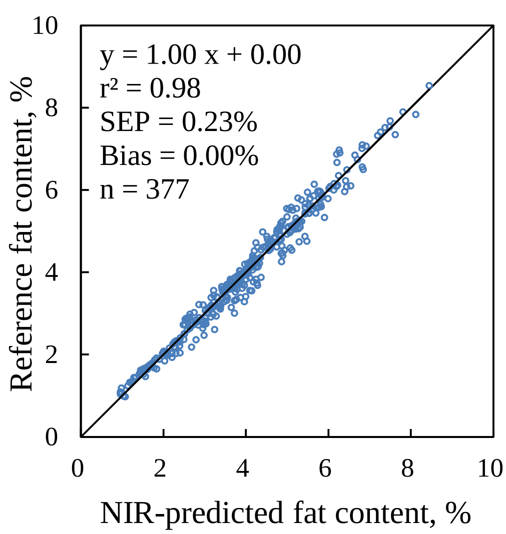

Figure 4. Correlation between reference fat content and NIRS-predicted fat content

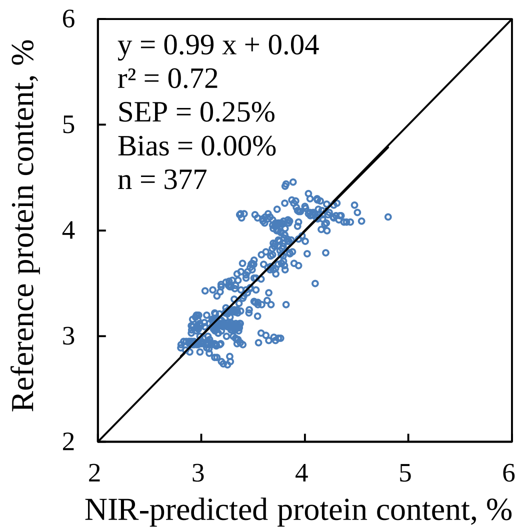

Figure 5. Correlation between reference protein content and NIRS-predicted protein content

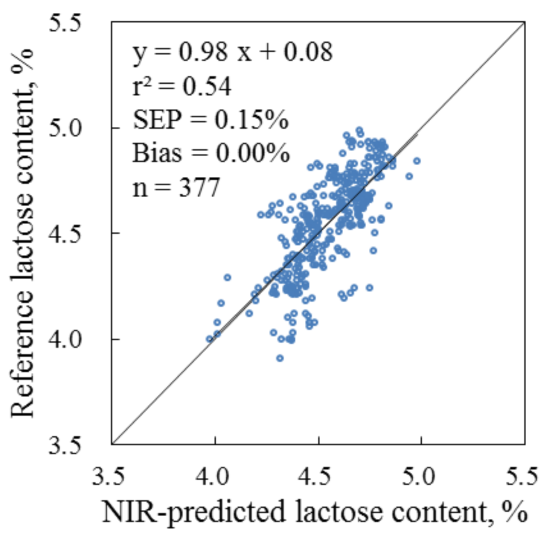

Figure 6. Correlation between reference lactose content and NIRS-predicted lactose content

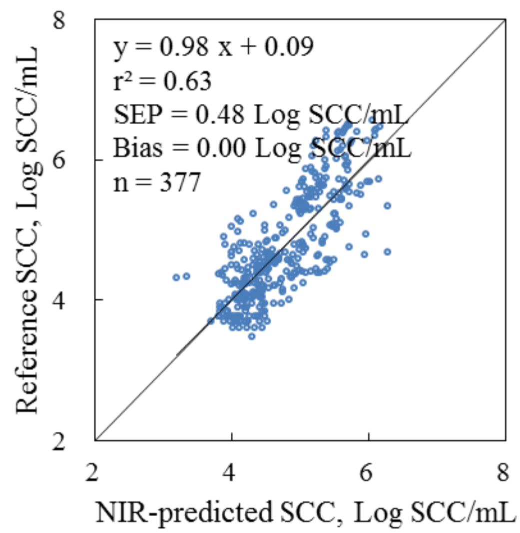

Figure 7. Correlation between reference SCC and NIRS-predicted SCC

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Development and Performance Evaluation of Pulse Shelling Machine

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ABSTRACT

IAR pulse sheller was developed in Ahmadu Bello University Zaria in 1985. New varieties were later developed whose acceptability in practice override. This requires a new machine that can shell different crop varieties, hence a new design. The machine size was modified resulting in the modification of all its components for pulse shelling. It consists of the hopper, shelling cylinder, removable concave, blower, chaffs outlet, grains delivery chute, clearance adjuster and frame. The machine performance was evaluated using cowpea as test crop. A combination of three cylinder speed levels; 2.39, 2.59, and 2.79 m/s (120, 130 and 140 rpm) and three feed rate levels; 12, 15 and 18 kg/min were used for the evaluation. The results were analyzed statistically using analysis of variance (ANOVA). Least Significant Difference (LSD) method was also used to assess the effect of parameter. The optimum performance was found at a cylinder speed of 2.79 m/s (140 rpm) with a feed rate of 12 kg/min and a 10 mm concave clearance. These resulted in output capacity, shelling efficiency, cleaning efficiency, scatter loss, and damaged grains of 546.18 kg/h, 93.24 %, 98.31 %, 0.625 % and 0.00 %, respectively. The effects of the selected variables on the performance indices were assessed and found that the effects of cylinder speeds and feed rates were not significant on all indices except on scatter loss and output capacity.

Keywords: Modification, Sheller, Performance evaluation, Performance indices, Pulses, Parameter levels

1. INTRODUCTION

Pulses are annual leguminous crops yielding grains or seeds used for food, feed and sowing purposes. Pulses are crops yielding from one to twelve seeds of variable size, shape, and colour within a pod. In addition to their values as food and feed stuffs, pulses are also important in cropping systems for their ability to produce nitrogen and thus increase the fertility of the soil (FAO, 2011). Cowpea is one of the most economically and nutritionally important indigenous African grain legumes produced throughout the tropical and subtropical areas of the world (GATE, 2008).

Groundnut (*Arachis hypogaea L.*) also known as peanut, is a member of the family *papilionaceae*, the largest and most important of the three divisions of *leguminasae* (Alonge and Adegbulugbe, 2005). It is one of the world's most popular crops cultivated throughout the tropical and sub-tropical areas where annual precipitation is between 1000 – 1200 mm for optimum growth of the crop. Groundnut is the 13th most important food crop of the world (John, 2010). It is the world's 4th most important source of edible oil and 3rd most important source of vegetable protein (Taru *et al*., 2008).

In Africa, despite the value of these crops, the methods involved in their production, harvesting and shelling are mostly manual. For instance, shelling is done by pounding in a mortar with a pestle or spreading the dried crop on the floor where they are beaten with a stick (Dauda, 2001).

IAR Groundnut Sheller was developed long ago and the design was based on the properties of the then variety known as Ex-Dakar. The performance of the Sheller was satisfactorily with high output capacity of 200kg/hr as reported by IAR (1987). Genetically modified varieties were later developed whose acceptability in practice override, this has conspicuously affects the performance of the machine. A preliminary test on the machine was carried out using groundnut variety; SAMNUT 23, and its performance was evaluated. The results indicated a very low output capacity of 76.50 kg/hr at a combination of 160 rpm and 3 kg/min cylinder speed and feed rate respectively. This could be due to influence of some factors such as; varietal difference, depreciation over time, low cylinder speed, high cleaning fan speed, or inappropriate power transmission system. The machine was also associated with some percentage of unshelled pods both from the grains and chaffs outlets, more especially the pods carrying single seed and also some percentage of leftover of the pods in the shelling chamber. These could be due to high cylinder-concave clearance, worn out tooth, or flatness of the tooth. Another overwhelming issue was operators' exposure to posture discomfort in terms of the height and hopper orientation of the machine. These problems lead to the modification of the machine. It was modified to shell modern varieties of groundnut as well as a selected pulse (cowpea). Cowpea was selected due to lack of an efficient motorized machine to shell it, (Adewumi *et al.*, 2007a). Small-scale farmers generally depend upon manual shelling. These are time-consuming operations and do not match the shelling requirements within a limited period of time. The search for more efficient and cost-effective way of shelling raised the demand for the modification of IAR groundnut shelling machine for the selected pulse. Physical and mechanical properties of four varieties of groundnut and cowpea were determined in order to facilitate the re-design and modification of the machine.

2. MATERIALS AND METHODS

2.1 Materials Used

Gauge 16 (A36 mild carbon steel) with a minimum yield stress of 250 MPa and ultimate tensile strength of 400 – 550 MPa was used for the production of machine members such as cylinder, sides and top cover of cylinder housing while gauge 18 plate was used for blower casing, fan blades, chaffs outlet frame, feed hopper, grain delivery chute among others. Medium carbon steel alloy rod (C1040) with yield stress of 568.7 MN/m^2 and ultimate tensile strength of 668.8 MN/m^2 was used for the shafts. The beaters were made from cast iron bars. The materials used for the performance evaluation of the machine were 12 bags of unshelled cowpea (Kanannado) for preparation of samples, tachometer for the measurement of cylinder speed, weighing balance for quantifying samples, and stopwatch to record shelling time.

2.1.1 Sample preparation

A local variety of cowpea known as Kanannado, used for this study, was procured locally from local farmers in Zaria. The bulk of materials were prepared in 28 samples of 12, 15 and 18 kg as feed rates.

2.2 Methodology

2.2.1 Description of the modified machine

The pulse sheller used in this present study, is a modified form of IAR groundnut shelling machine (Plate I). The machine shells and cleans. The two processes are achieved in one operation with the delivery of clean grains at the grains outlet. It consists of prime mover, shelling unit and cleaning unit. The prime mover is a diesel engine of 6 hp capacity. The components of the machine are hopper, shelling cylinder, removable concave, clearance adjuster, blower, chaffs outlet, grains delivery chute and frame.

Plate I: A pictorial view of the modified shelling machine in operation

2.2.2 Operational procedure

The crops were fed through the hopper to the shelling chamber where shelling is achieved by impact and rubbing action of the cylinder. The shelled materials were pushed through the concave to the cleaning chamber where a stream of air from the blower passed across the falling materials to blow off the chaffs to the chaffs outlet and allow grains to be delivered to the grains outlet.

2.2.3 Machine re-design consideration

This research work adapted a cylinder speed range of 130 rpm (2.59 m/s) to 160 rpm (3.18 m/s) Abou El-Kheir and Shoukr (1993). The machine height of 110 cm was adapted from the report of Smith *et al.*, (1994), for the purpose of the machine height reduction to enable easy access during operation. A moisture level of 11.11 % was used as the moisture content of the crop during the operation.

2.3 Power Required for Shelling

The power required for shelling as reported by Abubakar and Abdulkadir (2012) is;

$$H = WK_k\, F_C Log \frac{L_1}{L_2} \qquad (1)$$

Where: H = Power W, F_C = Crushing strength of groundnut (N/m^2), K_k = Kick's constant (1.2), W= Average weight of unshelled groundnut (kg), L_1 = Average length of unshelled groundnut (m), L_2 = Average length of shelled groundnut (m). This was determined to be 0.387 kW (0.526 hp) for the used variety

2.4 Re-design Calculations

2.4.1 Shafts design

2.4.1.1 Determination of shafts torsional moment

Hall and Hallowenko, (1982) gave torsional moment as;

$$M_t = \frac{60P}{2\pi N} \qquad (2)$$

Where: P = Power required for shelling (W) and S = Speed of the prime mover (rpm) M_t = 20.62 Nm and 48.65 Nm for cylinder and fan shaft, respectively

2.4.1.2 Determination of shaft bending moment

The bending moment (M_b) was determined based on the lateral loadings on the shaft. The loads were weight of the pulleys, weight of the shelling drum, weight of the fan blades and belt tensions. Total bending moment, M_b = 177.90 Nm and 75.11 Nm for cylinder and fan shaft respectively.

2.4.1.3 Shafts diameter

The shafts sizes were determined using relationship given by Hall and Hallowenko, (1982). As;

$$d_s = \frac{16}{\pi\tau_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (3)$$

Where: d_s = Shaft diameter (mm), K_b = Shock and fatigue factor applied to bending moment = 1.5, K_t = Shock and fatigue factor applied to torsional moment = 1.0, M_t = Torsional moments (Nm), τ_s = Allowable stress of the steel shaft (40 N/mm^2)
Hence, d_s = 32.42 mm and 25.00 mm for cylinder and fan shaft respectively.

2.4.2 Power transmission parameters

2.4.2.1 Belt length

The effective belts length was determined using the relationship outlined by Sanjay (2010);

$$L_b = \frac{\pi}{2}(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4x} + 2x \quad (4)$$

Where: D_1 = Diameter of driver pulley (cm), $D_2 =$ Diameter of driven pulley (cm), $x =$ Center to center distance between the driver and driven pulley (cm) Hence, the fan belt length was 142.10 cm while the cylinder belt was 112.44 cm.

2.4.2.2 Belt tension

The following expressions were used to determine the belt tension (Sanjay 2010);

$$M_t = (T_t - T_s)R \quad (5)$$

$$\frac{T_t}{T_s} = e^{\mu\theta Cosec\beta} \quad (6)$$

Where: T_t and T_s = Tension in the tight and slack side of the belt respectively (N), $R =$ Radius of the shaft pulley (m), μ = coefficient of friction between the pulley and belt, θ = angle of contact between the pulley and belt (^{o}), β = half angle of groove of the pulley (^{o}), when μ = 0.25, 2β = 34^o, and θ = 170^o. Therefore, the tensions in the tight and slack side of the fan belt were determined 877.5 N and 6.5x10^{-61} N respectively while those of cylinder belt were 1755 N and 1.6x10^{-60} N respectively.

2.4.2.3 Belt speed

Belt speed was estimated using the expression given by Khurmi and Gupta (2007) as;

$$V = \frac{\pi DN}{60} \quad (7)$$

Where: V = Belt speed (m/s), N = Drive speed (rpm), D = Diameter of drive pulley (m)
The fan and cylinder belt speeds were 5.03 m/s and 2.51 m/s respectively.

4.1.1.1 2.4.2.4 Pulley diameters and speed ratio relationship

The pulleys diameter was determined using the expression outlined by Sanjay (2010) as;

$$N_1 D_1 = N_2 D_2 \quad (8)$$

Where: N_1 = Speed of driving pulley (rpm), N_2 = Speed of driven pulley (rpm)
D_1 = Diameter of driving pulley (cm), D_2 = Diameter of driven pulley (cm)

The sizes and speeds of 4 pulleys were determined as prime mover pulley (D_p = 8 cm and N_p = 1200 rpm), fan shaft pulleys (D_{f1} = 8 cm and N_{f1} = 1200 rpm, D_{f2} = 4 cm and N_{f2} = 1200 rpm) and cylinder shaft pulley (D_c = 38 cm and N_c = 130 rpm).

2.4.3 Blower design parameters

2.4.3.1 Number of blades required

For the number of blades required the following expression was used (Mohammed 2009).

$$N_b = \frac{4WDV_t}{\pi L d^2} \quad (9)$$

Where: d = Diameter of air flow rate channel (0.08 m), W = Width over which air is required (0.12 m), L = Width of the inlet duct minus the clearance (0.187 m), V_t = Terminal velocity of the seed (7.59 m/s), D = Dimensional properties of crop seeds (0.836 m).Therefore, N_b = 4 blades.

2.4.3.2 Weight of the fan blades

The weight of the fan blades was determined using the relation (Mohammed, 2009);

$$W_f = \delta g v \quad (10)$$

Where: W_f = Weight of the fan blade (N), δ = Density of the fan galvanized steel blade (7850 kg/m^3), g = Acceleration due to gravity (m/s^2), v = Volume of the fan blades (8.453x10^{-5} m^3). Hence, W_f = 6.51 N

2.4.3.3 Air discharge through the blower

The air discharge through the blower was determined as

$$Q = VD_aW_a \quad \text{(Joshua, 1981);} \quad (11)$$

Where: Q = Air discharge rate (m^3/s), V = Velocity of air required for cleaning (19.48 m/s), D_a = Depth of airsteam (0.08 m), W_a = Width over which the air is required is 0.12 m. Therefore, Q = 0.187 m^3/s

2.5 Machines Performance Evaluation

The performances were evaluated using the following equations as outlined by Abubakar and Abdulkadir, (2012). (see Appendix A)

i) Shelling efficiency, S_e (%):

$$S_e = \frac{(Q_T - Q_U)}{Q_T} x100 \quad (12)$$

ii) Cleaning efficiency, C_e (%):

$$C_e = \frac{Q_G}{W_C} x100 \quad (13)$$

iii) Grains split, G_s (%):

$G_s = \frac{Q_D}{100} x 100$

(14)

iv) Scattered loss, S_L (%):

$S_L = \frac{W_S}{Q_T}\ x\ 100$

(15)

v) Output capacity, C_P (kg/hr):

$C_P = \frac{Q_g}{T}$

(16)

Where: Q_D = Quantity of damaged groundnut in sample (kg), Q_g = Total quantity of grains collected per unit time (kg), Q_G = Quantity of shelled groundnut (kg), Q_L= Quantity of scattered, damaged, and unshelled grains (kg), Q_T = Total quantity of groundnut sample (kg), Q_U = Quantity of unshelled groundnut (kg), T = total time of shelling (hr), W_C = Weight of whole materials collected at the outlet (kg), W_S = Weight of scattered groundnut (kg)

3. RESULTS AND DISCUSSION

3.1 Effect of Cylinder Speed and Feed Rate on Machine Performance

3.1.1 Effect of cylinder speed on shelling efficiency at various feed rates

The shelling efficiency using cowpea ranges from 92.29 % to 95.75 % at a speed of between 2.39 m/s (120 rpm) and 2.79 m/s (140 rpm). The minimum efficiency was obtained at a feed rate of 12 kg/min while maximum was at 18 kg/min (Appendix A). Dauda (2001) presented threshing efficiency between 84.1% to 85.9% for a manually-operated cowpea thresher while Adewumi et al. (2007a) reported threshing efficiency in the range of 67.5 - 97.7 % for a motorized medium-scale thresher-cleaner while Irtwange (2009) reported a range of 95.49 – 96.98 % threshing efficiency of a motorized cowpea thresher for Nigerian small-scale farmers.. The shelling efficiency increased with increase in cylinder speed at different feed rates which was due to increase in impact force on the pods as shown in Figure 3.1. It could be seen from the figure that the shelling efficiency increased with increase in feed rates at all speed levels except 2.39 m/s. This is because the feed rates do not chock up the shelling chamber and the cowpea pods were not hard; hence, could easily be shelled. The results of the analysis of variance shows that the effect of speeds, feed rates and their interactions were not significant on shelling efficiency at 5% level of confidence (Appendix B).

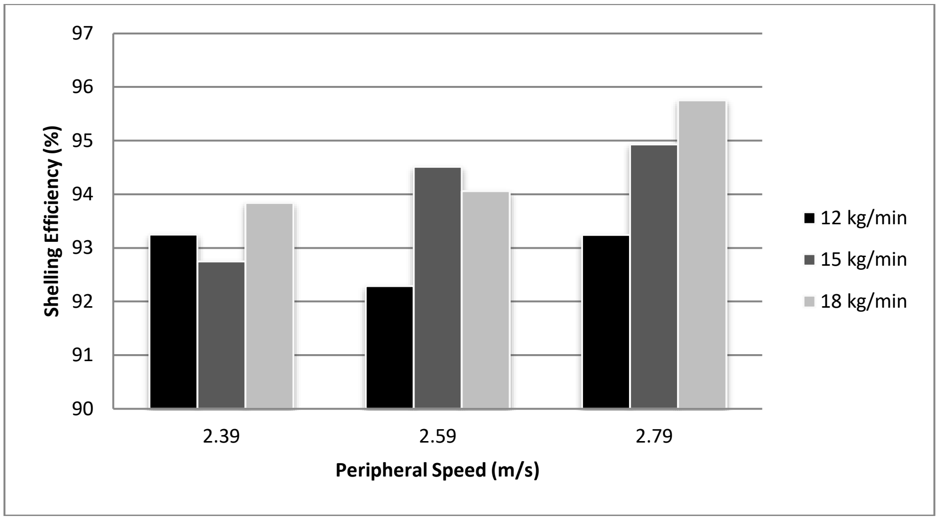

Fig. 1: Variation of cowpea shelling efficiency with the cylinder speeds at various feed rates

3.1.2 Effect of cylinder speed on cleaning efficiency at various feed rates

The cleaning efficiency of cowpea ranges from 96.90 % to 98.32 %. The minimum efficiency was obtained at a speed of 2.79 m/s (140 rpm) and a feed rate of 15 kg/min while the maximum was at a speed of 2.79 m/s (140 rpm) and a feed rate of 18 kg/min (Appendix A). Dauda (2001) reported a winnowing efficiency in the range of 92.35 - 92.75 % while the cleaning efficiency of the medium-scale thresher cleaner reported by Adewumi *et al*. (2007b) had an effectiveness rate of 98 - 100 % for Ife-Bimpe while Irtwange (2009) reported a range of 94.62 – 96.95 % cleaning efficiency of a motorized cowpea thresher for Nigerian small-scale farmers. The cleaning efficiency increased with increase in cylinder speed at different feed rates (Fig. 3.2) which was due to the fact that the aerodynamic properties of the cowpea pods makes its chaffs sensitive to the change in air speed and liable to be blown off as the cylinder speed increases. It could be seen from the figure 2 that the cleaning efficiency decreased with the increase in feed rates at all speed levels except 2.79 m/s. This could be because of the inadequate volume of air required to separate the materials in bulk at a lower speed level. The results of the analysis of variance shows that the effects of speeds, feed rates and their interactions were not significant on cleaning efficiency at 5 % level of confidence (Appendix B).

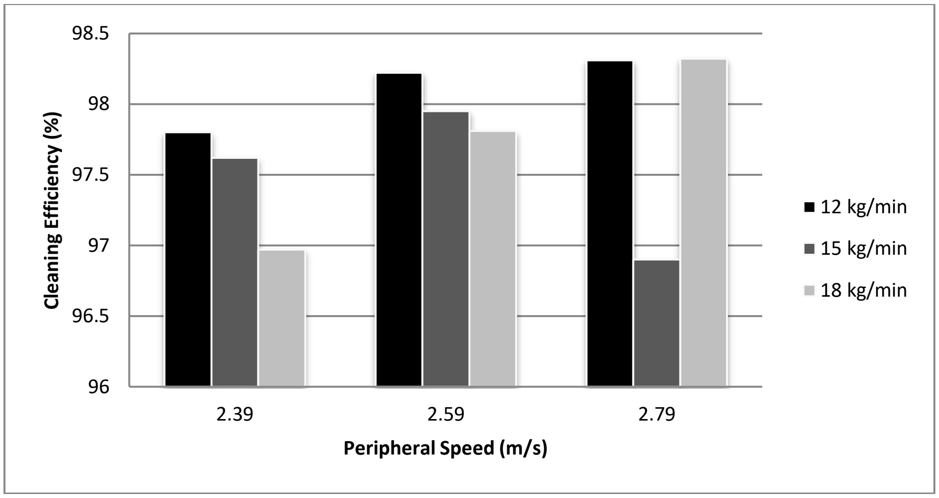

Fig. 2: Variation of cowpea cleaning efficiency with the cylinder speeds at various feed rates

3.1.3 Effect of cylinder speed on grain damage at various feed rates

The mechanically damaged grains for cowpea shelling were found to be 0.01 % for all the treatment of the cowpea shelling (Appendix E_3). However, Irtwange (2009) reported a range of 1.97 – 5.08 % grain damage of a motorized cowpea thresher for Nigerian small-scale farmers and Dauda (2001) reported 1.8 - 2.3 % for a manually-operated cowpea thresher. This implies that the machine was not associated with mechanical grain damage at the selected speed and feed rate levels as far as cowpea shelling is concerned. This is attributed to the nature of the crop variety used that it is hard and the impact force exerted while shelling at all speed levels do not exceed its crushing strength. Hence, the grains might not break at all instances.

3.1.4 Effect of cylinder speed on scattered loss at various feed rates

For cowpea shelling, a maximum scattered loss of 0.625 % was obtained at a speed of 2.79 m/s (140 rpm) with a feed rate of 12 kg/min while a minimum of 0.175 % was obtained at a speed of 2.39 m/s (120 rpm) with a feed rate of 15 kg/min (Appendix A). Irtwange (2009) reported a range of 3.02 – 4.51 % scattered loss of a motorized cowpea thresher for Nigerian small-scale farmers. The scatter loss of the machine increased with the increase in cylinder speed at various feed rates, but adapted a pattern of decrease then increased with the increase in feed rates at all speed levels (Fig. 3.3). These were because at higher speeds there could be more volume of airstream required to blow off the chaffs hence increasing the tendency of the premature grains to be blown. The analysis of variance shows that the effect of speeds was highly significant at 1% level while that of feed rates was significant at 5% level on the scattered losses but their interactions were not significant at 5% level (Appendix B). Further analysis of cylinder speed levels using LSD method shows that the effect of 2.79 m/s was greater than that of 2.59 m/s but 2.59 m/s and 2.39 m/s were statistically having the same effects in terms of scatter loss. For the feed rate levels, 12 kg/min and 18 kg/min were statistically at par but their effects were higher than that of 15 kg/min (Appendix C). Therefore, a speed level of 2.59 m/s or 2.39 m/s in combination with a feed rate level of 15 kg/min could be the best in terms of minimum losses.

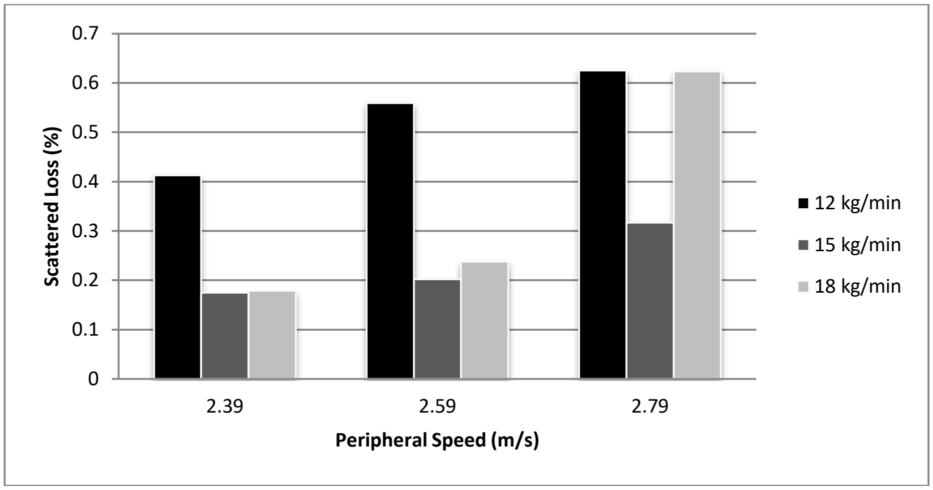

Fig. 3: Variation of cowpea grains scatter loss with the cylinder speeds at various feed rates

3.1.5 Effect of cylinder speed on output capacity at various feed rates

The output capacity, when evaluated with a cowpea, increased with increase in cylinder speed at various feed rates but does not have specific pattern with increase in feed rate at various speed levels (Fig. 3.4). A maximum output capacity of 546.65 kg/h was obtained at a speed of 2.79 m/s (140 rpm) with feed rate of 12 kg/min. A minimum of 276.76 kg/hr was obtained at a speed of 2.39 m/s (120 rpm) with feed rate of 18 kg/min (Appendix A). Dauda (2001) reported throughput capacity for a manually-operated cowpea thresher of 95.4, 93.5 and 92.8 kg/h for Kanannado, Borno Brown and Aloka Local, respectively while Irtwange (2009) reported a range of 74.33 – 110.86 kg/h output capacity of a motorized cowpea thresher for Nigerian small-scale farmers. Both the effects of speeds and feed rates were highly significant at 1% on the output capacity, likewise their interactions (Appendix B). When the effects of both speed and feed rate levels were further analyzed, a speed level of 2.79 m/s was the best while for feed rates; 15 kg/min was the best. For their interactions, a speed level of 2.59 m/s and a feed rate of 18 kg/min formed the best interaction (Appendix C).

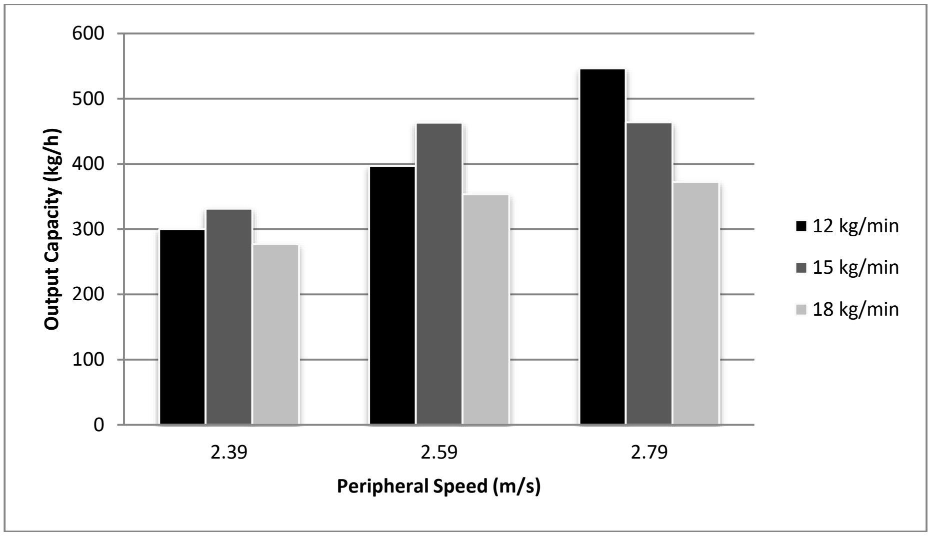

Fig. 4: Variation of cowpea output capacity with the cylinder speeds at various feed rates

4. CONCLUSIONS

The existing IAR groundnut sheller was modified for pulse shelling and the performance of the modified shelling machine was evaluated using cowpea as test crop. Most of the performance indices increased with increase in cylinder speed but indicated no specific pattern with increase in feed rate. The best performance of the modified machine was found at speed of 2.79 m/s (140 rpm) with a feed rate of 12 kg/min and 10 mm concave clearance. These gave an output capacity, shelling efficiency, cleaning efficiency, scattered loss and grain damage of 546.18 kg/h, 93.24, 98.31, 0.625 and 0.00 %, respectively. The effects of the selected variables on the performance indices were assessed and revealed that the effects of cylinder speeds and feed rates were not significant on all indices except scattered loss and output capacity.

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6. APPENDICES

Appendix A: Average calculated data for the evaluation of pulse sheller using cowpea

S/N	TRMT	CRC	SPD	FDR	S_e	C_e	G_s	S_L	C_p
		Mm	m/s	kg/min	%	%	%	%	Kg/h
1	S1F1	10	2.39	12	93.25	97.80	0.000	0.413	299.93
2	S1F2	10	2.39	15	92.75	97.62	0.000	0.175	331.12
3	S1F3	10	2.39	18	93.84	96.97	0.000	0.179	276.76
4	S2F1	10	2.59	12	92.29	98.22	0.000	0.559	396.70
5	S2F2	10	2.59	15	94.51	97.95	0.000	0.202	463.27
6	S2F3	10	2.59	18	94.06	97.81	0.000	0.238	353.15
7	S3F1	10	2.79	12	93.24	98.31	0.000	0.625	546.18
8	S3F2	10	2.79	15	94.93	96.90	0.000	0.317	463.65
9	S3F3	10	2.79	18	95.75	98.32	0.000	0.623	372.21

Where: TRMT = Treatment, SPD = Cylinder Speed, CRC = Concave to cylinder clearance, FDR = Feed rate, Se = Shelling efficiency, C_e = Cleaning efficiency, M_d = Damaged grains, S_L = Scattered loss, C_P = Output Capacity

Appendix B: Summary of the analysis of variance for the performance indices of cowpea shelling

Source of Variance	DF	Calculated F – Values				Tabulated F - Values	
		S_e	C_e	S_L	C_p	5 %	1 %
Replication	2	1.997^{NS}	0.220^{NS}	7.724^{**}	0.90^{NS}	3.63	6.23
Speed	2	2.630^{NS}	0.468^{NS}	8.403^{**}	203.60^{**}	3.63	6.23
Feed rate	2	0.213^{NS}	0.658^{NS}	4.581^{*}	54.14^{**}	3.63	6.23
Speed x Feed rate	4	1.553^{NS}	0.651^{NS}	1.497^{NS}	14.45^{**}	3.01	4.77
Error	16						
Total	26						

Where: DF = Degree of freedom

Appendix C: Shows an operation parameters ranks based on fisher's least significant difference (lsd) method for cowpea shelling

Machine	Pulse shelling machine - Cowpea			
Operation parameters	S_e		C_p	
	%		kg/h	
Performance indices	Speed	FDR	Speed	FDR
	S_3^a	F_1^a	S_3^a	F_2^a

Ranks	S_2^{b}	F_3^{ab}	S_2^{b}	F_1^{b}
	S_1^{bc}	F_2^{b}	S_1^{c}	F_3^{c}

Where: S = Speed levels, F = Feed rate levels

Energy Efficiency and Optimization of Convective Hot Air Drying Conditions of Okra Slices

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ABSTRACT

This work presents the energy efficiency of a hybrid solar-electric convective vegetable dryer as well as the optimization of hot air drying conditions of okra slices based on the specific energy consumption and drying time using response surface methodology (RSM). Drying experiments were performed with 900g batch of sliced okra (*Abelmoschus esculentus*) samples dried from initial moisture content of 87.8 to 0.5% moisture content (w.b). The Box-Behnken approach of Design Expert 7.0 statistical package was used to illustrate the effects of the different levels of the drying parameters: air temperature (50, 60 and 70^{o}C), air velocity (1, 1.5 and 2ms^{-1}) and sample slice thickness (10, 15 and 20mm) on the drying time and specific energy consumption of okra slices. All responses were fitted into a second order polynomial model and R^2-values > 0.959 were observed in all treatment combinations. Suitability of the developed predictive response models was verified and validated with statistical analyses of the process parameters, experimental data, normal % probability plots, as well as simulated versus experimental data plots. Results obtained showed that the maximum and minimum mean energy consumptions were 69.02kWh and 2.02kWh, respectively. Regression models of specific energy consumption for each slice thickness were developed and their respective R^2 compared. Thermal utilization efficiency of okra slices were in the range of 11.1 to 38.8%. The energy efficiency varied in the range of 11.2 to 45.6%; whereas the drying efficiency ranged between 28.1 and 49.6%. The desirability index technique was used to predict the optimum drying condition. The best drying conditions of 59.81^{o}C, 2ms^{-1} and 10mm air temperature, air velocity and slice thickness, respectively were obtained. The corresponding predicted response values of 94.54minutes and 3.54kWhg^{-1} were obtained for drying time and specific energy consumption, respectively. The results of this study make available to food industries the optimized drying conditions for better quality dried okra slices as well as improve the dryer energy efficiency and reduce cost of drying operation.

Keywords: Energy efficiency, convective drying, crop dryer, optimization, response surface methodology, okra slices, Nigeria.

1. INTRODUCTION

High energy demand in the food industry has prompted extensive study on the dynamics of drying energy and its consumption for optimal product quality drying, increased energy efficiency and cost effectiveness. Convective hot air crop drying using artificial dryers requires substantial amount of energy input when compared to other production processes as a result of relatively low energy efficiency of the dryer (approximately 30%), inefficient heat transfer between convective air and food material, large quantity of energy loss through the exhaust air (even as temperature reaches the wet bulb temperature), and increased latent heat of vaporization of water (Beigi, 2016; Kudra, 2012; Raghvan *et al*., 2005). In most developed nations, the energy consumption for drying operations accounts for 7 – 25% of the nation's total industrial energy demand (Motevali *et al.,* 2014; Akpinar *et al.,* 2005). Convective hot air-drying is regarded as the commonest method for crop drying. There is often limited heat transfer to the inner sections (matrix) of food materials during conventional heating as a result of low thermal conductivity of food materials during the falling rate drying period (Kudra, 2012). Energy efficiency of convective dryers is of great importance since it represents about 85% of all industrial dryers (Devahastin, 2000). Kudra (2012) suggested that partial recycling of exhaust air or heat recovery in addition to the use of multi-stage dryers can improve the overall energy efficiency of dryers. In order to achieve optimal drying conditions and gross reduction in energy utilization, performance of energy analysis is very important.

Energy analysis involves practical quantitative evaluation of the amount of energy required for drying and associated energy losses in the system during drying process. Technical information obtained from energy analysis of convective dryers is beneficial to design of new dryers, optimize the drying conditions, and design heat recovery systems for improved efficiency. From the energy point of view, energy efficiency and specific energy consumption amongst various indices are frequently used to characterize the performance of a convective drying system (Kudra, 2012; Baker and McKenzie, 2005). Dryer performance evaluation through the specific energy consumption seems to be more beneficial in preference to the energy efficiency index as a result of its clearly defined reference point value for an adiabatic dryer, whereas dryer performance assessment through energy efficiency requires knowledge of the maximum energy efficiency, which depends on the product characteristics and drying conditions (Kudra, 2012).

In Nigeria, okra (*Hisbiscus esculentus or Abelmoschus esculentus L.*) is regarded as an important vegetable crop for its economical and nutritive values. In the Eastern part of Nigeria, many good local varieties such as perkin's long pod, new lady's finger, *nwaidu etc.* exist (Anyanwu *et al.*, 1986). Okra is usually available in large quantities between April and December in the South eastern part of Nigeria. Two distinct seasons exist for its production in Nigeria: the peak and the lean seasons. During the lean season (October to March), the product is produced in small quantities and the product becomes very scarce and expensive. Large quantities are produced in the peak season (April to September) in excess of the consumption capacity of the local populace and thereby requires some level of preservation. Considerable amounts of energy is required during its drying process to a desired safe moisture level (Nwakuba *et al.,* 2016) due to its high initial moisture content of about 88 – 90% wet basis (Doymaz, 2005; Kumar *et al.,* 2011; Tiwari, 2012). This makes it susceptible to deterioration which leads to chemical, physical and biological changes as well as appreciable economic loss in the annual income of the farmer. Therefore, with increasing pressures to reduce environmental degradation, both from the public and governments, it is necessary to improve drying processes by optimizing its process parameters to reduce its high energy consumption and greenhouse gas (GHG) emissions, while still providing a high quality dried okra with minimal increase in economic input. This, in all would reduce the cost of drying operation, enhance the crop shelf-life, product diversity, substantial volume reduction, availability and acceptance of dried food products in the market at a reasonable price (Maskan, 2001; El-Mesery and Mwithiga, 2012). The objectives of this study were to dry sliced okra samples in a convective hybrid solar dryer and to optimize the drying conditions for high dried product quality as well as analyze the overall energy efficiency in terms of the specific energy consumption, drying efficiency and thermal utilization efficiency of the process.

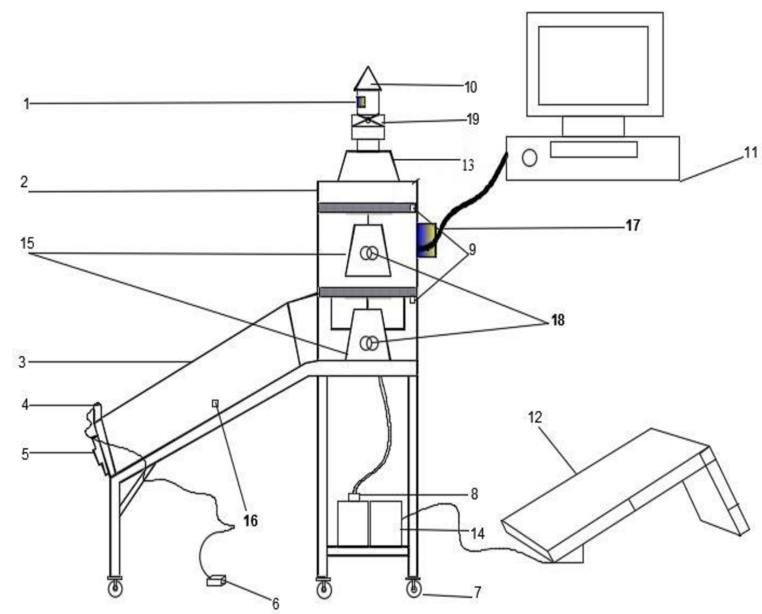
2. MATERIALS AND METHODS

2.1 Sample preparation

Fresh okra samples were purchased from one of the municipal markets (Relief market) in Owerri, Imo State of Nigeria. The okra samples were selected based on similar colour, size and shape; and sliced to three thickness sizes of 10, 15 and 20 mm using a sharp stainless-steel knife and a vernier caliper with the direction of cutting perpendicular to the vertical axis of the samples. The initial mass of the sliced samples was determined using a digital weighing balance (0.01 g, Camry instruments, China). The sliced samples were placed side-by-side on the drying racks in thin layers in such a way that the drying air flows axially into the sample matrix for uniform drying and increased drying rate. The sample initial moisture content was determined gravimetrically (Koyuncu *et al.,* 2007; Darvishi *et al.,* 2013).

2.2 Experimental procedure

The drying equipment was positioned in the open and the solar collector faced towards the North-South axis for maximum solar flux collection. Steady-state condition was allowed to be maintained in the drying chamber. The dryer was operated at three different air temperatures (50, 60 and 70^{o}C), air velocities (1.0, 1.5 and 2.0 ms^{-1}) and slice thicknesses (10, 15 and 20 mm). Fresh sliced okra samples with initial moisture content of 87.8% (wet basis) was dried using the hybrid heat unit. The quantity of moisture loss at 30-minutes intervals were recorded with a high definition (up to 0.01g) weighing balance (Figure 1, S/N 18). The amount of energy consumed at the three slice thicknesses, three air temperatures and three air velocities were measured and recorded by the control unit. The experiment was repeated for varying air velocities, air temperatures and sample thicknesses for a batch of 900 g. Drying was terminated when the samples attained a weight corresponding to a safe moisture level of 0.5 % w.b.



ITEM	DESCRIPTION
1	Temperature/ humidity sensor
2	Drying chamber
3	Solar collector
4	Pyranometer sensor
5	Inlet fan
6	Pyranometer
7	Roller
8	Battery
9	Chamber temp/ humidity sensor
10	Chimney
11	Personal computer
12	Solar panel
13	Drying chmaber hood
14	Solar charge controller
15	Weighing balance
16	Solar collector temp/humidity sensor
17	Control unit
18	Weight sensors
19	Exhaust fan

Figure 1: A schematic view of the dryer.

2.3 Experimental design

The drying experiments were designed using the Box-Behnken method of Design Expert statistical package (version 7.0) and randomized in order to reduce the unexplainable effects in the observed experimental responses. Three independent process variables: air temperature (50, 60 and 70^{o}C), air velocity (1.0, 1.5 and 2.0ms^{-1}) and slice thickness (10, 15 and 20mm) replicated three times to generate five dependent or response variables. Response surface methodology (RSM) was adopted in determining the relative contributions of each of the experimental variables (air temperature, air velocity and slice thickness) to the response variables (drying time, specific energy consumption, colour change, firmness, and rehydration capacity). Table 1 presents the Box-Behnken design RSM layout adopted for the drying experiments, which was a three-factor, three-level (3^3) arrangement applied to evaluate the linear (main), interaction and quadratic (curvature) effects of the process variables in order to optimize the convective hot air drying conditions for quality dried okra slices in a hybrid solar-electric dryer.

Table 1: Levels of independent process variables of the randomized factorial design layout used in the RSM optimization of okra drying conditions.

Process variables	Symbols		Levels	
	Actual	Coded	Actual	Coded
Air temperature (^oC)	T	A	50^oC 60^oC 70^oC	-1 0 1
Air velocity (ms^{-1})	A	B	1.0 ms^{-1} 1.5 ms^{-1} 2.0 ms^{-1}	-1 0 1
Slice thickness (mm)	S	C	10 mm 15 mm 20 mm	-1 0 1

The experimental data analyses involved the use of multiple regression method using the least squares method. A second order polynomial function was used to express the response variable (V_r) as given in Equation (1):

$$V_r = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 AB + \beta_5 AC + \beta_6 BC + \beta_7 A^2 + \beta_8 B^2 + \beta_9 C^2 \quad (1)$$

Where: V_r is the response variable (drying time in mins and specific energy consumption in kWh/kg); β_0 represents the model intercept; A, B, and C represent the independent variables: air temperature (^oC), air velocity (ms^{-1}), and sample slice thickness (mm) respectively; $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8, \beta_9$ are coefficients of regression. Also $\beta_1 A$, $\beta_2 B$, and $\beta_3 C$ represent the linear effects; $\beta_4 AB$, $\beta_5 AC$, and $\beta_6 BC$ represent the interaction or cross-product, whereas $\beta_7 A^2, \beta_8 B^2$, and $\beta_9 C^2$ represent the quadratic or curvature effects.

2.4 Energy consumption

Artificial dryers are known for promoting high-quality dried food products in spite of their considerable energy consumption (Nwakuba *et al.*, 2016). The energy consumption of any drying equipment during drying operation is an important criterion in the economic evaluation of the process. Specific energy consumption is referred to as the ratio of the total energy consumed in evaporating a kilogram of water from a drying product during the drying process to the initial mass of the dried sliced product sample. The total energy consumption for drying a 900 g batch of the sliced okra samples in the hybrid solar dryer at the given air velocities, slice thicknesses, and air temperatures is expressed in Equation (2) (Afolabi *et al.,* 2014; Koyuncu *et al.,* 2007; Minaei *et al.,* 2014; Nwakuba *et al*., 2016) as:

$$E_T = Av\rho_a C_{pa}\Delta TDt \qquad (2)$$

Where: E_T is total energy consumption per batch (kWh); A is area of rack (m^2), v is air velocity (ms^{-1}), ρ_a is air density (kgm^{-3}), t is total drying time per batch (h), ΔT is temperature difference between ambient and hot air (°C), and C_{pa} is specific heat of air ($kJkg^{-1}$°C).

The total energy consumption (E_T) for drying a batch of sliced okra samples at varying process conditions was obtained by adding the electrical energy (as measured by the arduino micro-processor) and the solar energy absorbed by the solar collector (measured by the pyranometer). Comparison was made between the measured and calculated E_T values which was less by an average of 5.2% of the calculated E_T values. This marginal difference was as a result of the constant air density and air velocity used in the calculated E_T values; whereas in the measured E_C values, varying air velocities were considered by the arduino-micro-processor where air densities varied with air temperature, thus a negligible value difference. The calculated E_T values were used to calibrate the system as well as validating the measured E_T values.

The specific energy consumption is expressed by Equation (3) (Koyuncu *et al.,* 2007; Motevali *et al.,* 2014; Afolabi *et al.,* 2014; Minaei *et al.,* 2014) as:

$$E_S = \frac{E_T}{M_o} \qquad (3)$$

Where: E_S is specific energy consumption ($kWhkg^{-1}$); M_o is mass of moisture expelled (kg).

2.5 Thermal utilization efficiency

Thermal utilization efficiency (TUE) is an indicator of the degree of accomplishment of air-to-material transfer process or energy conversion in a device that consumes thermal energy. It is defined as the ratio of latent heat of vaporization of sample moisture to the energy requirement for moisture evaporation from free water. TUE was determined using Equation (4) (Beigi, 2016; Minaei *et al.,* 2014; Hebbar *et al.,* 2004) as:

$$\eta_{th} = \frac{P.A_S.h_{fg}.M_w}{Q.t}$$
(4)

Where: η_{th} = thermal utilization efficiency, %; $M_w = \frac{(M_i - M_f)}{(100 - M_f)}$ = mass of water removed, g; P = load/weight density of sample (gm^{-2}); A_s = total sample area (m^2); h_{fg} = latent heat of vaporization ($kJkg^{-1}$); M_i and M_f = initial and final moisture contents respectively (%w.b); Q = power of the heat source (kW); t = operation time of the heat source (minutes).

The latent heat of vaporization was calculated using Equation (5) (Aghbashlo *et al*., 2013) as:

$$h_{fg} = 2.503 \; x \; 10^6 - 2.386 \; x \; 10^3(T_{abs} - 273.16) \tag{5}$$

Where: T_{abs} is the absolute temperature of drying air, ^oK.

2.6 Energy efficiency

This is the ratio of heat energy utilized for sample moisture evaporation to the heat supplied to the dryer. Energy efficiency is expressed as in Equation (6):

$$\eta_e = \frac{Q_s}{E_T} \tag{6}$$

Where: E_T is the total energy consumption per batch (kWh); Q_s is the heat supplied to dryer (kJ) expressed as Equation (7) (Motevali *et al*., 2014).

$$Q_s = h_{fg}.M_w \tag{7}$$

2.7 Drying efficiency

This is the ratio of the energy used for heating the sample evaporation moisture to the total energy supplied/consumed. This was determined using Equation (8):

$$\eta_D = \frac{Q_s + Q_m}{E_T} \tag{8}$$

Where: Q_m is energy used for heating the product (kJ) and was determined using Equation (9) (Beigi, 2016).

$$Q_m = W_{ds}C_p(T_{mo} - T_{mi}) \tag{9}$$

Where: W_{dm} is the weight of the dry sample (g), T_{mi} and T_{mo} are the inlet and outlet sample temperature (^oK), respectively; C_p is the sample specific heat capacity ($3.97kJkg^{-1o}K$).

2.8 Optimization technique and statistical analysis

Multivariate response method of numerical optimization of the drying conditions was performed (Equation 10), which is referred to as overall desirability function/index, Dx (Abano *et al*., 2014; Giri and Prasad, 2007; Myers and Montgomery, 2002):

$$D_X = (V_1 \, X \, V_2)^{\frac{1}{n}} \qquad (10)$$

Where: V_1 and V_2 are response variables; n is the total number of responses = 2.

DI ranges between 0 and 1, with 0 and 1 representing the least and most desirable coded levels respectively. DI illustrates how well matched or desirable the experimental responses are at any given level of input/independent variable. The goal in RSM optimization studies is the maximization of DI. This numerical RSM optimization process involves goals and priorities for the process/independent and response variables (Abano *et al.,* 2014). This study however, has the goal for the process variables at any level within the range of the design values; whereas the response variables had a goal of minimization of specific energy consumption and drying time.

A second order polynomial function (Equation 1) was used in fitting the average values of the experimental data with Design Expert version 7.0 statistical package (Stat-Ease Inc., Minneapolis, USA) in order to analyze data, carry out response surface plots to obtain three dimensional graph for the response variables. Analysis of variance (ANOVA) was used to determine the significant variables in the model for the response variables at 5% level of probability. The model adequacies were checked by calculating R^2, adjusted-R^2, adequate precision, PRESS and CV. The model accuracy was checked against the normal probability residual plots, predicted versus actual plots and R^2-values. For the two responses, one process variable was kept constant and 3-D response surface plots for other two variables were generated.

3. RESULTS AND DISCUSSION

The experimental results of Box-Behnken design (BBD) are presented in Table 2, with the input factors expressed in actual and coded forms. The estimated effects for the process variables (air temperature, air velocity, and slice thickness) and their interactions (Equation 1) as well as the values of the corresponding coefficient of determination (R^2) and coefficient of variation (CV) were determined as shown in Table 3. Coefficients A, B, C, AB, AC, BC, A^2, B^2, and C^2 are as earlier defined. The R^2-value indicates the degree of fit of the polynomial model for each response variable and is referred to as the ratio of explainable variation to the total variable (Kumar *et al*., 2011, Giri and Prasad, 2007). The analysis of variance in Table 3 indicates that the models for all the response variables are highly significant ($p > 0.05$) as well as the R^2-values (> 0.95). The CV values according to Kumar *et al.* (2011) should be < 10% and what was observed was < 8.5% for the models. This is an indication of model adequacy.

Table 2. Process and response factors of Box-Behnken design.

Run No	Actual values (coded values)				
	A	B	C	DT (mins.)	E_S (kWh/kg)
1	60.00 (0)	2.00 (1)	20.00 (1)	150	23.44
2	50.00 (-1)	1.50 (0)	10.00 (-1)	180	14.95
3	60.00 (0)	1.50 (0)	15.00 (0)	180	21.91
4	50.00 (-1)	1.00 (-1)	15.00 (0)	240	42.05
5	60.00 (0)	1.50 (0)	15.00 (0)	180	21.91
6	70.00 (1)	1.00 (-1)	15.00 (0)	120	13.83
7	60.00 (0)	1.00 (-1)	10.00 (-1)	150	15.15
8	50.00 (-1)	2.00 (1)	15.00 (0)	180	22.84
9	60.00 (0)	2.00 (1)	10.00 (-1)	90	4.36
10	50.00 (-1)	1.00 (0)	20.00 (1)	240	56.47
11	60.00 (0)	1.50 (0)	15.00 (0)	180	21.91
12	70.00 (1)	2.00 (1)	10.00 (-1)	120	3.21
13	70.00 (1)	2.00 (1)	15.00 (0)	60	4.32
14	60.00 (0)	1.50 (0)	15.00 (0)	180	21.91
15	60.00 (0)	1.50 (0)	15.00 (0)	180	21.91
16	70.00 (1)	1.50 (0)	20.00 (1)	150	21.89
17	60.00 (0)	1.00 (-1)	20.00 (1)	210	42.86

Specific energy consumption (E_S), Drying Time (DT).

Table 3. Regression coefficients of the response surface quadratic model for the process variables.

Process variables/model terms (coded units)	Estimated coefficients	
	DT (mins.)	E_S (kWh)
Intercept (β_0)	180	22.05
A	-48.75	-11.63
B	-30	-7.37
C	26.25	13.37
AB	8.7	2.43
AC	-7.5	-5.71
BC	21.4	-2.16
A^2	-3.75	-5.62
B^2	-26.25	-3.18
C^2	-3.75	8.21
R^2	0.9689	0.9796
CV (%)	7.72	8.36

3.1 Effect of process factors on response variables

3.1.1 Drying time

The effect of the process factors on drying time of okra slices is presented in Table 4. In this case, the effect of the linear terms, B, and C), the interaction effect of air temperature and slice thickness (AC), quadratic/curvature effects of air temperature (A^2) and slice thickness (C^2) on drying time were significant. The result of the second order quadratic model fitted to the drying time in coded terms is given by Equation (11) as:

$$V_{DT}= 180-48.75A-30B+26.25C-7.5AC-3.75A^2-3.75C^2 \qquad [R^2=0.9689] \qquad (11)$$

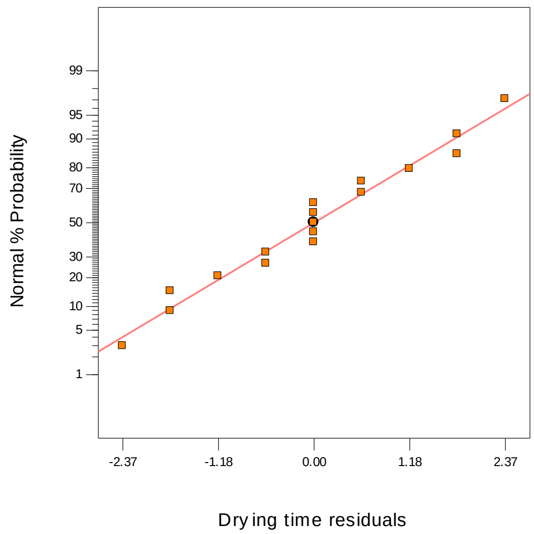
Where: V_{DT}, A, B, and C are as earlier defined.

Table 4. Analysis of variance for drying time by response surface quadratic function.

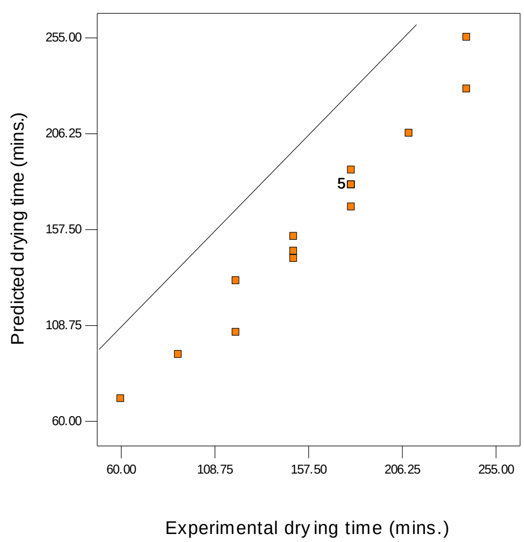
Source	Coefficient estimate	Sum of squares	Df	F-value	P-value Prob. > F
Intercept (β_0)	180				
Model		35086.76	9	24.26	<0.0002*
$\beta_1 A$	-48.75	19012.50	1	118.30	< 0.0001*
$\beta_2 B$	-30	7200.00	1	34.30	0.0006*
$\beta_3 C$	26.25	5512.50	1	74.80	0.0003*
$\beta_4 AB$	8.7	138.31	1	0.000	1.0000ns
$\beta_5 AC$	-7.5	225.00	1	1.40	0.0353*
$\beta_6 BC$	21.4	78.42	1	0.000	1.0000ns
$\beta_7 A^2$	-3.75	59.21	1	0.37	0.0230*
$\beta_8 B^2$	-26.25	2901.32	1	18.05	0.5736ns
$\beta_9 C^2$	-3.75	59.21	1	0.37	0.0213*

*Significant; ** Not significant; lack of fit is insignificant at P > 0.05.

The quadratic effect of air velocity (B^2), interaction effects of air velocity-slice thickness (BC), air temperature-air velocity (AB) were statistically insignificant ($P > 0.05$) on the drying time, and as such were not added in Equation (11). The high R^2 (0.9689) showed that a greater percentage of the experimental variability was described by the response surface quadratic model. Figures 2a and b show the suitability of the model verified with the normal probability plot of the drying time residuals and the plot of predicted versus experimental drying time respectively.



2a

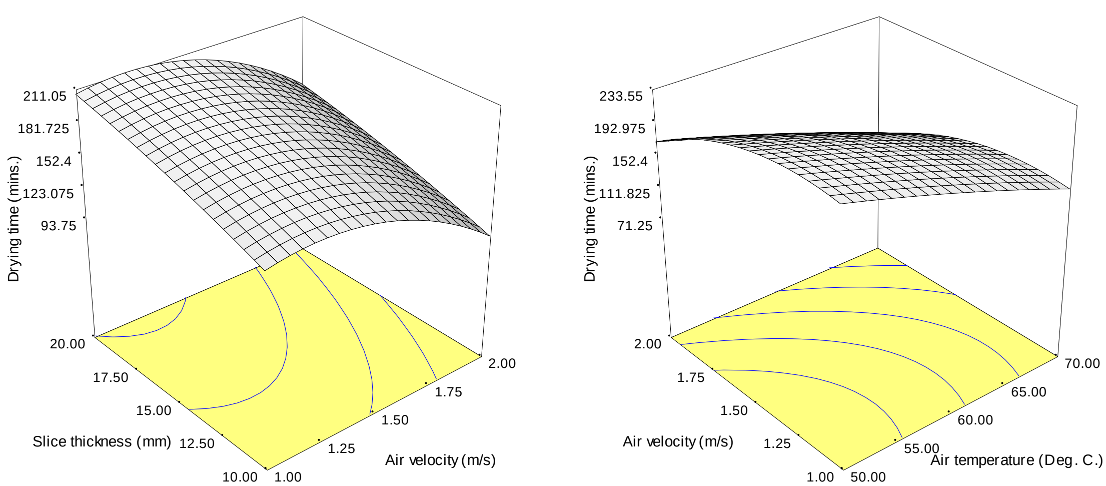


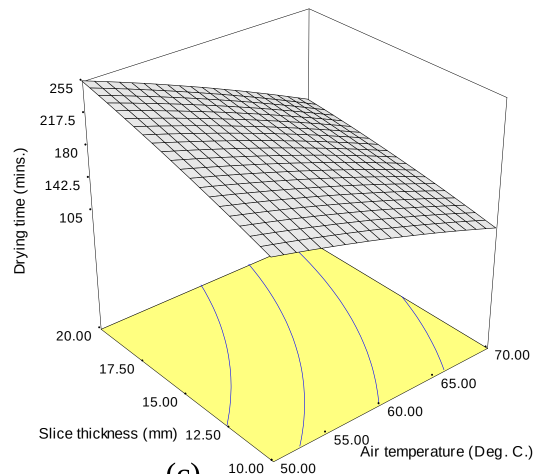
2b

Figure 2. (a) Normal % probability plot of drying time residuals; (b) Predicted versus experimental drying time of sliced okra samples.

The model was validated by the closeness of the plotted data to the straight line (at 45^0) which indicated agreement between the predicted and experimental drying time of dried okra slices as well as good agreement with the normality and severity of outliers in the experimental data of the drying time. The 3-D response surface plots for the drying time quadratic model is presented in Figure 3. Increasing the drying air temperature and air velocity decreased the drying time significantly (Abano *et al.*, 2014; Kumar *et al.*, 2011; Montgomery and Runger, 2002). This was as a result of increased kinetic energy of internal water molecules to diffuse and evaporate at a higher rate from the interior and surface of the okra sample to the ambient air respectively; increased drying air temperature gradient between the drying air and the sliced okra samples which increased the moisture diffusion and surface water evaporation rates from the sample matrix to the convective air. This thus, increased the drying rate and reduced the drying time. Whereas increasing the slice thickness of the okra samples significantly increased the drying time. This is as a result of increased capillary distance of the sample matrix through which internal moisture diffused to the surface for evaporation into the ambient air.

Different relative importance however, can be deduced from the variations in the estimated coefficients of the independent variables. Air temperature was observed to have the highest effect on the drying time, followed by the slice thickness and lastly the air velocity. The least drying time was observed at the highest air temperature and air velocity. The independent variables: air temperature, (A) air velocity (B) and slice thickness (C) had significant effects on the drying time. Increasing A and decreasing C at constant B increased the drying time, whereas increasing C at constant A and C increased the drying time as shown in Figure 3. The effects of air temperature on the drying time of okra slices corroborated with the reports of Abano *et al.* (2014) for tomato slices; Afolabi *et al.* (2014) for ginger slices; Doymaz (2004a and b) for carrot and okra slices respectively.





(c)

(a) (b)

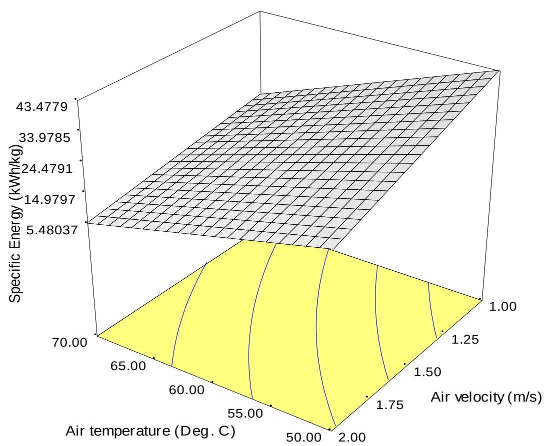
Figure 3. Response surface plots showing the effects of different drying conditions on drying time: (a) Air velocity and temperature at constant slice thickness; (b) slice thickness and air velocity at constant temperature; (c) slice thickness and air temperature at constant air velocity.

4.1.2 3.1.2 Specific energy consumption

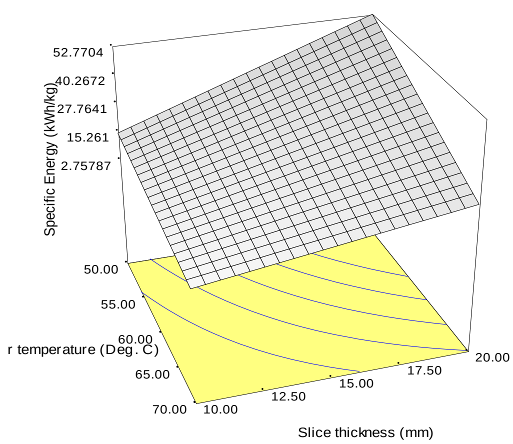
The experimental result of the model fitted to the specific energy consumption under varying drying conditions as presented in Table 2 is expressed as Equation (12):

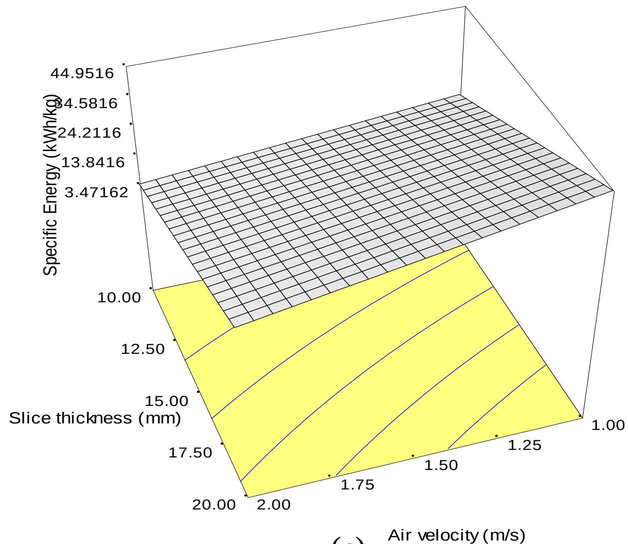
$$E_C = 22.05 - 11.63A - 7.37B + 13.37C - 5.71AC + 16.94A^2 + 3.17C^2 \qquad [R^2=0.9796] \qquad (12)$$

As a result of the statistical non-significant effects of the means of AB, BC and B^2 on specific energy consumption, they were not included in Equation (12). It is evident that drying air temperature (A), air velocity (B) and sample slice thickness (C) had remarkable effects on the specific energy consumption for drying of okra slices in the hybrid solar dryer (Figure 4). Drying a thicker sample layer at a low air temperature and air velocity increased the specific energy consumption (Figure 4a). This was as a result of more time taken for the larger sample layer to diffuse product moisture to the surface for eventual evaporation by a slow-moving convective hot air, thus increased drying time and specific energy consumption. The maximum and minimum specific energy consumption (56.47kWhkg^{-1} and 3.21kWhkg^{-1} respectively) were obtained at 50°C, 1.0ms^{-1} 20mm, and 70°C, 2.0ms^{-1} 10mm, respectively. This generally implied that less specific energy was consumed at increased air temperature and air velocity for drying any slice thickness.


43.4779
33.9785
24.4791
14.9797
5.48037
Specific Energy (kWh/kg)
70.00
65.00
60.00
55.00
50.00
Air temperature (Deg. C)
1.00
1.25
1.50
1.75
2.00
Air velocity (m/s)

(a) (b)


52.7704
40.2672
27.7641
15.261
2.75787
Specific Energy (kWh/kg)
50.00
55.00
60.00
r temperature (Deg. C)
65.00
70.00
10.00
12.50
15.00
17.50
20.00
Slice thickness (mm)



(c)

Figure 4. Response surface plots showing the effects of different drying conditions on the specific energy consumption: (a) air temperature and air velocity at constant slice thickness; (b) air temperature and slice thickness at constant air velocity; (c) slice thickness and air velocity at constant air temperature.

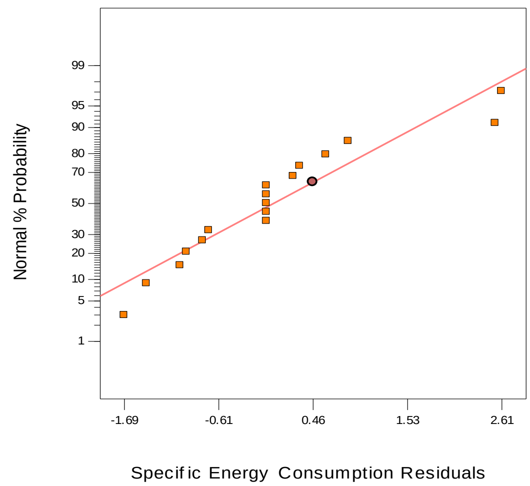
This result agrees with the findings of Sharma and Prasad (2006) for glarlic cloves; Jindarat *et al.* (2011) for non-hygroscopic materials; Afolabi *et al*. (2014) for ginger slices; El-Mesery and Mwithiga (2012) for onions slices with a decreasing trend in specific energy consumption with increase in the drying air temperature and air velocity. With increased drying air temperature and decreased sample thickness, less specific energy was consumed (Figure 4b), since more moisture diffused at increased air temperature and drying time decreased, thus reduction in the specific energy consumption. The specific energy consumption increased with increasing sample thickness at reducing air velocity (Figure 4c) as a result of gross reduction in mass transfer rate and increased capillary distance for moisture diffusion. Table 5 shows that the quadratic function was highly significant at $P < 0.05$, with a high R^2 value (0.9796). This shows that the RSM model described a greater percentage of the experimental variability (Abano *et al.*, 2014). The P-values for the linear (main) terms had significant effect on the specific energy consumption for drying ($p < 0.05$). Variables A (air temperature) and B (air velocity) had negative coefficients, whereas S was positive. This is an indication that increased air temperature and air velocity may have a significant reduction effect on the specific energy consumption, and also increase in the sample slice thickness may increase the specific energy consumption.

Table 5. ANOVA result for the specific energy consumption by response surface quadratic model.

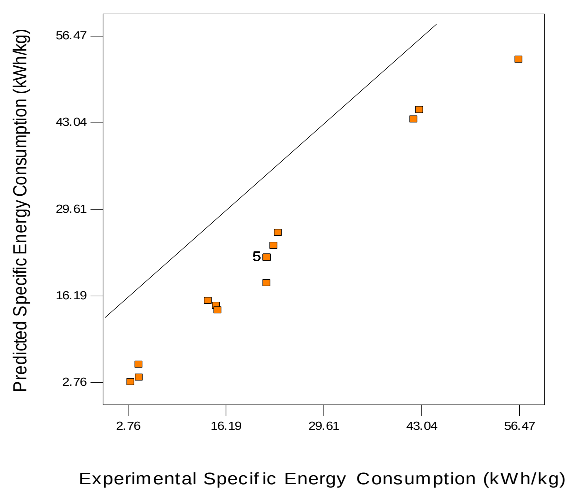
Source	Coefficient estimate	Sum of squares	Df	F-value	P-value Prob. > F
Intercept (β_0)	22.05				
Model		3120.03	9	107.74	< 0.0001*
$\beta_1 A$	-11.63	1082.52	1	224.28	0.0042*
$\beta_2 B$	-7.37	434.09	1	89.94	< 0.0021*
$\beta_3 C$	13.37	1430.86	1	296.45	< 0.0013*
$\beta_4 AB$	2.43	23.52	1	4.87	0.0518ns
$\beta_5 AC$	-5.71	130.42	1	27.02	0.0004*
$\beta_6 BC$	-2.16	18.62	1	3.86	0.0779ns
$\beta_7 A^2$	16.94	1876.24	1	11.21	<0.0001*
$\beta_8 B^2$	-20.41	1459.73	1	8.35	0.3822ns
$\beta_9 C^2$	3.17	128.87	1	9.41	0.0003*
CV	7.36%				

*Significant; ns Not significant; lack of fit is insignificant at P > 0.05.

The quadratic effect of air velocity, interaction effects of air temperature-air velocity and air velocity-slice thickness had no significant effect on the specific energy consumption of okra slices. A coefficient of variability (CV = 7.36%) less than 10% was observed (Giri and Prasad, 2007; Kumar *et al.*, 2011), and it indicates that the quadratic function adequately represented the experimental data and closely predicted the specific energy consumption for drying of okra slices as observed by Kumar *et al.* (2011). The suitability of the model was further validated with the normal probability plot of the specific energy consumption residuals and the predicted versus experimental specific energy consumption plot (Figures 5 a and b respectively). The closeness of the data to the straight line indicated equality between the predicted and experimental specific energy consumption values as well as showing that no problem existed between the normality and severity of outliers in the experimental data of energy consumption (Abano *et al.*, 2014). The positive coefficients of the model terms were indication of positive quadratic effect on the specific energy consumption for drying of okra slice in the hybrid solar dryer. The interaction effect of the process factors on the specific energy consumption is presented in the response surface plots (Figures 4a – c). All model terms had significant effect on the specific energy consumption ($P < 0.05$) except the interaction effects of velocity ($P \geq 0.05$) between drying air temperature and air velocity, air velocity and slice thickness, and the quadratic effect of air velocity.



(a)



(b)

Figure 5. (a) Normal % probability plot of drying time residuals; (b) Predicted versus experimental specific energy consumption for drying of sliced okra samples.

3.2 Optimization of the drying conditions

The optimal drying conditions were obtained for maximum desirability index of 0.808 (Equation 10). The optimal simulated values of the process variables at 95% confidence level were: 59.81^{o}C air temperature, 2ms^{-1} air velocity and 10mm slice thickness. The corresponding simulated values for response factors (drying time and specific energy consumption) were 94.54 mins and 3.54kWhkg^{-1} respectively. These predicted values are closer to their corresponding experimental values. The surface plot of the desirability for the optimum conditions is shown in Figure 6. The optimum values of the independent variables were close to that of Kumar *et al.* (2011) for microwave drying of okra slices, with 2.41Wg^{-1} of specific energgy use. Abano *et al.* (2014) obtained an optimum drying time of 752.603mins of similar batch size in a convective type dryer at lower temperature thresholds.

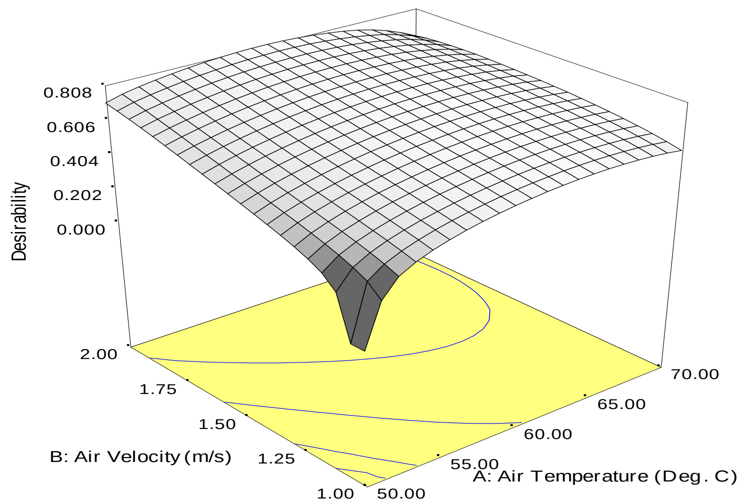


Figure 6. Response surface plot of the desirability index for the optimum drying conditions.

3.3 Energy analysis

3.3.1 Total energy consumption

The total energy consumption for drying a batch of okra slices increased with increase in slice thickness and decreased with air temperature at constant air velocity as shown in Figure 7. With increasing slice thickness, sample capillary distance increased, more time was taken to diffuse and evaporate product internal and surface moisture, which increased the mean energy consumption but decreased as air velocity increased. At increased air velocity, more convective air passes across the product surface increasing surface moisture evaporation as well as reducing the drying time, thus decreasing the energy consumption. Increasing the air velocity at increasing air temperature reduced the mean energy consumption because of more convective air entering the drying chamber to increase the rate of surface moisture evaporation as well as increasing the sample kinetic energy of internal moisture for rapid diffusion and reduced resistance to capillary transport. For each slice thickness and air velocity, mean energy decreased as air temperature increased because of faster drying rate due to increased thermal gradient between the drying air and the sample product. Less drying time was obtained at higher air temperatures, thus less energy consumed by the sliced samples. The maximum and minimum energy consumed in drying of 900 g batch size of sliced okra were 33.94 and 1.02 kWh, respectively. The results obtained were similar to those obtained by Koyuncu *et al.*, 2007 (for Cornelian cherry fruits); Sarsavadia, 2011 (for sliced onions); El-Mesery and Mwithiga, 2012 (onion slices); Motevali *et al.*, 2012 (Jujube fruits); Afolabi *et al.*, 2014 (for ginger slices); Minaei *et al.*, 2014 (for St. John's Worth leaves); and Beigi, 2016 (for apple slices).

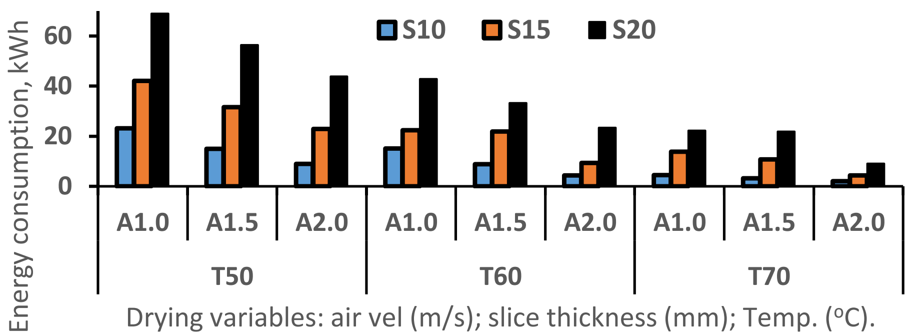


Figure 7. Energy consumption of 0.9kg batch of okra slices in a hybrid dryer

Equations (13) – (18) were obtained for the second order polynomial relationship between energy consumption and drying air velocity, as well as the energy consumption and drying air temperature at varying slice thicknesses:

$$E_{C10mm} = 0.0193T^2 = 3.3209T + 142.34 \qquad [R^2 = 0.9703] \quad (13)$$

$$E_{C10mm} = 1.3387A^2 - 12.743A + 24.47 \qquad [R^2 = 0.9731] \quad (14)$$

$$E_{C15mm} = 0.0475T^2 - 7.4031T + 297.4 \qquad [R^2 = 0.9882] \quad (15)$$

$$E_{C15mm} = 3.6278A^2 - 24.492A + 46.557 \qquad [R^2 = 0.9812] \quad (16)$$

$$E_{C20mm} = 0.0594T^2 - 9.7334T + 414.88 \qquad [R^2 = 0.9946] \quad (17)$$

$$E_{C20mm} = 6.2603A^2 - 38.45A + 77.499 \quad [R^2 = 0.9938] \tag{18}$$

The high R^2 values ranging between 0.9703 and 0.9946 indicate strong correlation between the energy consumption parameters and drying variables at different slice thicknesses. The coefficient of determination increased with increase in slice thickness for air temperature and air velocity treatment combinations.

3.3.2 Thermodynamic parameters

The thermal utilization efficiency (TUE) for drying of okra slices varied from 10% to 38.8% as presented in Table 6. TUE increased with increase in drying air temperature, decrease with air velocity and reduced sample thickness. The highest TUE (38.8%) was observed at 70^{o}C air temperature, 0.1ms^{-1} air velocity and 10mm slice thickness, whereas the lowest TUE (11.1%) was observed at 50^{o}C air temperature, 2.0ms^{-1} air velocity and 19mm slice thickness. Similar trends were observed by Jindal and Reyes (1987; El-Mesery and Mwithiga (2012); Minaei *et al.* (2014). Since TUE is a ratio of latent heat for moisture evaporation to energy required for moisture evaporation, increasing the sample thickness increased the quantity of moisture in the sample structure per fixed energy input. Much of the heat required for sample surface moisture evaporation were absorbed by the sample matrix to initiate capillary diffusion, leaving a marginal heat quantity for the actual surface moisture evaporation, thereby slowing down the moisture evaporation rate to a point that the input energy could not effectively overcome the sample energy barrier for internal water diffusion, thus low TUE. Increasing the air temperature had noticeable effect on the thermal utilization due to higher mass and moisture reduction associated with increased air temperature which usually increase TUE. This is consistent with the result of Aviara *et al.* (2014) in a tray dryer for cassava starch and Azadbakht *et al*. (2017) on fluidized bed dryer for sliced eggplant. Additionally, low air velocity had more resident contact time with the drying samples and evaporated their surface moisture more efficiently than at higher velocity - creating turbulence in the drying chamber plenum and exhausted with less contact effect on the samples. These observations are in agreement with the results of Beigi (2016), Minaei *et al.* (2012), Motevali *et al.* (2014), and Koyuncu (2007) for apple slices, St John's worth leaves, jujube fruits, and cornelian cherry fruits, respectively.

Table 6. Thermal utilization efficiency of okra under varying drying conditions

Slice thickness (mm)	10			15			20		
Air vel. (ms^{-1})	1	1.5	2	1	1.5	2	1	1.5	2
Air temp. (^{o}C)	**Thermal utilization efficiency (%)**								
50	33.2	29.4	26.2	23.4	20.4	18.2	14.9	12.3	10.0
60	35.5	31.3	28.3	25.2	22.3	20.1	17.7	15.2	13.2
70	38.8	34.9	30.2	27.5	24.9	20.6	19.2	17.5	15.4

Figure 8 shows the energy efficiency (η_e) for drying of okra samples at different drying variables calculated using Equation (6). The energy efficiency values varied between 11.2 – 45.6%. Energy efficiency increased with increase in sample thickness and drying air temperature and decrease in air velocity. This is because, at larger sample thickness, more heat is consumed to remove moisture from the inner sections of the samples at constant temperature, hence increased η_e (since it is a ratio of heat used to total heat supplied). Increasing the air temperature increased the energy consumed for moisture removal at constant air velocity and slice thickness. However, increase in air velocity increased the heat and mass transfer rate but affected the energy utilized for moisture evaporation negatively through turbulence at the dryer plenum, hence reduced energy efficiency. These observations are in conformity with the results of Beigi (2016) in drying of apple slices; Motevali *et al.* (2014) for flowers; Minae *et al.*(2014) for St. John's wort leaves.

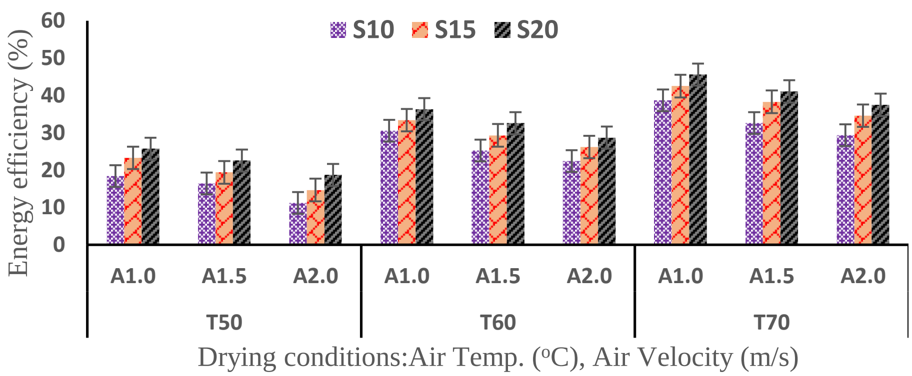


Figure 8. Energy efficiency of okra at varying drying conditions in a hybrid solar dryer

The drying efficiency of the okra samples at different drying air conditions and sample thicknesses is shown in Table 8. Increase in air temperature at decreasing air velocity and slice thickness increased drying efficiency; whereas any increase in air velocity and slice thickness at constant or varying air temperature decreased drying efficiency. This is because, at higher air temperatures, more energy was utilized which caused vapour pressure deficit and increased the kinetic energy for moisture diffusion and evaporation, hence increased drying rate. Drying efficiency varied from 22.7 – 49.6% as a result of less amount of heat used for moisture evaporation, as larger proportion of the heat supplied was used in raising the product temperature from ambient level to drying air temperature level. Much of the supplied heat was lost through air turbulence at higher air velocity and exited through the chimney without much impact on the product. Thus the need for incorporation of heat recovery units to improve the energy efficiency of the dryer (Kudra, 2012; Aghashlo *et al.*, 2013). The efficiency for drying reduced as the capillary distance increased. More energy was consumed to reduce the product energy barrier and initiate capillary diffusion. Heat and mass transfer rate was better at low air velocity due to more residence time of drying air within the products. These results agree with the reports of Azadbakht *et al.* (2017), Beigi

(2016), Jindarat *et al.* (2011), Vieira *et al.* (2007). It can be observed from Figure 8 and Tables 6 and 7 that drying efficiency is higher than thermal utilization and energy efficiencies since greater proportion of the energy consumed was used in heating up the drying air and increasing the product temperature, assuming negligible thermal loss.

Table 7. Drying efficiency values at varying drying air conditions and sample thicknesses

Slice thickness (mm)	10			15			20		
Air vel. (ms^{-1})	1	1.5	2	1	1.5	2	1	1.5	2
Air temp. (^oC)	Drying efficiency (%)								
50	40.1	36.3	33.1	37.1	34.2	30.6	33.4	30.7	28.1
60	44.3	39.7	36.4	39.3	36.3	28.1	35.4	27.0	25.6
70	49.6	44.5	40.1	44.9	39.1	32.4	37.0	24.6	22.7

4. CONCLUSION

This study revealed that mean energy consumption for drying of okra slices increased with decrease in air temperature and air velocity and increased with increase in slice thickness. The maximum mean energy consumption (69.02kWh) occurred at 50^{o}C air temperature, 0.1ms^{-1} air velocity and 20mm slice thickness, whereas the minimum mean energy consumption (2.02kWh) was obtained at 70^{o}C air temperature, 2ms^{-1} air velocity and 10mm slice thickness. Second order polynomial models of the energy consumption at varying slice thicknesses were developed. The R^2-values were found to increase with increase in slice thickness at varying drying parameters. Thermal utilization efficiency increased with increase in air temperature, decrease in air velocity and sample thickness. The highest thermal utilization efficiency (38.8%) was observed at 70^{o}C air temperature, 0.1ms^{-1} air velocity and 10mm slice thickness. Energy efficiency increased with increase in sample thickness and air temperature and decrease in air velocity. Maximum energy efficiency (45.6%) was obtained with 70^{o}C air temperature, 1ms^{-1} air velocity and 20mm slice thickness. Drying efficiency increased with increase in air temperature at decreasing air velocity and slice thickness. The maximum efficiency obtained was 49.6% at 70^{o}C air temperature, 1ms^{-1} air velocity and 10mm slice thickness.

The effects of three independent variables (air temperature, air velocity, and slice thickness on two response variables (drying time and specific energy consumption) of dried okra slices were also studied. The drying variables were optimized based on the specific energy and dried okra quality. Second order polynomial functions and response surface plots were developed. The drying factors had significant effects on the response variables. Increasing the drying air temperature and air velocity decreased the drying time significantly, whereas increase in slice thickness increased the drying time. Increasing the sample thickness at low air temperature and air velocity increased the specific energy consumption. The optimal predicted drying conditions obtained for maximum desirability index of 0.808 were

59.81^{o}C, 2ms^{-1} and 10mm for air temperature, air velocity and slice thickness, respectively. At this optimum condition, the respective values of drying time and specific energy consumption obtained were 94.54 mins and 3.54kWhkg^{-1} respectively.

5. ACKNOWLEDGEMENT

The authors are thankful to Mr. Oliver Okafor in writing the arduino program, building and installing the electronic components of the hybrid solar dryer system.

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Interaction between Moisture Content and Physical Properties of three Varieties of Cowpea (*Vigna Unguiculata*)

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ABSTRACT

The interaction between moisture content and physical properties of common cowpea varieties in North east Nigeria, being IT89K-573-1-1, IT98KD-288 and Ife brown were studied. It was to obtain data useful for the design of handling and processing equipment for the crop. Gravimetric properties such as: Size, sphericity, Surface area, 1000seedmass, volume, bulk density, true density, angle of repose and frictional angle were determined at 8%, 12%, 16% and 20% Moisture content. The length of the grain range from 8.3 to 9.07mm, 11.28 to 11.5mm and 9.58 to 10.06mm, width range from 7.14 to 7.63mm, 8.54 to 8.77mm and 6.95 to 7.48mm and thickness range from 5.66 to 5.94mm, 6.59 to 6.68mm and 5.18 to 5.39mm respectively for the 3 varieties. The result showed that variety and moisture content had significant effect ($P \leq 0.05$) on all the physical properties studied except angle of repose on which the interaction between moisture content and variety was not significant. Regression equations that could be used to express the relationships existing between the physical properties and grain moisture content were established.

Keywords: Agro-processing, Cowpea, Physical properties, Moisture content, Interaction, Nigeria.

1. INTRODUCTION

Cowpea (*Vigna Unguiculata (L.)Walp*) is an annual grain legume indigenous to tropical Africa and is widely grown in Africa, Latin America, south eastern Asia and southern United States (International Institute of Tropical Agriculture, IITA, 2005). It is used as fodder for animal, or as a vegetable. In West Africa, legumes especially cowpea, are of major importance in the livelihood of millions of relatively poor people and accounts for up to 80% of the total dietary protein intake for adults and are virtually the only source of protein for many children (Food and Agricultural Organization FAO, 2015).

Rapid and accurate determinations of physical attributes are needed in processing agricultural materials (Stroshine and Hamann, 1995). Faleye *et al*., (2013) studied the physical and mechanical properties of 5 varieties of cowpea grains. The results obtained when subjected to analysis of variance revealed significant differences in all the various properties tested except for the coefficient of friction on plywood, for which the mean values were 0.3978, 0.3972, 0.39806, 0.402 and 0.38194 for IT 16, IB, SR, WH and Oloka respectively. Information on physical, mechanical and aerodynamic properties of agricultural products is needed in the design and adjustment of machines used during harvesting, separation, cleaning, handling and storage of agricultural materials and to convert them into food, feed and fodder (Gursory & Guzel, 2010).

The objective of this study is to determine some physical and engineering properties of three cowpea variety popular in North eastern Nigeria and to investigate the effect of moisture content on these physical properties. The moisture content range was selected from 8% to 20% w.b., being the range of moisture contents for the harvest, storage and processing of cowpea. This study would be useful to both researchers, agro-processing machine developers in the efficient development of processing processes for cowpea.

2. MATERIALS AND METHODS

2.1 Material selection and preparation

Cowpeas were obtained from Cham community in Gombe state, Ngurore and Sangere areas of Adamawa state from farmers who spread the crop for drying. It was taken to the Agricultural Development Programme (ADP) office where it was identified. They were collected, cleaned and sorted for testing. The oven dry method was used to determine its moisture content prior to testing (ASAE standards, 1998). The results are found in Table 1.

The rewetting method was used to condition the cowpea into four moisture levels by adding predetermined amount of distilled water. Thereafter, the cowpea was packaged in an airtight polythene bag and kept in the refrigerator at temperature of 5°C for 72 hours. This was done to ensure even moisture absorption by the seeds and prevent microbial actions. The cowpea was taken out 2 hours before use to acclimatize to the room temperatures. Similar method was used by Singh and Goswami, (1996). The relation used is shown in equation (1)

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \tag{1}$$

Where; Q is the mass of water to be added in g; W_i is the initial mass of sample to be conditioned in g; M_f is the final or desired moisture content and M_i is the initial moisture content.

2.2 Physical properties

The physical properties of cowpea that were investigated included: size, sphericity, surface area, 1000 seed mass, volume, bulk density, true density, angle of repose, and frictional angle.

2.2.1 Dimensions and shape

Sixty whole seeds were selected at random and their corresponding length (L), width (W) and thickness (T) were measured and recorded. These dimensions were measured with a digital Vernier Calliper having a resolution, reliability and maximum error of 0.01, 0.01 and 0.02 mm respectively, in line with Kibar *et al.* (2010). Sphericity, Arithmetic mean diameter (D_a), Equivalent diameter (D_e), Surface area (S) and Volume (V) were estimated using equations 2, 3, 4, 5, and 6 respectively (Stroshine and Hamann, 1995; Davies & Zibokere, 2011).

$$\text{Sphericity} = \left(\frac{LWT}{L}\right)^{\frac{1}{3}} \qquad (2)$$

$$D_a = \frac{(L+W+T)}{3} \qquad (3)$$

$$D_e = (LWT)^{\frac{1}{3}} \qquad (4)$$

$$S = \pi {D_e}^2 \qquad (5)$$

$$V = \frac{\pi}{6} {D_e}^3 \qquad (6)$$

2.2.2 Mass of cowpea seeds

The apparatus used were sample container and electric weighing balance. 1000 whole seed of each variety were selected, placed in a container of known mass and weighed. This was repeated until four consecutive readings were taken and recorded in line with Wang *et al*., (2007), Igbozuike and Aremu (2009).

The average mass of the individual seed is estimated as shown in (7) (Mohsenin, 1986),

$$\text{Mass of seed (g)} = \frac{\text{Total mass}}{\text{Number of seeds}} \qquad (7)$$

2.2.3 Bulk density & true density

The bulk density is the ratio of the mass sample of the seeds to its total volume. It was determined by filling predetermined container from a constant height. The bulk density (γ) was determined by filling a 100 ml beaker with seeds by dropping them from a height of 150mm and the seeds weighed in line with Kaleemullah (1992). Dropping the seeds from a height of 150mm produces a tapping effect in the container to reproduce the settling effect during storage. The results are as presented in Table 1.

The bulk density of the sample was calculated as shown in equation (8)

$$\text{The bulk density } (\gamma) = \frac{M}{V} \qquad (8)$$

Where γ is bulk density of cowpea sample, g/cm^3, M is bulk mass of cowpea sample, g, V is bulk volume of cowpea sample, cm^3.

2.2.4 Angle of repose

Sample container, metal funnel and meter rule were used. The metal funnel was erected on flat metal surface. A known quantity of cowpea seed was filled into the funnel by means of the sample container. The funnel was lifted gradually from the flat metal surface to allow the seeds flow freely to form a conical shape on the flat surface. The height, H and length of the base of the conical heap, L_B were measured and the corresponding angle of repose computed following the relationship given by Ozguven and Kubilay (2004).

$$\theta_r = tan^{-1}\left[\frac{2H}{L}\right] \qquad (9)$$

The procedure was repeated until five readings were obtained using each variety and the mean value determined and the values were recorded. Similar method was used by Akaaimo and Raji (2006).

2.2.5 Coefficient of static friction

The tilting table was used to compute coefficient of static friction. It was determined on plywood and glass surfaces. The coefficient of static friction was calculated from equation (10).

$$\mu = tan\theta \qquad (10)$$

Where μ is the coefficient of static friction and θ is the angle of tilt of table. Similar method was use by Bart-Plange *et al*, (2012). The result is presented in Table 1.

2.3 Statistical analysis

Descriptive statistics was used to analyze the data. A 3 X 4 factorial experiment in Completely Randomized Design (CRD) with three (3) replicates for the gravimetric properties and sixty (60) replicates for the dimensional properties. The results obtained from the study were subjected to the mean analysis of variance (ANOVA), correlation and regression analyses using SPSS 20 and Microsoft Excel 10 Software.

3. RESULTS AND DISCUSSION

The results for dimensions, arithmetic mean diameter, equivalent diameter, surface area, volume, sphericity, 1000seed mass, angle of repose, coefficient of static friction for glass and plywood, bulk density and true density of IT89K-573-1-1, IT98KD-288 and Ife brown at moisture content of 8%, 12%, 16% and 20% are presented in Tables 1, 2 and 3.

3.1 Seed Dimensions

The dimensions of length, width and thickness for the three varieties of cowpea investigated increased linearly with increase in moisture content i.e from 8% to 20% w.b (Fig. 1). The effects of variety, moisture content and the interaction between variety and moisture content were significant ($p \leq 0.05$) on the dimensions (Table 2). These results agree with Kibar *et al* (2010) for rice at moisture content range of 10-14% db, which was attributed to expansion/swelling as a result of moisture intake in the intercellular spaces within the seed.

3.2 Arithmetic Mean Diameter and Equivalent Diameter

Arithmetic mean diameter and the equivalent diameter for the three varieties observed increased with increase in moisture content. The variant test showed that variety, moisture content and the interaction between variety and moisture content made significant difference ($p \leq 0.05$) on arithmetic mean diameter and equivalent diameter (Table 2). The linear regression equations presented in Table 4 showed that Arithmetic mean diameter and Equivalent diameter were positively correlated with moisture content, having high correlation coefficient for the three varieties.

3.3 Volume, Surface Area and Sphericity

The volume and surface area increased with increase in moisture content. Sphericity on the other hand exhibited mostly a decrease with increasing moisture content (Table 1). The interaction between variety and moisture content showed no significance ($p \leq 0.05$) for sphericity. Every other effect were significant on volume, surface area and sphericity (Table 2). The results of volume, Surface area and Sphericity agree with Theertha *et al* (2014) for black grain and Ehiem *et al* (2016) for Canarium Schweinfurthii Engl.fruits for all the varieties tested. Surface area agrees with Yalcin (2006) for cowpea seed and sphericity refuse to agree with Kibar *et al* (2010).

Table 1: Physical properties of three varieties of cowpea determined at 4 moisture content levels *****Standard deviation

LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	De (mm)	AMD (mm)	SPHERIC (decimal)	VOL (mm^3)	S.A (mm^2)	TSM (g)	REPOSE (^{0})	Coef.friction PLYWOOD (decimal)	Coef.friction GLASS (decimal)	BULK DENSITY (kg/m^3)	TRU DENS (kg/
8.3	7.14	5.66	6.95	7.03	0.8471	175.71	151.73	203.03	20.64	0.3404	0.1853	717.00	102
(0.021)*	(0.026)	(0.025)	(0.015)	(0.015)	(0.002)	(1.174)	(0.676)	(0.025)	(0.84)	(0.001)	(0.001)	(12.437)	(1
8.72	7.50	5.76	7.22	7.33	0.8286	197.31	163.92	207.28	20.88	0.3522	0.3679	712.14	101
(0.038)	(0.022)	(0.025)	(0.018)	(0.019)	(0.003)	(1.51)	(0.836)	(0.903)	(0.483)	(0.004)	(0.001)	(2.529)	(1
8.77	7.53	5.81	7.27	7.37	0.8286	200.98	165.95	218.03	21.4	0.3739	0.4224	707.71	100
(0.065)	(0.025)	(0.032)	(0.023)	(0.025)	(0.005)	(1.93)	(1.064)	(0.2040	(0.355)	(0.002)	(0.003)	(0.454)	(0
9.07	7.63	5.94	7.44	7.55	0.8199	215.32	173.75	229.78	22.53	0.3909	0.4899	704.86	100
(0.160)	(0.025)	(0.032)	(0.041)	(0.051)	(0.01)	(3.59)	(1.919)	(0.458)	(0.551)	(0.002)	(0.001)	(0.624)	(1
11.28	8.54	6.59	8.59	8.80	0.7619	332.53	232.14	361.33	19.53	0.3269	0.2867	703.57	107
(0.021)	(0.026)	(0.018)	(0.011)	(0.011)	(0.001)	(1.27)	(0.59)	(0.864)	(0.456)	(0.001)	(0.002)	(0.342)	(
11.39	8.58	6.6	8.64	8.86	0.7586	337.85	234.62	366.75	19.85	0.3463	0.362	695.43	106
(0.026)	(0.021)	(0.024)	(0.015)	(0.014)	(0.002)	(1.735)	(0.803)	(0.182)	(0.494)	(0.001)	(0.001)	(0.537)	(0
11.41	8.64	6.62	8.67	8.89	0.7602	341.85	236.47	397.15	20.35	0.3522	0.4515	680.14	105
(0.026)	(0.023)	(0.024)	(0.016)	(0.015)	(0.002)	(1.846)	(0.753)	(0.528)	(0.304)	(0.002)	(0.001)	(0.801)	(1
11.50	8.77	6.68	8.77	8.98	0.7623	352.93	241.54	413.95	22.03	0.4081	0.4557	659.86	104
(0.03)	(0.018)	(0.043)	(0.020)	(0.018)	(0.002)	(2.440)	(1.114)	(0.601)	(0.188)	(0.001)	(0.001)	(0.402)	(1
9.58	6.95	5.18	7.01	7.24	0.732	180.66	154.56	218.31	19.2	0.3443	0.3502	761.00	110
(0.024)	(0.029)	(0.015)	(0.012)	(0.013)	(0.002)	(0.92)	(0.523)	(0.557)	(0.164)	(0.003)	(0.001)	(1.3)	(1
9.69	7.1	5.31	7.15	7.33	0.7377	191.36	160.61	221.8	19.9	0.3561	0.4061	741.29	109
(0.032)	(0.02)	(0.026)	(0.016)	(0.019)	(0.002)	(1.31)	(0.732)	(0.488)	(0.276)	(0.006)	(0.0004)	(0.645)	(0
9.75	7.11	5.38	7.2	7.41	0.7383	195.36	162.84	230.6	20.51	0.3739	0.4802	730.71	108
(0.024)	(0.026)	(0.02)	(0.014)	(0.014)	(0.002)	(1.138)	(0.633)	(0.705)	(0.901)	(0.005)	(0.002)	(0.332)	(0
10.06	7.48	5.39	7.40	7.64	0.7358	212.47	172.22	235.63	22.23	0.3899	0.4877	723.00	106

(0.025)	(0.027)	(0.027)	(0.015)	(0.015)	(0.002)	(1.288)	(0.696)	(0.520)	(0.18)	(0.001)	(0.001)	(0.557)	(0

Table 2: ANOVA summary of dimensionally measured and calculated parameters of cowpea studied at levels of moisture content

Source of variation	Df	Length (mm)	Width (mm)	Thickness (mm)	De (mm)	AMD (mm)	Sphericity (decimal)	Volume (mm^3)	S.A (mm^2)
replicate	59								
MC	3	2339.995	8928.455	1713.765	9701.072	8889.606	46.359	8630.043	9348.514
Variety	2	140735.6	248255.6	151550.1	447455.5	401138	43076.19	508674.9	488857.6
Interaction	6	286.076	996.032	204.292	795.052	765.395	117.108	371.393	575.404
Error	708								
Total	**719**								

All significant at 5%

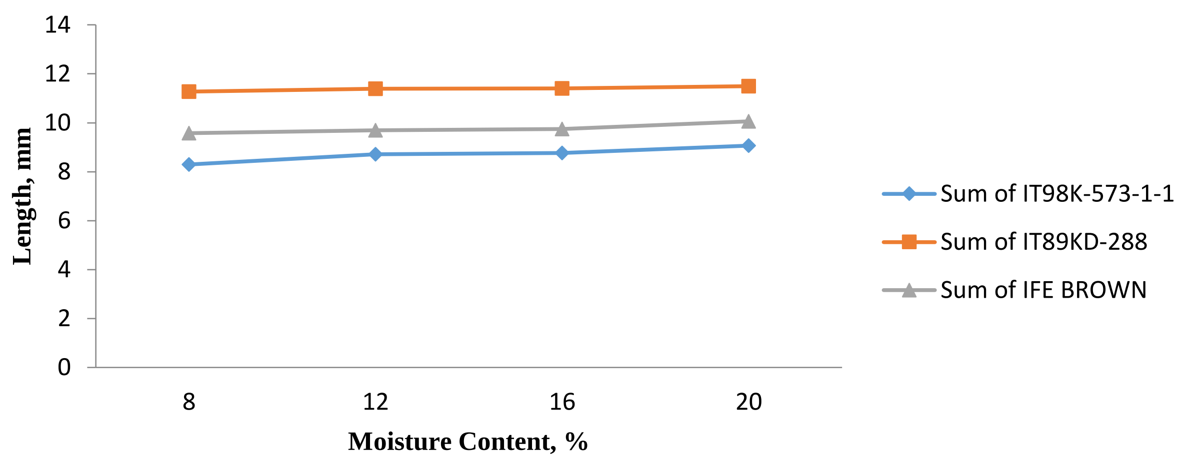

Figure 1: Effect of moisture content on the length of three varieties of cowpea

3.4 1000Seed Mass

The 1000 seed mass for the three varieties tested increased linearly with increase in moisture content. The IT98K-573-1-1 increased from 203.03g to 229.78g, IT89KD-288 increased from 361.33g to 413.95g and Ife brown from 218.31g to 235.63g (Figure 2). The analysis of variance showed that the effect of variety and moisture content was significant ($p \leq 0.05$) on 1000seed mass. The interaction effect of variety and moisture content was also significant (Table 3). the result of seed mass agree with Davies and Zibokere (2011) and Ehiem *et al* (2016).

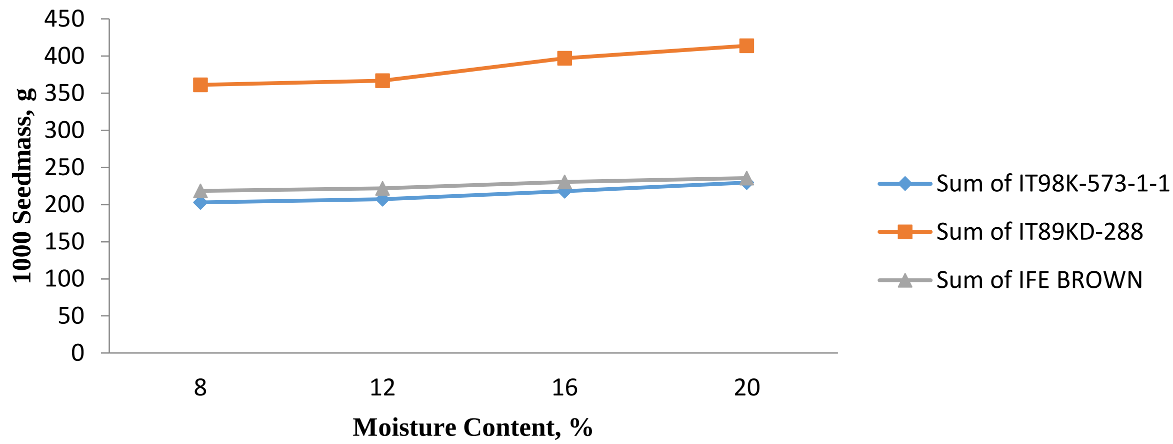

Figure 2: Effect of moisture content on the 1000seed mass of three cowpea varieties

3.5 Bulk density and True density

Bulk and true densities decreased with increasing moisture content within the range of 8% to 20%w.b as shown in Table 1 and Figure 3. Both variety, moisture content and their interaction had significant effect ($p \leq 0.05$) on bulk density and true density. Bulk density agrees with Kiber *et al* (2010) and Theertha *et al* (2014) from 692.3 - 661.5kg/m3 ($p \leq 0.05$) while true density disagrees with the results.

Table 3: ANOVA summary of measured gravimetric and physical parameters of cowpea studied at levels of moisture content

Source of Variation	Df	1000seed mass (g)	Repose (^{0})	Coeff. of friction Plywood (decimal)	Coeff. of friction Glass (decimal)	B.D (kg/m^3)	T.D (kg/m^3)	Porosity (%)
Replicate	2							
MC	3	6340.268	43.549	644.49	46441.69	117.604	1532.931	7.083
Variety	2	341933.2	13.862	21.954	8027.664	641.109	15400.72	413.268
Interaction	6	772.063	0.735NS	34.129	2722.432	14.012	17.693	6.227
Error	24							
Total	**35**							

NS= Not Significant

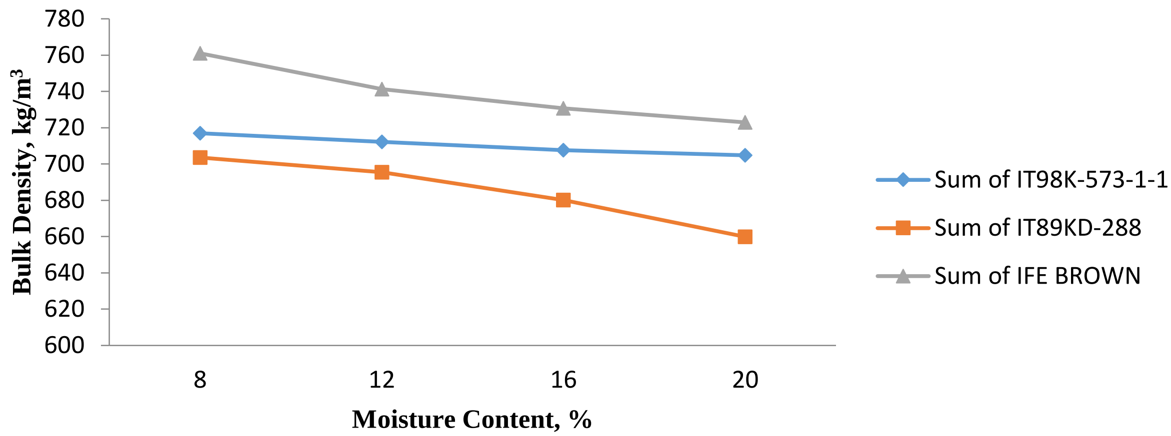

Figure 3: Effect of moisture content on bulk density of three cowpea varieties

3.6 Porosity

The porosity for IT89KD-288 and Ife brown increased linearly from 34.47% to 36.64% and 31.09% to 32.31% respectively with increasing moisture content from 8% to 20%. Whereas IT98K-573-1-1 decrease through 30.08% to 29.54% with the increase in moisture content. The analysis of variance in all the tested parameters showed that they all had significant difference ($p \leq 0.05$) on the porosity. It agrees with Kibar *et al* (2010) except for the 573-1-1 variety.

3.7 Angle of Repose and Static Coefficient of Friction

The angle of repose increased for all varieties tested with increasing moisture content within the range of 8% to 20% (Figure 4). The effect of moisture content and variety on angle of repose were significant while the interaction between moisture content and variety was not significant.

The static coefficient of friction tested for plywood and glass both increased with increase in moisture content for all varieties tested. The plywood values for static coefficient of friction were higher than those of glass. This shows that the plywood offered more resistance than the glass. The analysis of variance of the variety, moisture content and the interaction between the variety and moisture showed that they all had significant effect on the static coefficient of friction on plywood and glass at 5% significant level. Both angle of repose and coefficient of friction agrees with Davies and Zibokere (2011). The behaviour of angle of repose could be attributed mainly to increase in size of the seeds as reported by Olalusi *et al* (2009).

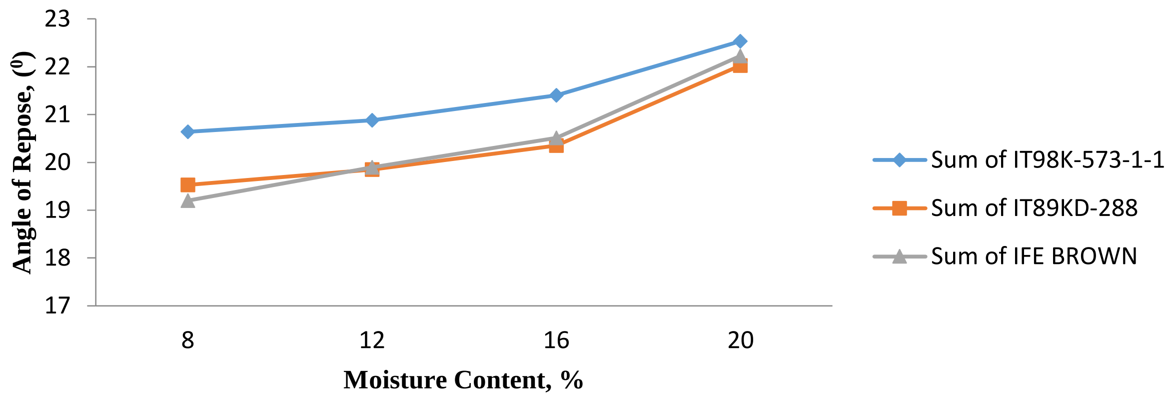

Figure 4: Effect of moisture content on the angle of repose of three varieties of cowpea

Table 4: Equation representing relationship between physical parameters and moisture content.

VARIETY	**IT89K-573-1-1**		**IT98KD-288**		**IFE BROWN**	
PROPERTY	**Model Equation**	**r**	**Model Equation**	**r**	**Model Equation**	**r**
L	7.89 + 0.06Mc	0.93	11.16 + 0.02Mc	0.94	9.25 + 0.04Mc	0.89
W	6.93 + 0.04Mc	0.81	8.37 + 0.02Mc	0.93	6.60 + 0.04Mc	0.84
T	5.48 + .02Mc	0.97	6.52 + 0.01Mc	0.86	5.07 + 0.02Mc	0.87
De	6.69 + 0.04Mc	0.93	8.48 + 0.01Mc	0.95	6.76 + 0.03Mc	0.95
AMD	6.77 + 0.04Mc	0.92	8.68 + 0.01Mc	0.96	6.95 + 0.03Mc	0.93
SPHER	0.85 - 0.001Mc	-0.90	0.76 + 0.00Mc	0.05	0.73 + 0.00Mc	0.30
VOL	154.5 + 3.06Mc	0.93	318.5 + 1.63Mc	0.95	160.2 + 2.48Mc	0.94
S.A	140.0 + 1.70Mc	0.93	225.7 + 0.75Mc	0.95	143.2 + 1.38Mc	0.95
TSM	182.7 + 2.28Mc	0.96	318.9 + 4.71Mc	0.94	205.3 + 1.52Mc	0.98
REPOSE	19.19 + 0.16Mc	0.90	17.64 + 0.20Mc	0.86	17.07 + 0.24Mc	0.93
PLYWOOD	0.304 + 0.004Mc	0.99	0.271 + 0.01Mc	0.85	0.312 + 0.00Mc	0.99
GLASS	0.028 + 0.02Mc	0.92	0.180 + 0.02Mc	0.91	0.260 + 0.01Mc	0.93
B.D	724.7 - 1.02Mc	-0.99	736.0 - 3.66Mc	-0.97	782.6 - 3.12Mc	-0.95
T.D	1042 - 2.08Mc	-1.00	1095 - 2.69Mc	-0.99	1129 - 3.04Mc	-0.99
POROSITY	31.52 - 0.10Mc	-0.87	32.69 + 0.19Mc	0.91	30.60 + 0.10Mc	0.72

4. CONCLUSIONS

The following conclusions are drawn from the effect of moisture content on the properties of three varieties of cowpea seeds in the 8% to 20% moisture content:

1. The result showed that dimensions, equivalent diameter, arithmetic mean diameter, volume, surface area, 1000seed mass, angle of repose, coefficient of static friction for both glass and plywood increased with increasing moisture content, whereas bulk and true densities decreased with increasing moisture content.
2. The interaction between moisture content and variety had no significant effect on angle of repose. Meanwhile moisture content and variety had significant effect on all the properties investigated ($p \leq 0.05$).
3. Linear regression equations as a function of moisture content were generated. They are useful in the prediction of behavioural patterns of seeds during storage and processing.
4. Useful data necessary for design purpose were also determined.

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Aerodynamic and thermal properties of melon (*Citrullus lanatus*) seeds under varying drying temperature for separation from shells and processing

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ABSTRACT

The effect of temperature on aerodynamic and thermal properties of melon seed is very important in the design of drying, processing and storage equipment. To this end, some thermal and aerodynamic properties of melon seed were investigated as a function of temperature. The thermal conductivity, specific heat capacity and thermal diffusivity were the thermal properties that were determined. Terminal velocity, seed drag force and drag coefficient were the aerodynamic properties investigated. The results obtained for the terminal velocity of the seed at temperatures of 30ºC, 35ºC, 40ºC, 45ºC, 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, and 75ºC were 7.415, 7.135, 6.32, 9.95, 5.885, 5.62, 5.32, 5.205, 4.88m/s respectively. The values continued to reduce until 100ºC with a value of 3.37m/s. The drag force of the melon seed attained its maximum value at temperature of 50ºC (1.777N). A minimum value was attained at the temperature of 100ºC (0.343N). At various temperature levels of 35ºC, 40ºC, 45ºC, 55ºC, 60ºC, 65ºC, and 70ºC, values for drag force were 1.472N, 1.349N, 1.275N, 1.079N, 0.981N, 0.883N, and 0.884N respectively. The drag coefficient was at its maximum at temperature of 80ºC with a value of 1.179, and minimum at 30ºC with a value of 0.743. For the thermal properties, the specific heat capacity attained a maximum value of 2.995KJ/Kg/K at a temperature of 30ºC, while it attained a minimum value of 1.596KJ/Kg/K at temperature of 100ºC. The thermal conductivity was maximum at 30ºC with a value of 3.62W/m/K, and minimum at 100ºC with a value of 0.46W/m/K. In the same vein thermal conductivity reduces with an increase in temperature. At the temperatures of 30ºC, 35ºC, 40ºC, 45ºC, 50ºC, 55ºC, 60ºC, 65ºC, 70ºC, 75ºC, and 80ºC, the thermal conductivity values were 3.26W/m/K, 1.545W/m/K, 1.1W/m/K, 1.83W/m/K, 1.725W/m/K, 0.64W/m/K, 0.605W/m/K, 0.555W/m/K, 0.53W/m/K, 0.52W/m/K, and 0.505W/m/K respectively. The thermal diffusivity attained a maximum value at 30ºC ($6.19\times10^{-5} m^2/s$) and a minimum value of $1.16\times10^{-6} m^2/s$ at 100ºC. Therefore, it can be clearly observed that temperature has a very great effect in the aerodynamic and thermal properties of egusi melon and these values are vital to engineers and food processors in the design of storage and processing equipment for melon seeds.

KEYWORDS: Thermal properties, Aerodynamic properties, Egusi melon seed, Terminal velocity, Thermal heat conductivity, Thermal heat diffusivity.

1. INTRODUCTION

One of the important food and cash crops that is grown in most African countries is melon (Egusi) *(Citrullus colocynthis lanatus*) and used as food source, in medicine, engineering and cosmetics (Jeffrey, 1980). Melon (Egusi) is a tendril climbing herbaceous crop. It belongs to the family of *Cucurbitaceae*, with excellent genetic diversity, vegetative and reproductive characteristics. *Citrullus lanatus* is classified into three sub-species; *lanatus*, *mucosospermus fursa* and *vulgaris fursa.* Some of the species are edible and grown in most parts of the world (Enoch et al., 2008). Egusi is grown and utilized as food source in most parts of Africa. Melon seed is also an important component of the traditional cropping system usually inter-planted with such staple crops as cassava, maize, sorghum, etc and by nature, a creepy growing plant which covers large area when properly grown, and as such control weeds, thereby improving soil fertility. Its leaves are deeply lobed and blue-gray, and are alternately arranged (Jeffrey, 1980; Enoch et al., 2008). The yellow-green fruit at maturity, which is identified by the drying of its leaves, is about the size of edible watermelon, but its flesh is white and the back is often shiny. The melon pod has an almost spheroidal external shape and ellipsoidal seed cavity (Oloko and Agbetoye, 2006).

Melon (Egusi) originated fron Africa and Asia and over the years, it is widely cultivated in the Caribbean, Indonesia and Africa. In Nigeria, the existence of melon dates back to the 17th century. Melon (popularly known as *Egusi* in the Igbo speaking parts of Nigeria) is a popular crop because of the edible seeds which are commonly used in the preparation of local soup or stew and snacks such as fried melon seed ball known as *Robo* in South Western Nigeria, and grinded melon mixed with bitter leave known as *ofeegusi* in eastern part of Nigeria. Recent statistics shows that 100,000 and 488,000 metric tons of melon were produced in Nigeria in 1992 and 1997. The melon (Egusi) seed, *C. lanatus* had been reported to contain an average about 22g of protein, 30g of fat and 11g of carbohydrate and as well as good quantities micronutrients per 100g sample. It is a good source of amino acids such as arginine, vitamins B1, vitamins B2, niacin, tryptophan and methionone, and minerals such as zinc, iron, potassium, phosphorus, sulphur, manganese, calcium, lead, chloride and magnesium (Eugene and Gloria, 2002). Melon seeds contain between 30-50% by weight of oil which is comparable to other oil plants and the oil contains a high level of saturated fatty acids. According to Oloko and Agbetoye (2006), melon seeds offer valuable sources of vegetable oil for local and export trade. Recently, it has been proved to be a fed-stock for bio-fuel (Gusmini et al., 2004; Solomon et al., 2010). Melon has about 60% protein content that enriches the diet of the consumer. Melon such as (*Citrulluslanatus*), Bara *(Colocynthiscitrullus*) and Sereweare are most common in Nigeria. The *Colocynthis citrullus* has the widest distribution. The geographical distribution was attributed to consumers' preference rather than physiological adaptation of the crop.

Despite the huge economic, nutritional, medicinal and cultural potential of these product, very little is known of the aerodynamic and thermal properties. As a result, there is scarcity of machines, systems and gadgets for wide scale post harvest operation such as processing, distribution and value addition accessioned by dearth of design data. In most African countries in general and Nigeria in particular, postharvest operations are carried out manually with its attendant drudgery, poor quality product and low productivity and economic value. To transform these product into internationally acceptable and marketable products, their aerodynamic, thermal properties are expedient as well as high quality maintained. Since only a few agricultural crops such as fresh fruits and vegetables go from field to the table without any thermal processing, therefore thermal processing becomes unavoidable. Thermal processing (include treatments such as pasteurization, concentration, drying, cooling, etc.) is frequently used in food processing, transportation, storing and cooking to improve the shelf life and good quality of the material. To achieve these, there is therefore need to determine the thermal properties of these product.

Knowledge of the aerodynamic and thermal properties of melon seeds are vital in equipment design for operations such as pneumatic conveying in loading/unloading operations of melon seeds. It is also useful to both engineers and food scientists; plant and animal breeders and also for data collection in the design of machines, structures, processes and controls; and in determining the efficiency of a machine or an operation. On the other hand, the knowledge of temperature requirements plays a very vital role on the storability of the seed. Pneumatic conveying may offer important functional and economic advantages in handling materials. The utilization of forced-air streams for the transport and drying of agricultural materials is becoming increasingly important in Nigeria. It is, therefore, necessary that the aerodynamic characteristics of this material at varying temperature be investigated so that their behaviour in an air stream can be estimated with a degree of certainty, and so a fair basis on which to establish blower design can be provided.

Thermal properties of food and agricultural materials are important engineering parameters in the mathematical modeling and design of systems and equipment needed for drying, storing, aeration, and refrigeration. These properties are also essential for the prediction of drying and refrigeration processes. A number of researchers have determined three moisture-dependent thermal properties (such as specific heat capacity, bulk thermal heat conductivity, and thermal heat diffusivity) for several grains, seeds, and kernels such as minor millet (*Sestaria italia* , *Panicum miliare*, *Panicum miliaceum*, *Paspalum sorobiculatum*, *Eleusine coracana* , *Echinochola colona*) (Subramanian and Viswanathan, 2003), guna seed (*Citrullus colocynthis)* (Aviara et al., 2008), coriander (*Coriandrum sativum* L) and anise (*Pimpinella anisum* L) seeds (Hacikuru and Kocabiyik, 2008), chickpea (*Cicer arietinum* L) (Singh et al., 2008), pumpkin seeds (*Cucurbita pepo* L) (Kocabiyik et al., 2009), peanut (*Arachis hypogaea* Linnaeus) pods, kernels and shells (Bitra et al., 2010), pigeonpea (Singh and Kotwaliwale, 2010), prairie carnation (*Saponaria vaccaria)* (Shrestha and Baik, 2010), roselle seeds (*Hibiscus sabdariffa* L) (Bamgboye and

Adejumo, 2010), and black pepper (Panniyur-1) (Meghwal and Goswami, 2011). Alagusundaram et al. (1991) determined only the thermal conductivity of lentil (Laird) as a function of moisture content.

Also, the effect of temperature on thermal properties of melon seeds is very important in the design of drying, processing and storage equipment. Therefore, this work seeks to determine the aerodynamic (terminal velocity, drag force and drag coefficient) and thermal properties (thermal conductivity, thermal diffusivity and specific heat capacity) of melon seeds *(citrullus L.)* under varying drying temperature.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

The study was carried out using local but common variety of melon (Egusi) seeds, *Colocynthiscitrullus*, which also has the widest distribution. Samples of the melon seeds were purchased from a local market known as Ogige Market in Nsukka, Enugu State, Nigeria. The seeds were shelled and cleaned. Contaminants, immatured and other foreign materials were removed manually before the experiment was conducted. Samples of the seeds were oven dried and conditioned to the required temperature (30 to 100^oC) which spans the temperature range of harvest to the post harvest processing operations.

Figure 1. Shelled melon samples

2.2 Determination of Aerodynamic Properties of Melon Seeds

2.2.1 Determination of terminal velocity of melon seeds

The terminal velocity, V_t of melon seeds measured in metre per second (m/s) was determined according to the method by Shahbazi (2013). A vertical wind tunnel as shown in Figure 2 was developed and used. A. centrifugal fan powered by an HP motor was used in the inlet of the wind tunnel to supply airflow. The airflow rate of the fan was controlled by changing the velocity of the electric motor through an inverter set and a diaphragm. The final section of the wind tunnel consisted of a Plexiglas region where the terminal velocity of the seed was measured. To determine the terminal velocity, each seed was placed in the centre of the cross-section of the wind tunnel on the screen. The airflow was then increased until the seed flotation point. At this moment, when the rotational movement of the seed was lowest, the air velocity was measured using a hot-wire anemometer with an accuracy of 0.1 m s^{-1}.

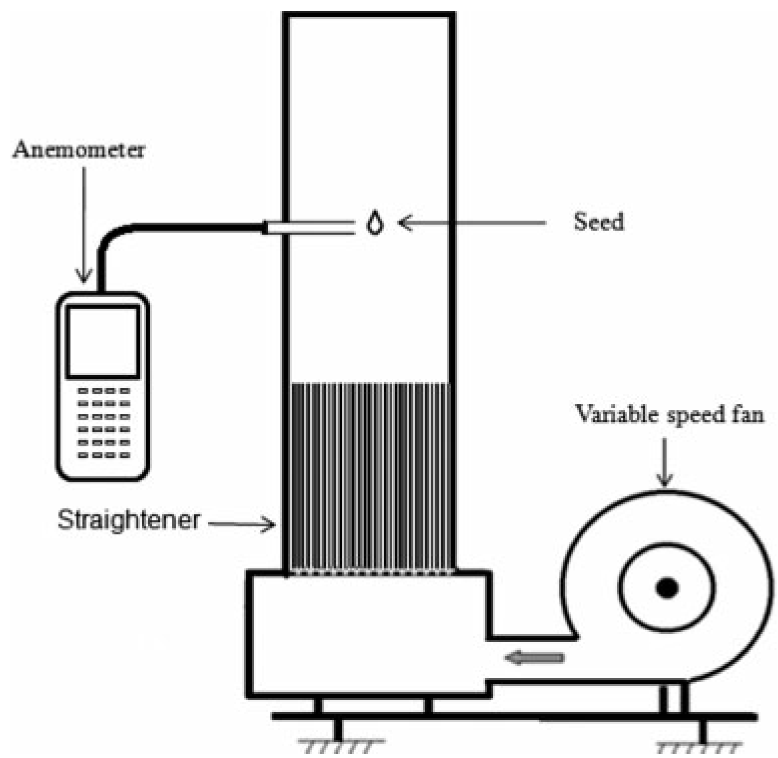

Figure 2. Set up for the measurement of terminal velocity of melon seeds

2.2.2 Determination of drag force

The drag force is a resistive force, opposing the motion of the melon seeds. The most familiar form of drag force is made up of friction forces, which act parallel to the object's surface, plus pressure forces, which act in a direction perpendicular to the object's surface. For a solid object moving through a fluid, the drag is the component of the net aerodynamic or hydrodynamic force acting in the direction of the movement. The component perpendicular to this direction is considered lift. Therefore drag acts to oppose the motion of the object. The drag force can be computed using equation (1)

$$F_d = \frac{C_d \ell_a A_p V_t^2}{2} = C_r V_t^2 \qquad (1)$$

The projected area of the melon seed can be calculated using equation (2)

$$A_p = \frac{\pi L W}{4} \qquad (2)$$

Where, F_d is the drag force (N); C_d is drag coefficient (dimensionless); ℓ_a is air density (1.25, kg/m^3); A_p particle area projected to air (m^2); V_t is terminal velocity (m/s); C_r is resistance coefficient (kg/m); L is length of the melon seed and W is width of the melon seed.

2.2.3 Determination of the drag coefficient of the corn seeds

Among aerodynamic properties, the drag coefficient (commonly denoted is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment such as air or water. It is used in the drag equation, where a lower drag coefficient indicates the object will have less aerodynamic or hydrodynamic drag. The drag coefficient is always associated with a particular surface area. It is computed with equation (3)

$$C_d = \frac{2F_d}{V_t^2 \ell_a A_p} \qquad (3)$$

Where, all the parameters and units are as defined earlier.

2.3 Determination of Thermal Properties of Melon Seeds

2.3.1 Determination of thermal conductivity of melon seeds

Steady state technique was used in the determination of thermal conductivity of melon seeds. The instrument used in this work is guarded hot plate. In this process, some melon (egusi) samples were placed between the plates. One plate is heated to a required temperature and the other is cooled or heated to a lesser extent. The temperature of the plate is monitored until they are constant. The steady state temperature, the thickness of the sample, and the heat input to the hot plate are used to calculate thermal conductivity using equation (4) given according to Isaj et al. (2014).

$$\lambda = \frac{Q \times d}{T_1 - T_2} \qquad (4)$$

Where λ is thermal heat conductivity (W/m/K), Q is the quantity of heat passing through a unit area of the melon samples in unit time (W/m^2), d is the distance between the sides of the sample in metre (m), T_1 is the temperature on the hotter side of the sample (k) and T_2 is the temperature on the colder side of the sample (k). Figure 3 shows the schematic diagram of Guided Hot Plate used for the determination of thermal heat conductivity.

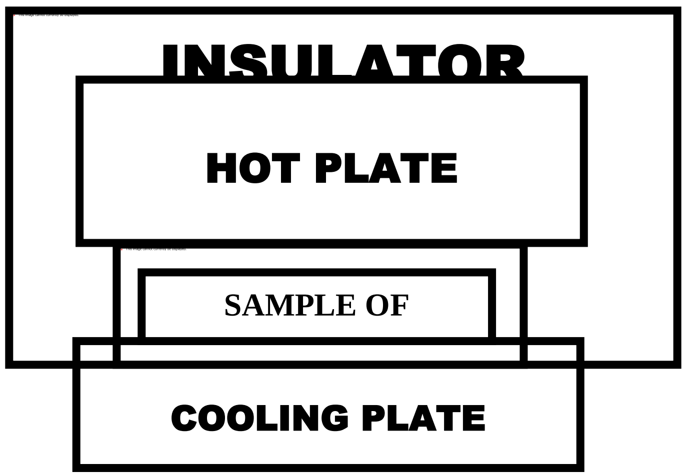

Figure 3. Schematic diagram of Guided Hot Plate for the determination of thermal conductivity

2.3.2 Determination of thermal diffusivity of melon seeds

The thermal diffusivity of melon seeds was determined according to Indian standard (IS: 10698 -1983). The apparatus consists of a thermal diffusivity tool and an insulated water bath of 25 liters capacity. The cylinder was filled with milled melons and the entire assembly was placed with end caps and thermocouples in a water bath. Heat at constant rate is applied to the water bath with the help of 1000 Watt immersion heater. The water in the bath was stirred with the help of a stirrer at suitable speed, driven by a motor of 40 Watt, 4000rpm and coupled to a speed regulator. The thermal diffusivity was computed by using the expression by Kachru et al. (2002) and Alam et al. (2002) as shown in equation (5)

$$\alpha = \frac{R^2 A}{4(T_R - T_C)} \qquad (5)$$

Where, α is thermal diffusivity (m^2/s) of the melon seeds, R is radius of the thermal diffussivity tube (m), T_R-T_C is constant temperature difference at any time between temperature at the surface T_R and temperature at the centre T_C of thermal diffusivity tube in (^{o}C) and A is constant slope of temperature versus time curve (^{o}C/s).

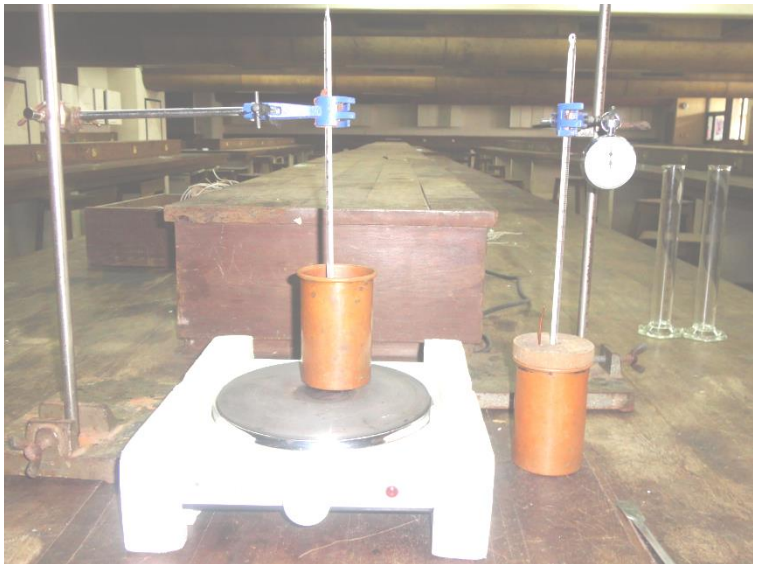

Figure 4. Set up for determination of thermal diffussivity of melon seeds

2.3.3 Determination of specific heat capacity of melon seeds

The method of mixtures has been the most common widely reported technique in literature for measuring the specific heat capacity of biomaterials (Razavi and Taghizadeh, 2008). For the determination of specific heat capacity of melon seeds, the method of mixture was used. Molded melon samples of known mass and temperature were dropped into a cupper calorimeter containing water of known mass and temperature. The calorimeter was insulated so as to prevent heat loss to the room in which the experiment was performed. The mixture was stirred continuously using a glass stirrer. A digital thermometer was used to monitor the temperature of the mixture. The equilibrium temperature was noted. The specific heat capacity was determined using equation (6) according to Aviara and Haque (2001).

$$C_1 = \frac{M_2C_2(\theta_3 - \theta_1) + (M_3 - M_2)C_w(\theta_3 - \theta_1)}{M_1(\theta_2 - \theta_3)} \qquad (6)$$

Where, M_1 is mass of the melon sample (kg), M_2 is mass of the calorimeter (kg), M_3 is mass of calorimeter + water (kg), Θ_1 is the initial temperature of water (K), Θ_2 is the temperature of the melon sample (K), Θ_3 is the final temperature of the mixture (K), C_1 is the specific heat capacity of the melon sample (J/kg/K), C_2 is the specific heat capacity of calorimeter, which was 400J/kg/K and C_w is the specific heat capacity of water, which was (4200J/kg/K).

2.4 Methods of Statistical Analyses

Data for both aerodynamic and thermal properties was analyzed statistically using SPSS and simple Excel packages. Analysis of Variance (ANOVA) was performed to determine the significance of the treatment and interaction effects. When analysis of variance was significant at *5%* probability level, treatments were separated and presented by Duncan's New Multiple Range Tests (DNMRT) at the 5% level of probability. Simple Excel was used to plot the graph of the aerodynamic and thermal properties of the melon seeds against drying temperature (30-100^{o}C) of the melon seeds, to obtain graphical and linear representation of temperature effect on aerodynamic and thermal properties of the seeds.

3. RESULTS AND DISCUSSIONS

3.1 Aerodynamic Properties

Table 1 shows the summary result of the mean values of the aerodynamic properties of melon seeds at varying drying temperature.

Table 1. Mean values of aerodynamic properties of melon seeds at varying drying temperature.

Temperature (^{o}C)	**Terminal Velocity (m s^{-1})**	**Drag Force (N)**	**Drag Coefficient (dimensionless)**
30	7.415_{j}	1.567_{j}	0.734_{h}
35	7.135_{j}	1.472_{j}	0.801_{h}
40	6.32_{j}	1.349_{j}	0.869_{h}
45	5.95_{ij}	1.275_{ij}	0.925_{gh}
50	5.885_{i}	1.777_{i}	0.99_{g}
55	5.62_{h}	1.079_{h}	0.852_{f}
60	5.32_{h}	0.981_{h}	0.832_{e}
65	5.205_{gh}	0.883_{gh}	0.736_{d}
70	4.88_{g}	0.884_{f}	0.91_{dh}
75	4.57_{f}	0.785_{e}	0.993_{cd}
80	4.1_{f}	0.736_{d}	1.179_{c}
85	3.635_{ef}	0.589_{c}	1.084_{b}
90	3.6_{d}	0.54_{b}	1.165_{b}
95	3.4_{b}	0.441_{a}	0.939_{ab}
100	3.37_{a}	0.343_{ab}	0.869_{a}

3.1.1 Terminal velocity

Terminal velocity of melon seeds vary with drying temperature. As the temperature increased from 30^{o}C to 100^{o}C, terminal velocity decreased from 7.45 to 3.37m/s. At 30^{o}C, 35 and 40^{o}C terminal velocities were 7.415, 7.135 and 6.32m/s respectively. The terminal velocity was 5.95m/s at 45^{o}C and decreased by 1.1, 5.5, 10.6 and 12.5% as temperature increased to 50, 55, 60 and 65^{o}C respectively. Terminal velocities of melon seeds were 4.88, 4.57, 4.1, 3.635 and 3.6m/s at temperature of 70, 75, 80, 85, and 90 respectively. At temperature of 100^{o}C, the terminal velocity was 3.37m/s while at 95^{o}C, the terminal velocity was 3.4m/s.

3.1.2 Drag force

The drag force of melon seeds was 1.567N at 30^{o}C and 0.343N at 100^{o}C. at 35, 40, 45, 50, 55 and 60^{o}C, the drag force of melon were 1.472, 1.349, 1.275, 1.777, 1.079 and 0.981N respectively. Drag force decreased from 60^{o}C drying temperature to 65^{o}C by 10% and slightly increase by 0.1% from from 65 to 70^{o}C thereafter fell to 0.785N at 75^{o}C; 0.736N at 80^{o}C; 0.389N at 85^{o}C and 0.54N at 90^{o}C. The drag force of melon seed at 95 and 100^{o}C were 0.441 and 0.343N respectively.

3.1.3 Drag coefficient

As melon drying temperature increased from 30 to 50^{o}C, the drag coefficient rose from 0.734 to 0.79. At 55^{o}C, 60, 65, and 70^{o}C, the drag coefficients were 0.852, 0.832, 0.736 and 0.91 respectively. Mean drag coefficient was maximum at 90^{o}C (1.165) and minimum at 30^{o}C (0.734). Drag coefficient values were 0.993, 1.084, 1.165, 0.939 and 0.869 at drying temperature of 75, 85, 90, 95, and 100^{o}C respectively.

3.2 Thermal Properties

Table 2 shows the summary result of the mean values of the thermal properties of melon seeds at varying drying temperature.

3.2.1 Specific heat capacity

The mean specific heat capacity of melon seed was maximum at 30^{o}C (2.995KJ/Kg/K) and minimum at 100^{o}C (1.596KJ/Kg/K). Specific heat capacity decreased (2.8, 2.376, 1.906, 1.848, 1.811 and 1.785 KJ/Kg/K) with increasing temperature (35, 40, 45, 50, 55 and 60KJ/Kg/K). The value of specific heat capacity at 65^{o}C (1.766KJ/Kg/K) decreased by 0.9%, 1.6, 2.2 and 2.6% at 70, 75, 80 and 85^{o}C respectively. At 90, 95 and 100^{o}C, the specific heat capacity values of melon seeds were 1.655, 1.611 and 1.596KJ/Kg/K respectively.

3.2.2 Thermal heat conductivity

Thermal heat conductivity of melon seeds decreased between 30^{o}C (3.62W/m/K) and 40^{o}C (1.1W/m/K). Thereafter increased to 1.83W/m/K at 45^{o}C. It later decreased again from 50^{o}C (1.725W/m/K) to 100^{o}C (0.46W/m/C) by 73.3%. It has maximum value at drying temperature of 30^{o}C (3.62W/m/K) and a minimum value at 100^{o}C (0.46W/m/K).

3.2.3 Thermal heat diffusivity

The thermal heat diffusivity of melon seeds was maximum at 30^{o}C ($6.19\times10^{-5}m^2/s$), minimum at 100^{o}C ($1.16\times10^{-6}m^2/s$); $2.17\times10^{-5}m^2/s$; $1.21\times10^{-5}m^2/s$; $7.97\times10^{-6}m^2/s$; $5.89\times10^{-6}m^2/s$ and $4.71\times10^{-6}m^2/s$ at 35, 40, 45, 50 and 55^{o}C respectively. The thermal conductivity of melon seeds decreased with increased temperature. It was $3.55\times10^{-6}m^2/s$,

3.06×10^{-6}m²/s, 2.68×10^{-6}m²/s, 2.19×10^{-6}m²/s, 1.79×10^{-6}m²/s, 1.62×10^{-6}m²/s, 1.49×10^{-6}m²/s and 1.26×10^{-6}m²/s at drying temperature of 55, 60, 65, 70, 75, 80, 85, 90, and 95°C.

Table 2. Mean values of the thermal properties of melon seeds at varying temperature

Temperature (°C)	**Specific Heat Capacity (KJ Kg^{-1} K^{-1})**	**Thermal Heat Conductivity (W m^{-1} K^{-1})**	**Thermal Heat Diffussivity. (m^2 s^{-1})**
30	2.995_k	3.62_l	6.19E-05_o
35	2.8_k	1.545_l	2.17E-05_n
40	2.376_k	1.1_{kl}	1.21E-05_m
45	1.906_{cj}	1.83_k	7.97E-06_l
50	1.848_j	1.725_k	5.89E-06_k
55	1.811_i	0.64_j	4.71E-06_j
60	1.785_h	0.605_i	3.55E-06_i
65	1.766_g	0.555_h	3.06E-06_h
70	1.75_{fb}	0.53_g	2.68E-06_g
75	1.738_e	0.52_f	2.19E-06_f
80	1.728_d	0.505_e	1.79E-06_e
85	1.72_c	0.5_d	1.62E-06_d
90	1.655_c	0.499_c	1.41E-06_c
95	1.611_b	0.49_b	1.26E-06_b
100	1.596_a	0.46_a	1.16E-06_a

3.3 Statistical Analyses of Results

3.3.1 Aerodynamic properties

At 5% probability level, the mean values of terminal velocity of melon seeds at 30, 35, 40 and 45°C are statistically non significant. These values are significantly different from the mean terminal velocity value at 45°C (5.95 m/s). The mean value of terminal velocity of the seeds at 45°C is non significant from the value at 50°C (5.885m/s). The mean terminal velocity value of melon seed at 55°C (5.62m/s), 60°C (5.32m/s) and 65°C (5.205m/s) are all non significant from each other but the terminal velocity value at 65°C is significant from the values at 55°C and 60°C. It is non significant from the value at 70°C (4.88m/s). The values of terminal velocity of melon seeds at 75°C (4.57m/s), 80°C (4.1m/s) and 85°C (3.635m/s) are all the same statistically. The value of terminal velocity at 85°C is different statistically from those at 75°C and 80°C. The terminal velocity values of melon seeds at

90°C (3.6m/s), 95°C (3.4m/s) and 100°C (3.37m/s) are all statistically significant from one another at 5% probability level.

The mean drag force values of melon seeds at 30°C, 35°C, 40°C and 45°C are all statistically non significant. The drag force value at 45°C (1.275N) is significant from values at 30, 35 and 40°C but statistically the same with the drag force value at 50°C (1.777N). Mean drag force values at 55°C (1.079N), 60°C (0.981N) and 65°C (0.883N) are all statistically the same at 5% probability level, but for the value drag force at 65°C which is significantly different from those at 55°C and 60°C respectively. The drag force values at 70°C (0.884N), 75°C (0.785N), 80°C (0.736N), 85°C (0.589N), 90°C (0.54N) and 95°C (0.441N) are all significantly different from one another at 5% probability levels. However the drag force value of melon seed at 100°C (0.343N) is non significant with value at 90°C and 95°C respectively.

The mean values of drag coefficient of melon seeds at 30°C (0.75), 35°C (0.801), 40°C (0.869) and 45°C (0.925) are statistically the same, but the mean drag coefficient value at 45°C is different is different statistically fro 30, 35 and 40°C respectively. However, the same with the drag coefficient value at 50°C (0.99). The mean drag coefficient value at 55°C (0.852), 60°C (0.832) and 65°C (0.736) are all statistically significant, but the drag coefficient value of melon seed at 65°C, 70°C and 75°C are all non significant at 5% probability level. Mean drag coefficient value of melon seeds at 75°C (0.993) and 80 (1.179) are non significant. Drag coefficient values at 85°C (1.084), 90°C (1.165) and 95°C (0.939) are all non significant. The values of drag coefficient of melon seeds at 95°C are significant from values at 85°C and 90°C respectively.

3.3.2 Thermal properties

Specific heat capacity of melon seeds decreased with temperature, The mean values of the specific heat capacity of melon seeds was maximum at 30°C (2.995 KJ/Kg/K). and minimum at 100°C (1.596KJ/Kg/K). The values were all significantly different at the different temperature levels. However, the specific heat capacity at 85°C (1.72KJ/Kg/K) and 90°C (1.655KJ/Kg/K) were not significant ($p \leq 0.05$)

The mean values of thermal heat conductivity of melon seeds at 30°C (3.62W/m/K), 35°C (1.545W/m/K) and 40°C (1.1W/m/K) are non significant. The thermal heat conductivity of melon seeds at 45°C(1.83W/m/K) and 50°C are non significant at 5% level of probability. However, the thermal heat conductivity value of 1.1W/m/K at 40°C are significant from the values at 30°C, 35°C, and 45°C, 50°C respectively. The thermal heat conductivity value of melon seed at 55°C (0.64W/m/K), 60°C (0.605W/m/K), 65°C (0.555W/m/K) and 70°C (0.53W/m/K) are all significant. The thermal heat conductivity value of melon seeds at 75°C (0.499W/m/K), 95°C (0.49W/m/K) and 100 (0.46W/m/K) are all significantly different from one another at 5% level of probability.

All the thermal heat diffusivity values of melon seeds (m^2/s) are significantly different from one another at the different drying temperature levels (30 to 100ºC)

4. CONCLUSIONS

4.1 Conclusions

Increase in temperature reduced the values of terminal velocity and drag force of (egusi) melon seeds while it increased the values of the drag coefficient. The terminal velocity attained its maximum value which was found to be 7.414 m/s at the temperature of 30ºC, and attained its minimum value which was 3.37m/s at 100ºC. The drag force of the melon seed attained its maximum value of 1.777N at temperature of 50ºC and minimum value of 0.343N at temperature of 100ºC. At 35ºC, 40ºC and 45ºC, the drag force values were 1.472N, 1.349N, and 1.275N respectively. Drag coefficient has a maximum value of 1.179 at temperature of 80ºC and minimum value of 0.743 at temperature of 30ºC.

For thermal properties, as temperature increased, the values of specific heat capacity and the thermal conductivity of the melon seed decreased. The specific heat capacity attained its maximum value at temperature of 30ºC with a value of 2.995KJ/Kg/K, while it attained its minimum value 1.596KJ/Kg/K at temperature of 100ºC. The thermal conductivity was maximum at 30ºC with a value of 3.62W/mºK and minimum at 100ºC at a value of 0.46W/mºK. The thermal diffusivity attained maximum value of $7.97\times10^{-6} m^2/s$ at a temperature of 45ºC, and minimum at 100ºC with a value of $1.1\times10^{-6} m^2/s$.

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Development and Design of an Ergonomic Chair for *Gari*-frying Workers

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ABSTRACT

Most manual work are done on the workbench or table for assembly work in the industry. It is also observed most processing job on- or off-farm are also supposed to be carried out using this seat for ergonomic compliance with its attendant benefits. To this end, a sit-stand ergonomic chair has, therefore, been developed and designed for the teeming population in the *gari*-frying industry, to overcome the inherent challenges. Seventeen anthropometric data were collected from 120 subjects in the southern Nigeria. These data were analyzed and used to design and construct the workstation for a sit-stand worker who will be able to use both hands to overcome the traditional asymmetric, awkward posture of workers in the industry .The components of the chair designed for include the seat pan, height, width, depth, armrest and backrest. Features of this chair include adjustability. Other work-related injury associated with the job has been drastically minimized and eliminated in some instances. Its adoption is made easy, since operation is similar to what workers were used to with added ease of maintenance as it simulates the traditional method of production and is relatively cheaper than available mechanical fryers. This is recommended for other workers with similar work method in other food processing industries.

Keywords: Workstation, *Gari*-frying, Cassava processing, Work-related musculoskeletal disorders, Anthropometry, Ergonomics.

1. INTRODUCTION

Posture is the relative orientation of parts of the body in space. Everyone performs activity in a particular posture. It is a basic requirement in workplace design. The work under consideration usually determines the posture best suited to the task. For example, one may require large force to perform certain tasks or do fine job requiring one to have close look at the job at hand, it may require that one maintains a particular position for hours performing certain tasks. In all these, working posture must be well designed, otherwise job performance would be hindered or efficiency would be low. Sometimes, injury would occur frequently engendering work-related musculoskeletal disorders.

Unfortunately, some of the problems resulting in unsuitable working posture do not actually occur immediately; they are cumulative traumas resulting in musculoskeletal disorders. These include awkward posture, repetitive loading, contact stress, etc. For example, awkward posture is the position of the body that deviates significantly from the neutral position while a work system is being used or tasks are being performed. Spinal motion segments are susceptible to extreme postures at work. But fortunately and interestingly, these problems lend themselves to ergonomic interventions which are mostly simple and cheap to apply.

The need for body movement during work has been emphasized, without which one is only involved in static work (Pheasant, 2003). We often sit because of fatigue that arises from standing. Sitting is a more efficient way to perform many occupational and non-occupational tasks. Sitting in many jobs makes good sense, as it relieves the body's supporting muscles, offers them a chance to rest, and is less demanding on the blood circulation to the legs. Sitting allows the chair, to support the seated person's body mass. For all this said, it must be realized that the body was designed not to sit, but rather to move.

For people who spend a large part of their day in one position for a long time, this can lead to a number of problems. These problems can happen so slowly that one hardly notices, but it is often difficult to undo some of the damage that poor posture can cause once it is done. Poor posture in sitting can lead to muscle shortening – pressure ulcers (sores) – pain, increased spasms, breathing difficulties, loss of balance and problems keeping your head upright, among others.

Common working postures are sitting, standing and alternating between sitting and standing. Workers take one or a combination of these postures during work, and this must be designed to ensure work is done in a comfortable posture that, not only facilitate the work done, but also preserve the health of the worker. Incidentally, the working posture most prevalent is sitting. That the most common working posture is sitting is very glaring, going by our daily activity and many physical engagements. Examples abound to establish this point. When in transit during transportation, the posture usually adopted is sitting, whether in the aircraft, in an automobile or at sea in boat, ship or ocean liner. Some of these travels take hours in transit and the posture usually taken is sitting, whether one is the driver or the passenger. When resting, apart from reclining, the posture normally taken is sitting. Many processing tasks on-/off- farm as well as in the industry require sitting posture all-through. Only in cases where large forces need be applied or any other special requirements are necessary is where posture other than sitting is usually adopted and that often takes less time compared to sitting posture at work. Hence tasks requiring sitting posture must be adequately designed for. For sitting posture, ergonomic chair must be designed to mitigate the inherent musculoskeletal problems.

An estimated 50% of people in the industrialized world suffer some form of back complaint and many of these are related to poor seat design. How we sit and what we sit on affects the health of the spine. The lumbar region is the most frequently damaged (L4 and L5). The vertebrae in the lumbar region are the largest in the spine (CUErgo, Cornell University Ergonomic Web). The purpose of seat is to provide stable bodily support in a posture that is comfortable over a period of time, physiologically satisfactory, and appropriate to the task or activity in question. All seats are uncomfortable in the long run, but some seats become uncomfortable more rapidly than others, and in any particular seat, some people will be more uncomfortable than others. Comfort may also be influenced by the task or activity that the user is engaged in at the time. In other words, comfort (or more strictly the rate of onset of discomfort) will depend upon the interaction of seat characteristics, user characteristics and task characteristics.

Satrika and Dawal, (2011) while investigating the physiological effects of standing using a sit/stand stool and standing with a footrest during sorting tasks, showed that using the sit/stand stool and footrest reduced the perceived discomfort and percentage maximal voluntary contraction (% MVC).

There are three types of chair namely, fixed posture chair, dynamic chair and combined chair. Depending on chair and posture, some proportion of total body weight is transferred to the floor via the seat pan and feet, armrests and back rests. When sitting, the pressure fall on to the two small "sit bone" or ischial tuberosities. Compressive stresses are exerted on areas of buttocks beneath the tuberosities. When sit upright, approximately two-thirds of body weight is distributed to the chair seat, with the backrest, armrest and floor supporting the remainder.

When sitting, weight is transferred to a supporting area by the ischial tuberosities. Chairs remove weight from the feet to maintain a stable posture. Muscles not directly involved with the work can then relax. Ideally, there is no single ideal sitting posture. It is impossible to design a chair for the best single way to sit. We need a variety of chairs that allow different users to each sit in a variety of postures.
Ergonomic sitting is a comfortable working posture with neutral alignment of all your joints from head to toes. When done correctly, it helps to reduce the stress and strain on the muscles, tendons, and skeletal system thus reducing the risks of developing ergonomic problems.

Helander et al (1995) investigated the ease of adjustability of 'ergonomic chairs' classified according to their different control features. They discovered that control discernibility and users feedback significantly influenced users' understanding of adjustability controls. Also, controls with long levers were preferred to short ones, while the chair with the greatest number of adjustability controls took significantly greater time to adjust and was also judged to be the most comfortable. Onawumi and Lucas (2012) explored participatory ergonomics to determine ergonomic mismatch of seats in imported vehicles used as taxicabs in Nigeria. The ergonomic mismatch was established and the data collected served as the required data for the Nigerian population using the imported vehicles and was recommended for future use as criteria for suitable automobiles for the Nigerian population.

Niekerk et al (2012) investigated the influence of chair modifications as an intervention involving 293 participants who were involved in predominantly seated occupations where the outcome measure included neuro-musculoskeletal comfort and/or postural alignment. The jobs included garment factory, office environment as well as university students. Findings indicated a consistent trend that supports the role of a chair intervention to reduce musculoskeletal symptoms among workers who are required to sit for prolonged periods.
Ergonomic chair design provides easily adjustable and accessible features for seat height, backrest and level of lumbar support, and seat inclination. It gives stability by providing good support to the buttocks via the seat pan and to the back via the backrest. It allows the seated person to freely move within the seated position.
Basic features of well design ergonomic chair include a seat height that is easily adjustable and had pneumatic pedestal base; ability of user to easily make all adjustments while seated; good lumbar support; a backrest that adjusts vertically to support the lumbar spine as well as in an anterior – posterior direction and that is narrow enough to allow freedom of arm movement without chair interference; dynamic movement options of the backrest and seat pan; a seat pan with a curved front or waterfall edge to reduce pressure behind the knees.

In this paper, an ergonomic chair for sitting posture in the *gari*-frying task was designed for, after determining the best posture for the task (Samuel, 2011 and Samuel et al, 2011). In the research undergone by Samuel and Samuel et al, four working postures were identified namely as sitting beside, sitting in front, standing and alternating between sitting and standing, and these were analyzed using Cornell's Discomfort Rating, Rapid Upper Limb Analysis and Ovako Working Posture Analyzing System, among others. The result of analyses concluded that alternating between sitting and standing is the most efficient and best posture for the *gari*-frying task.
Ergonomic sitting implies comfortable working posture with neutral alignment of all joints from head to toes. It helps to reduce the stress and strain on the muscles, tendons, and skeletal systems, thus reducing the risk of developing a ergonomic problems (Pheasant, 2003).

2. MATERIALS AND METHODS

A sample size of 120 *gari*-frying workers, without any noticeable physical disability were randomly selected from six states (Lagos, Oyo, Ogun, Osun, Ondo and Ekiti – 20 from each) in the southwest of Nigeria. The age range of the women processor is between 18 and 67 years (mean = 42.36 years; standard deviation =12.02). Seventeen body dimensions were collected following standard procedure (Samuel 2015, 2016). The instruments used include Vernier Caliper, Stadiometer and measuring tape. The mean of three measurements were taken in each case these data were later analysed using Microsoft Excel Package following standard procedure (Samuel et al, 2015, 2016). These data were used in the design of a sit-stand ergonomic chair for the use of the *gari*-frying population in Nigeria. Parameters in the data collected included weight, height, shoulder height (sitting), eye height (standing), eye height (sitting), sitting height, buttock-popliteal length, buttock-to-knee length, popliteal height (sitting), knee height (sitting), thigh clearance, forearm-to-forearm breadth, waist depth, elbow rest height (sitting), knuckle height, hip breadth and lumbar height. Descriptive statistical analysis was performed on the data collected to show the range, mean, standard deviation and percentiles of the parameters. These were used to specify the chair dimensions for the design, following standard procedure.

The components of the chair include seat height, seat width, armrest, seat depth, seat pan and backrest. These were designed for using ergonomic criteria stated in Pheasant (2003)

5. 3. RESULTS AND DISCUSSION

3.1 Anthropometric Data for Ergonomic Chair Design

Table 1 shows anthropometric data collected and the resulting statistical analysis. Seventeen anthropometric data relevant to the design of ergonomic chair for the gari-frying population in the southwestern Nigeria were collected and statistically analyzed. The resuting descriptive statistics gives the summary of the body dimensions which were used to fit the chair to the users as is the requirement of ergonomic design for work systems. From Table 1 are used appropriate percentiles corresponding to the particular feature of chair design.

3.2 Seat Height

Seat Height = 5th %ile Popliteal Height is suggested, that is, 360.1mm from Table 1 (Pheasant 2003). This is for normal (conventional) sitting, where the angle between knee and the leg is usually taken to be 90^{o}. However, for a sit-stand operator the angle is normally > 90^{o}, and this also depends on the work surface and the activity in question, since these must match each other for compatibility. In this case (*gari*-frying), the work surface is higher than 500mm and the work surface for stirring must be 5%ile knuckle height with given clearance equal to elbow height.

Table 1. Anthropometric Data for Ergonomic Chair Design

Parameters	**Mean**	**S.D.**	**Min**	**Max**	**Percentiles**						
					2	*5*	*25*	*50*	*75*	*95*	*98*
Weight (kg)	63.37	17.11	38	126	38.42	43	50.13	60	74.63	93	107.86
Height	156.78	5.8	141	170	144	146.05	153	157	160	166	168.74
Shoulder Height (sitting)	54.87	2.03	49.35	59.5	50.4	51.12	53.55	54.95	56	58.1	59.06
Eye height (standing)	144.75	5.66	132	160	132.42	134.05	141	145	149	154	156.9
Eye height (sitting)	67.1	3.71	58.4	76.9	58.48	60.13	64.9	67.4	69.05	73.39	76.22
Sitting height	78.11	3.95	60.8	87.4	69.54	70.21	75.9	78.4	80.9	83.4	86.72
Buttock-popliteal length	49.22	2.93	40.9	56.7	41.78	44.91	47.2	49.1	51.05	54.5	55.94
Buttock-to-knee length	58.15	3.27	50.4	66.8	50.73	52.25	56.1	58.2	59.9	64.07	65.95
Popliteal height (sitting)	40.03	3.21	34.3	59.4	35.28	36.1	38.13	39.75	41.6	45.34	48.23
Knee height (sitting)	50.74	2.61	40.92	58.4	44.55	46.1	49.2	50.85	52.4	54.8	55.77
Thigh clearance	13.44	2.21	7.4	18.9	9.11	10.1	11.9	13.2	14.9	17.77	18.61
Forearm-to forearm breadth	42.98	5.49	29.24	59.81	31.57	35.16	39.44	41.97	46.72	52.59	56.05
Waist depth	26.2	3.06	12.3	34.2	18.43	21.45	25.03	26.18	27.48	32.05	33.7
Elbow rest height sitting	17.96	3.08	12.2	39.6	12.79	14.31	16.1	17.65	19.28	22.1	23.77
Knuckle height	68.88	3.34	60	77	61.42	63	67	69	71.2	74	75
Hip breadth (sitting)	31.14	3.53	23.63	41.34	25.36	26.16	28.29	30.66	33.64	38.13	39.91
Lumbar height	16.66	2.77	10.5	22.6	11.23	11.91	14.4	16.85	18.4	21.4	22.33

The seat dimensions were designed as follows:

Using knuckle height at 5%ile = 630mm (from Table 1) as maximum and taking 5%ile elbow rest height (143.1mm) as the clearance. The required height is approximately between 500mm and 600mm. Hence the seat pan was made adjustable to rotate along its axis, giving a range of about 100mm swivel along a hinge-like frame created by making the seat pan swing on the rigid pipe frame as with a welded joint on the chair frame between the backrest and the backleg frame of the chair. To achieve this a seat height of 600mm was used.

3.3 Seat Width

For the seat width, 95%ile of the hip breadth (380mm – from Table 1) was adjusted for clearance for clothing. Hence 400mm was used, while the seat pan of 360mm was used to give clearance for the swivel and other body movement.

3.4 Armrest

Armrest was deemed unnecessary for working posture, more so in this case when the user has to swing both hands through the whole length of the arm reach on the given work surface (curved frying pan).

3.5 Seat Depth

Seat Depth= 5^{th} %ile Bottom-popliteal length (449.1mm from Table 1) is suggested.
This is for the conventional sitting posture. However, for a sit-stand posture, sitting and exit from seat must be enhanced, hence it must not be too deep, that is, it must be less than this value, making it shorter, to satisfy this requirement and at the same time enable the user to use the backrest. Hence a shorter one of 400mm was used.

3.6 Seat pan

As for the seat depth, the size is determined also determined by it. Here the seat pan was made a little smaller to create clearance for swivel. Hence 360mm was used. We note that this eventually gives 400mm with the clearance given to maintain the seat depth used. The adjustability created allows the user to tilt the seat pan as desired or as work demands, which also makes for easy sitting and exit as required.

3.7 Backrest dimensions

A low-level backrest was used to provide support for the lumbar and lower thoracic region and only finishes below the level of the shoulder blades, thus allowing freedom of movement for the shoulders and arms. 5%ie of shoulder height (511.2mm from Table 1) is suggested. However, the sit-stand posture required and the demand of the work in this case required a rather shorter backrest. Hence 442mm height was used and the backrest framework was constructed accordingly. This was also made adjustable such that it can swing (swivel) along a rigid frame and support the lumbar of many workers in the industry as adjusted to their specific need. This also takes care of the backrest angle or rake, which is an obtuse angle, required for the design as this is determined by the particular worker

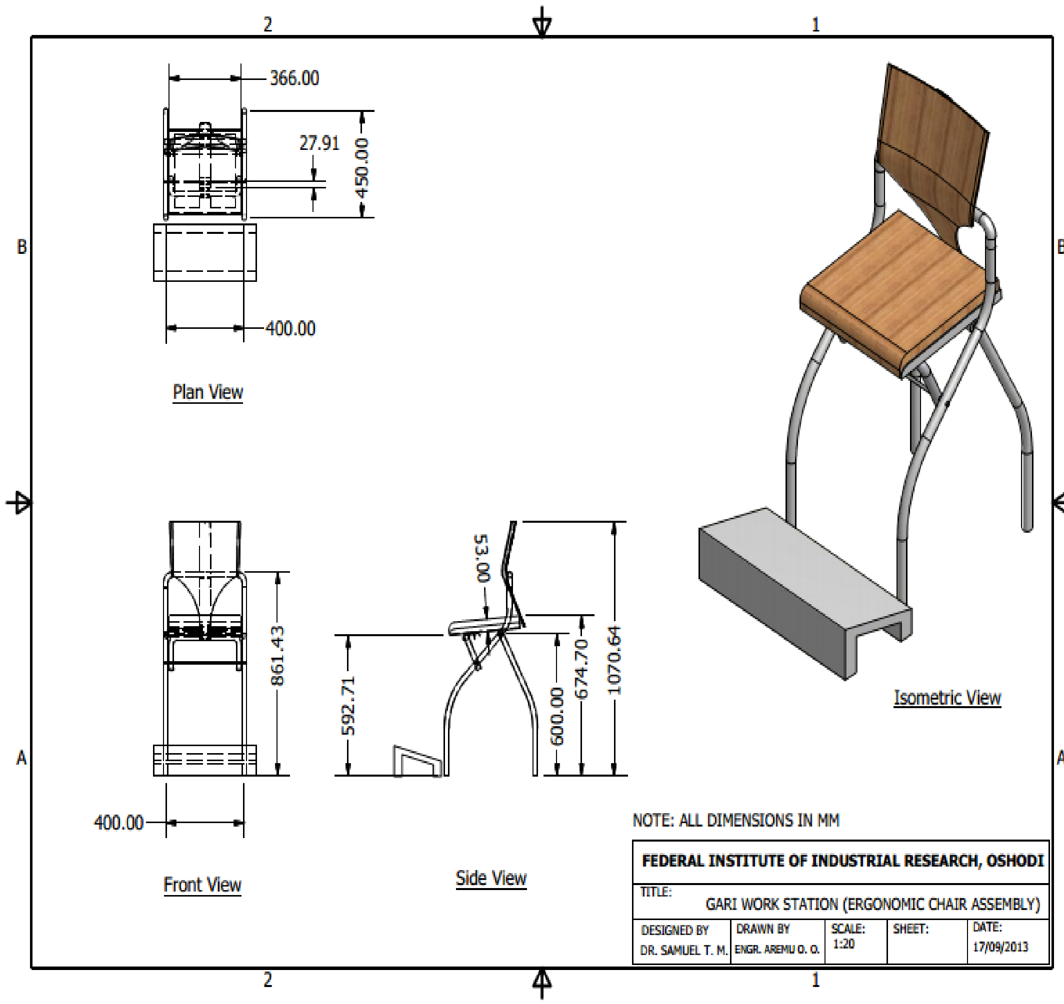

Figure 1: Ergonomic Chair Design Drawing for a Sit-stand Worker

Plate 1: Ergonomic Chair Picture for a Sit-stand Worker

4.0 DESCRIPTION AND OPERATION OF THE SIT-STAND ERGONOMIC CHAIR

The main frame of the chair consists of a 25mmØ hollow rod bent to shape to create the leg frame seat pan rest and frame for the short backrest. The seat pan consists of a 25x25mm angle iron joined to form a 360 x360mm square base to accommodate wood and cushion framework to be accommodated inside it. At the back side of the seat pan angle frame are two rings 22mmØ for a solid pipe to pass through which would create the swivel designed for adjustability. Along the length is passed a flat bar to serve as brace for the formwork of the seat pan to accommodate the cushion to be fixed inside under which three rings cut in a semi-circle frame were made so the adjustment to be done easily by the user at three levels through a pipe attached to the leg frame of the main frame of the chair to pass through when the user is to adjust the sit to the desired height. This incoming pipe was made such that it is curves and terminates at the base frame of the chair legs and pinned to that point where it would be easily slide along its axis for the desired adjustability.

Taking cognizance of the fact that the seat may be too high for some short workers, a footrest is provided for such user. It implies, only few users would actually use the footrest and that would be required just when seated; the tall users may not really need the footrest. The backrest framework made of cushioned woodwork was attached to the back frame of the main frame. With a convex shape, a flat bar frame was also attached to it, curved at a measured angle for the lumbar support with a ring at the centre curvature along which the hollow pipe of the main frame passed so it can freely swing along that axis, which creates another adjustability for the lumbar height, backrest height as well as the seat pan height as earlier discussed: by implication, both adjustability of the seat pan and the backrest work together; yet the seat is fixed as soon as the user adjusts the two swivels of seat pan and backrest and begins to work. The flat bar and the cushioned woodwork for the backrest were made such that the middle of the curvature always support the user's lumbar as reclines on the backrest. the space created in-between the backrest and the seat pan the automatically allows the user's buttock to protrude a bit backwards such that the lumbar is always supported at all times when the seat is used. Even then, a protrusion of the flat bar frame for the backrest cushioned woodwork also protects the user such that there is not sharp edges or get the buttock stuck in the seat.

When the user rises from the seat, the backrest may close, since it swings freely until the user sits. A comparatively shorter seat depth was used different from the conventional seats for workers taking sitting posture who has to be on the seat fully throughout work or rest.
This adjustability does not only make the chair more comfortable, it also enables the sit-stand posture to be achieved easily, since the worker does not sink in the seat (for more

seat depth) nor always tempted to be thrown out of it (for very low seat depth), adjustability of the seat at an angle bending downward for forward movement facilitates the worker's sit or stand posture.

Though fully ergonomic by design, it is a simple design with simple materials and durable too for reliability, more so as is required in the rural setting where this should be used. It is also foldable (the seat pan and the backrest), leaving only the frame fixed as it were. Materials for the construction is also very light consisting of pipes of light gauge, wood and cushion – only the angle iron for the seat pan frame and the flat bar of the backrest frame are a little heavy, but both are foldable. Hence movement from one place to the other becomes very easy. This can be easily manufactured by rural artisans when dimensions are fixed and curvatures are well specified.

6. CONCLUSION

A sit-stand ergonomic chair has been designed for *gari*-frying workers using 17 worker anthropometric characteristics of the southwestern Nigerian population. The seat pan, height, width, depth, armrest and backrest were designed for for gari-frying population of the Southwestern population of Nigeria. The adjustability of the chair is at the backrest and seat pan height; also at the lumbar height. This further improves the usability of the chair among the population designed for and beyond, since every user can adjust to suit their personal characteristics. This chair is capable of mitigating against the incidence of musculoskeletal disorder associated with the job by virtue of awkward posture and the rapid fatigue of the job without the chair or with long sitting posture (static work). This chair can also be used in other jobs, where bench work is required similar to this processing job either on/off farm as well as in the industry, with the ultimate aim of improving productivity and enhancing health of the worker.

7. ACKNOWLEDGEMENT

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Sukhiyaji Rajal Ergonomics in Sitting Posture. Sports Science

Fabrication of Manual Materials Handling Mechanism for Lifting and Feeding of Cassava Mash

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ABSTRACT

Manual materials handling (MMH) devices like jigs and fixtures are required for transporting or positioning materials in large-scale operations. An MMH device was designed to feed cassava mash into fry pan during batch *gari*-frying. Flow is facilitated through the tapered outlet of a 40 kg-capacity hopper while lifting is achieved by turning a triple-start screwed shaft handle, housed in a u-steel channel framework with wide rigid base that can support holding content in position without buckling. Feeding is done until the content is exhausted ready for reloading. It can deliver more than 160 kg/hr depending on the fry pan capacity and working rate. The worker avoids stretching, bending and twisting the trunk or the neck, or move round more frequently for reloading, thus overcoming the stated ergonomic risk factors and slowness of the work process. The device is also adaptable to other tasks requiring similar feeding mechanism.

Keywords: lifting device, manual materials handling, *gari*-frying, ergonomic risk factor, industrial operations, cassava processing

1. INTRODUCTION

Manual materials handling (MMH) is a component of many jobs and activities undertaken in life. Typically, it involves lifting, lowering, pushing, pulling and carrying objects by hand. Loading and unloading trucks, carts, boxes or crates; moving parts or assemblies from one place to another; loading paper to the copier or picking binders from an overhead shelf; lifting patients from a bed or transporting them in a wheelchair are typical MMH activities found in work settings.

In the *gari*-frying task, the work involves mainly collecting the grated cassava mash and pouring into the fry pan, fried/cooked while stirring and then discharge for bagging. Whether in sitting or standing posture during loading of the fry pan, the processor often bends, stretches and twists to get the mash usually by her side, then turns to pour into the fry pan. She does this for all batches required to be fried. Similar activity is involved in other unit operations prior to frying – peeling, washing, grating, pressing/dewatering, pulverizing. – which results in rapid fatigue and body discomfort. The one thing all these tasks have in common is the potential to result in some adverse health effect, from simple cuts, bruises and sore muscles to more serious occupational health diseases of low back pain (LBP). Based on available statistics, almost half of all low back injuries are related to lifting, about another 10 per cent are associated with pushing and pulling activities, and another 6 per cent occur while holding, wielding, throwing or carrying materials (Kadikon and Abdol Rahman, 2016). MMH tasks can be found in most workplaces and they may constitute a risk factor for work-related musculoskeletal disorders (WMSDs) – Mohammadi *et al*, (2013)

Ziaei *et al*, (2017) assessed the postural risk and imposed forces due to manual handling and loading of sugar bags. The study was conducted on male warehouse workers of a sugar manufacturing plant using rapid upper limb assessment (RULA) to assess the risks of awkward postures using computer-aided three-dimensional interactive application to estimate the forces and moments. RULA final scores were estimated to be 7 and 3 before and after the virtual redesign, respectively. They identified the main risk factors as heavy weight and poor control of sugar bags. They posited that virtual redesign can diminish bending and twisting postures, and, therefore, some resulting forces and moments.

Material handling is the movement of material in any direction both vertically and horizontally. In the selection of material handling equipment, a systems approach with the aim of attaining the lowest overall cost for the system as a whole should be adopted. This allows for a trade-off of initial and operating costs, and higher costs in some parts of a system for lower costs in other parts. The net result is usually the lower costs. Hence, the objectives or requirements of materials handling are to save money, save time and save labour by using better methods and equipment (Rene *et al*, 2017).

Igbeka (2013) emphasized the need to mechanize as many material handling operations as possible, if the operation itself cannot be eliminated. For efficiency, there should be a good plant layout. According to him, an efficient plant layout might eliminate many material handling operations or improve them. Typical arrangements of plants include provision for receiving, disposing, processing and conveying. He further categorized factors that will influence plant layout to include methods of operation, lighting and human factors engineering

Nourani *et al* (2017) designed a harvesting aid, a portable dates cluster harvesting machine comprised of stabilizing platform, lifting device, lowering device and cutting device. The lifting device is a telescopic mast extendable with the use of reel and cables actioned by two manual winches and supported by the platform with two mobile joints to make it mobile and fixable. The device is used to raise and lower the cutting device and the basket made of metal ring holding a textile bag, mounted through the basket support at the upper end of the telescopic mast, while the cutting device equipped with a return spring and a draw wire, consists of a rechargeable electric chainsaw mounted on an articulated arm. This is mounted at the upper end of the basket support.

Choi et al (2012) examined physical workloads associated with manual lifting activities and translated the academic research into effective prevention "good practices" for the reduction of injury risks in the construction workplace, using fourteen different construction trades.

Mohammadi *et al* (2013) determined prevalence of MSDs in Iraninan casting workers who performed MMH tasks, using Nordic musculoskeletal disorders questionnaire and the Snook tables. His results showed that hand/wrist symptoms were most prevalent (84%). He, therefore, recommended redesigning the MMH tasks to reduce the identified WMSDs among workers.

Harvested cassava root cannot be stored for too long; it perishes soon after harvesting and mass processing into storeable products is the best way to extend the shelf life of the root. Arching, caking and segregation are commonly encountered flow problems in the pulverizing and sieving. They quantified the flowability of cassava mash on the basis of angle of repose of 28^o at a moisture content of 73% (wet basis) while the pulverized mash with moisture content of 45% (wet basis) had an angle of repose of 49^o. They posited that the angle of repose of cassava mash is moisture content dependent (Kolawole *et al*, 2010, 2014).

Loading constitutes problems in the sense that the processor has to improvise sometimes using a bowl containing less than 40kg of cassava mash. The processor goes through these problems culminating in fatigue due to the ergonomic risk involved. A lifting devise that would hold the load in position for a longer period, eliminate the risk of frequent movement in loading the fry pan, is what is needed for this task. This material handling devise is designed and fabricated to fulfill this purpose.

2. MATERIALS AND METHODS

2.1. Requirements for Feeding Mechanism for the *Gari*-Frying Task

From the research conducted during pilot study, it was discovered that the *gari*-frying process material handling task could be divided into three main tasks excluding the activities that took place before and after frying which were mostly transportation, cooling, sifting and packaging activities. These tasks include loading, stirring and unloading.

2.1.1. Loading

This is the stage during which the grated cassava mash would be poured into the pan for frying. This task continues as long as there is still cassava mash available for frying. Normally for a batch, about 4-5 scoops are poured into the pan for frying depending on the size of the pan.

2.1.2. Stirring

This is the stage that usually comes after loading. It requires a continuous turning process of the *gari* in the pan while frying so as to avoid caking. This continuous process requires stirring for the period a particular batch in the pan would last to cook and dehydrate.

2.1.3. Unloading

This is similar to the loading task, but it involves removal of the fried *gari* from the pan into a container.

The aspect being investigated in this study is that of loading, using MMH method instead of the traditional way of using bowl or other handy container to do it.

3. COMPONENTS OF LIFTING/LOADING DEVICE.

3.1. Hopper

Geometrically, the hopper is cuboidal trapezium (topmost part is cuboid, bottom part is trapezium). It is made of stainless steel sheet metal. The choice of the shape is informed by its flow characteristic such that the hopper would easily empty its content into the inlet end of the fry pan wherein the hopper gate opens for feeding the content in a bid to control the feeding of the fry pan. The hopper is situated on the frame via a u-steel channel framework with base. The hopper and its content is held in a vertical position using a triple-start screwed shaft with handle which the worker turns (anti-)clockwise to cause up-and-down movement.

Capacity of hopper is calculated as follows:

Volume of the cuboid part = 550x400x348 = 76,560,000 mm^3 = 0.76,560,000 m^3

Volume of the trapezoidal part = 210 (400+550)/2 = 99,750 mm^3 = 0.00099750 m^3

Total volume of the cuboidal trapezoid hopper = 0.76,560,000 m^3 + 0.00099750 m^3 =

0.076,659,750 m^3

Bulk Density of Cassava Mash = 553 kgm^{-3} (Kolawole *et al*, 2014)

Mass of the hopper = density x volume = 0.076,659,750 x 553 = 42.396 kg ≈ 40 kg, since the hopper is not expected to be loaded to the brim at work for safe work ethics.

Note that hopper shape and the outlet was specially designed to aid ‘free-flow’ of the cassava mash which is controlled through the gate for each batch.

3.2. The Frame

The frame holds the hopper in position. The triple-start screw shaft, supported by the frame, lifts hopper content with a handle at the top for the processor to turn for the lifting operation after loading. It has a strong base to sustain the content of the hopper. This is made from 50 x 50mm U-channel and covers an area of 570 x 850mm and 1105mm high. The shaft which bears the hopper is held in-between two bearings within which it rotates to lift or lower the hopper. Provision for additional loading of weight was made at the base for balance and stability. There are supports at the side edges to hold the hopper rigidly in position. Figure 1 and Plate1 show the loading/lifting device. The height was made to suit the sit-stand posture of the *gari*-frying workers.

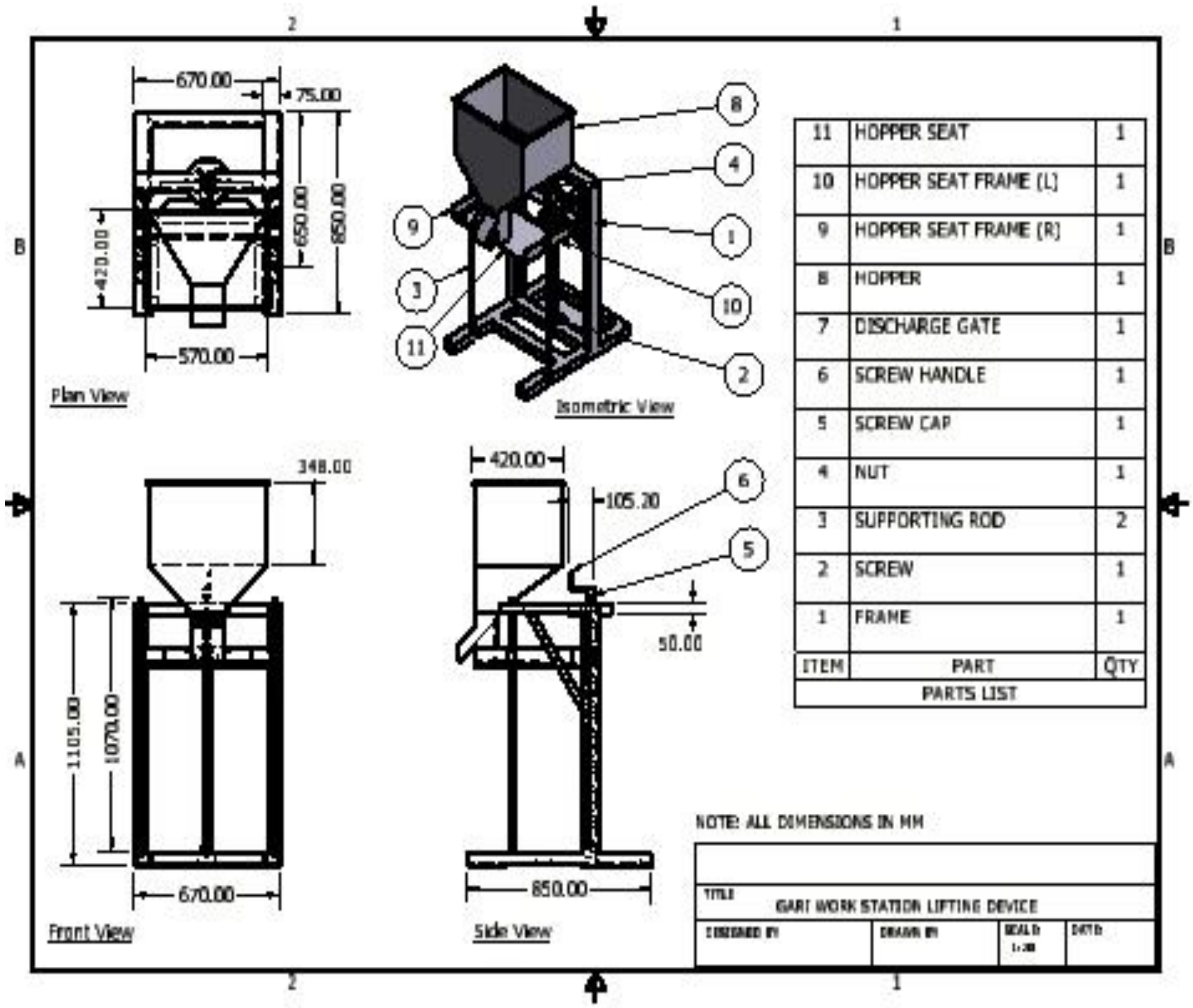

Figure 1: Lifting Device

Plate 1: Lifting Device

3.3. Lifting/lowering mechanism

This consists of a threaded shaft machined and erected on pillow bearings and supported by 12 mm diameter mild steel rod on both sides at the “cantilever” side of the hopper. The advantage of this is in its high capacity hopper and the lifting activity that relieves the worker of unnecessary frequent movements and stress in lifting the material from the floor onto the platform as well as in having to reload the hopper often. All this add to the efficiency of the worker since this device delays the onset of fatigue unlike in the traditional method of directly manual loading.

4. DESCRIPTION OF THE OPERATION OF THE LIFTING DEVICE

The setting of the lifting hopper is at the floor (base of the frame) from where it is loaded with materials and then conveyed up the frame by anticlockwise turning of the handle at the top of the frame. Positioned close to the processor’s seat and the fry pan to be supplied, the hopper is stopped at a height where the outlet of the hopper levels with the fry pan into where it discharges its content. This holds the content which is discharged for each batch of the frying operation when the gate provided is opened and closed for a batch operation. This hopper is designed to hold content more than required for one batch, say for five rounds or more, to minimize the frequency of loading and reloading, lowering and lifting. This process thus saves time and movement of the processor, who may have to complete five batches or more without having to reload, hence once discharge is made easy for the content to flow down a slopy framework provided at the other end of the fry pan, into which the processed cassava mash is emptied, the next batch is allowed into the fry pan without wasting time as in the traditional method where the processor may move from the seat to load the next batch. All that is required is to open the gate and let in the next cassava mash for the frying process.

5. CONCLUSION

A 40 kg capacity lifting device for feeding cassava mash into fry pan has been designed and constructed. Components include hopper, u-steel channel frame, triple-start screwed shaft with handle for up-and-down lifting on a wide rigid base, counterbalanced with weight. Using locally made materials and with simple construction, this has been made to assist the operator in manual feeding of the cassava mash into the fry pan. The simple operating principle of the mechanism and construction makes it possible to be replicated by artisans in the rural areas where this equipment is needed. The lifting device creates higher efficiency for the worker through efficient means of supplying materials as soon as possible as well as allowing more number of batches (5 times or more) to be done without unnecessary movement, transportation compelled to be in an awkward posture (bending, twisting or stretching) usually experienced before reloading the hopper. This saves time and preserves the health of the worker with the overall advantage of improved productivity. This equipment is also adaptable to other jobs with similar job flow.

5. ACKNOWLEDGMENT

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Performance of a Simplified Model Inner-Tube Biodigester for Biomethane Production for Household Use in Nigeria

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ABSTRACT

In the developing countries, methane capture from manures has been encouraged by using biogas plants which are predominantly household anaerobic digesters handling manure of livestock held by an average-sized family. This paper aims to assess the performance of a simplified model inner tube biodigester for biomethane production for household use in Nigeria. This paper also evaluates the biomass conversion technologies tested in the REEF (Renewable Energy Engineering Facility) Lab at the University of Exeter, the UK and the technology readiness level and implementation in Nigeria. Cow slurry and Inoculum were used to evaluate the operational efficiency and feasibility of the model Inner tube digester, with the aim of encouraging its use and adoption in Nigeria and Africa in general to help impact on the Sustainable Development Goals (SDG) on Climate Change and Energy Efficiency targets. The model digester as an option against the use of firewood, Kerosene or Liquid Petroleum Gas (LPG) system could increase the renewable energy potential in Nigeria while retaining organic matter and nutrients for soil replenishment for agricultural purposes. The 12-litre scale Biodigester showed a characteristic pattern of optimum biogas production efficiency and performance when mixed with inoculum, which indicates its prospect for future evaluation and use.

Keywords: Biomass; Inoculum; Cow slurry; Methane; Sustainable Development Goals; Inner tube biodigester

1. INTRODUCTION

1.1 Bioenergy Technology Development Worldwide

Access to affordable, clean energy is a major driver of Nigeria's and the Globe's actualization of the Sustainable Development Goals (SDGs). It also underpins other SDGs since energy access facilitates economic development, food security, health, education and other related objectives (Röder, Thornley, Campbell, & Bows-Larkin, 2014). Nigeria and other African Countries have a wide range of bioenergy feedstocks, which can be combined with a vast array of conversion technologies at a variety of scales to deliver sustainable bioenergy solutions from liquid fuels to cooking gas, and electricity (Andrew, 2014; Mirjam Röder, 2018). Bioenergy systems are already playing a key role in many countries towards achieving their climate change, emission reduction and renewable energy contribution targets (Andrew W, 2017). The term biomass is often referred to as the biodegradable fraction of products, waste and residues from the biological origin; agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of the industrial and municipal waste (Ben-Iwo *et al*., 2016). Biomass contributes to the supply of energy approximately to 12% of the global status of the renewable energy inputs ranging from 40% to 50% in some developing countries (Ben-Iwo *et al*., 2016; Tauseef *et al*., 2013). Despite this enormous and potential opportunity in bioenergy, Nigeria still lags in biofuel production amongst other African Countries such as Ghana, Kenya and South Africa(Ben-Iwo *et al.*, 2016). This paper aims to explore the prospects of a Simplified Model Inner-Tube Biodigester for Biomethane Production for Household Use in Nigeria.

In the last decade, a major part of the globe has witnessed consistent growth in bioenergy, a renewable and environmentally friendly energy source, owing to its usefulness and advances in biodigesters development globally allowing for this technology to become more readily available in different applications worldwide(Thornley *et al*., 2014). Precisely, the success stories of bioenergy are mainly due to the efforts of developed continents like South and North America, Asia, and European nations (Brazil, USA, China, India, Malaysia, the UK, etc.). See Figure 1, the Global trend of methane emissions from the management of livestock manure (Tauseef *et al*., 2013).

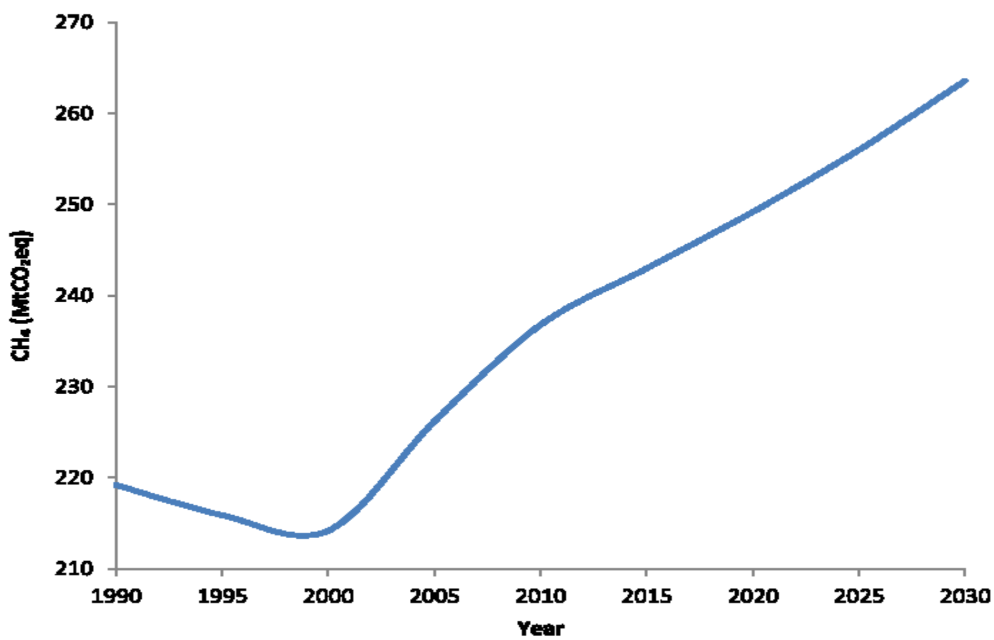


Figure 1. The global trend of methane emissions from the management of livestock manure(Tauseef *et al*., 2013).

1.2 Energy Crisis in Africa and Nigeria

Energy plays a very significant role in the socio-economic development of a region and its people. Over the years, Africa has not only been the poorest continent in the world, but also the only major developing region with negative growth in income per capita between 1980–2000 and till date (Ben-Iwo *et al*., 2016). In the rural communities, fuelwood and charcoal which is sourced from wood biomass is the predominant energy source used in Africa, resulting to about 74% of the total energy consumption for cooking and heating homes, when compared to 37% in Asia and 25% in Latin America (Ben-Iwo *et al*., 2016; Kevin, 2015). Most of the people living in Sub-Saharan Africa (SSA) region lack access to clean, affordable, and environmentally-friendly energy and depend on solid biomass (usually referred to as firewood in Nigeria) to meet their basic needs for cooking (Kumar & Bai, 2005). This has been a major contributor to poverty and a hindrance to the development of the African Continent. Even in recent times, nothing significant has really changed or improved on the biofuel production capacity in Nigeria (Galadima *et al*., 2011). Those living in the rural areas constitute the highest number of users of firewood because of their proximity to the biomass source and fewer regulations and monitoring on deforestation from the Government(Sunset, 2015).

Those in the urban and sub-urban areas who use modern cooking devices like gas cookers, burners, or stoves find it difficult to cope with the rising costs of the energy required to run those devices or systems. Over the year, the rising cost of Liquid Petroleum Gas (LPG) and Dual-Purpose Kerosene (DPK) have made most people living in these mentioned areas to abandon the use of gas cookers or stoves to cheaper alternatives such as firewood and some locally made charcoal powered stoves (Ben-Iwo *et al*., 2016; Sunset, 2015.). For those who persist in using LPG powered gas cookers, most of them buy on credit and pay at the end of the month when they receive their wages from employers. These set of people are usually the credit-worthy Civil Servants who project in Public Service institutions, or private industries where they get paid at month end. The LPG retailers know they are creditworthy and hence could afford to sell on ‘’buy now pay later’’, as it is often referred to in most part of Africa.

In Nigeria more specifically, the case is no different. Despite its rich source of crude oil, it has experienced a slow pace of growth in the bioenergy industry because it is historically plagued by civil unrest and poor government policies on energy supply and security, which are among the main contributor for its poor economic performance in the past and even recently (Ben-Iwo *et al*., 2016). Nigeria has four petroleum refineries with combined crude distillation capacity of 10.7 million barrels per day (bbl./d), an amount that far exceeds the national demand, the country still imports most refined petroleum products because the refineries are moribund (Ben-Iwo *et al*., 2016). This is due largely to the low capacity utilization of existing refineries and the poor government policies as mentioned earlier.

The growing number of oil discoveries in the African continent has had a questionable negative impact on the economies of Nigeria (Ben-Iwo *et al*., 2016). With the growing tensions in Niger Delta oil-rich regions because of the environmental impact of operations of major oil and gas companies (Shell, Agip, Mobil, Total, ADDAX and NNPC), have not helped in making the much-needed progress in the energy sector. Electricity supply from gas-powered turbine has suffered more due to the incessant crisis between the youths and gas companies in the region where the gas is produced. The availability of Dual Purpose Kerosene (DPK) for cooking and used as jet fuel have equally suffered a setback. Oil Companies and suppliers would rather sell to aviation industries or airline operators in the bid to make more money than those who simply use the kerosene to power their stove for cooking and heating purposes.

Biomass is the main energy resource in Nigeria owing to the huge reliance on the energy source for cooking and heating purposes by most of the Nigerian people(Ben-Iwo *et al*., 2016; Thornley *et al*., 2014). According to the global initiative on available, clean and efficient energy - Sustainable Energy for All (SE4ALL), not much progress has been made in providing access to non-solid cooking fuels (like firewood) since 1990. As visible in figure 2, below, in 2010, only 26% of the population had access to non-solid cooking fuels with a big difference between urban and rural areas (Ben-Iwo *et al*., 2016; López-Bellido, 2014). The government of Nigeria have made little or no efforts in trying to remedy these situations because it makes more money through oil exports.

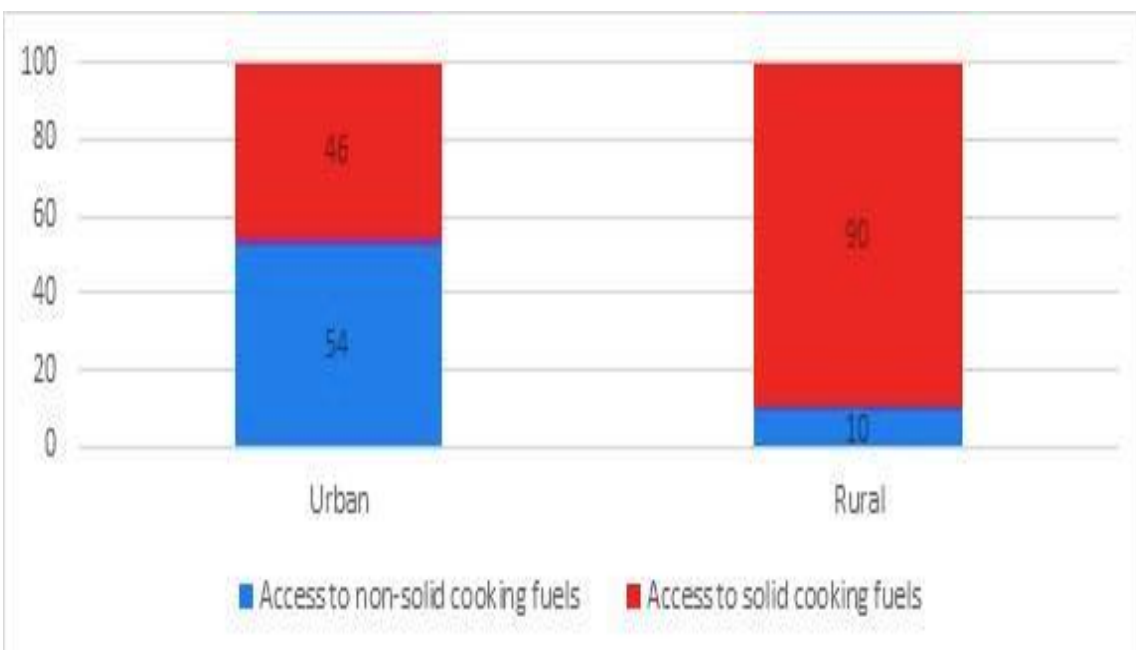


Figure 2. Access cooking fuels in rural and urban areas in 2010 (in %)(Ben-Iwo *et al*., 2016)

Regardless, the profits from oil exports could mean that the government in Nigeria can invest in domestic businesses (like the development of the bioenergy technology) and infrastructure, consequently promoting economic growth and attracting foreign investments(Ben-Iwo *et al*., 2016). However, with the growing concerns of Climate Change and demand to cut down on Green House Gases (GHGs) emissions, Nigeria is making efforts like other countries towards Research and Development(R&D) of alternatives to fossil fuels but these efforts have resulted in little or no major impact or results(Sunset *et al*.,2015). The argument is that the government must seek help from international corporations just like it has done with the crude oil(petroleum) industry. But this is equally not yielding the much-anticipated result like we see in developed countries(Ben-Iwo *et al*., 2016; Nand, *et al* 1991). Hence, in the bid to draw more attention from Government and the people both in the urban and most especially the rural areas, there is a need to design and construct a low cost and small-scale tailor-made bioenergy system that can be used to produce gas (Methane) for cooking, heating purposes thereby creating the much-needed awareness and attention on the feasibility of harnessing renewable energy from solid wastes (renewable energy), and improve on the energy security of the Country.

1.3 Biomethane from Biomass and Solid Waste in Nigeria

Globally, research and development on laboratory and field trials for biofuel systems has significantly increased over the last two decades and has become attractive as the right substitute for fossil fuels(Ben-Iwo *et al*., 2016; Liu & Wu, 2016). This is because of the increasing demand for clean energy, global climate change targets and policies towards reducing dependence on crude oil (Ben-Iwo *et al*., 2016). The processing of biomass into biofuel and its co-products has important effects on international policy and economy, and on rural development. It helps in reducing the overdependence on oil-producing countries and supports rural economies through job creation and an additional source of income(Ben-Iwo *et al*., 2016; Welfle, 2017). The solid biomass(wood) account for about 80% of the total primary energy consumed in rural and suburban communities in Nigeria(Ben-Iwo *et al*., 2016; Simonyan & Fasina, 2013). The Northern Part of Nigeria has the highest number of cattle husbandry and about 95% of these cattle graze in the open with the dungs disperse without proper collection(Ben-Iwo *et al*., 2016; Galadima *et al*., 2011). In the Southern part of the country where we have slaughterhouses (abattoirs) or sites where animals such as cows, goats or sheep (often referred to as Zongo) are sold, this waste is properly collected and could be used as fertilizer or dumped in the open.

Despite the difficulty of Ranching Cattles in Nigeria, cow slurry still holds a lot of prospects to help curb the energy crises in Nigeria(Galadima *et al*., 2011; Tauseef *et al*., 2013). Most especially in the production of biofuel for domestic purposes. It has been

estimated that slurry from animal husbandry produces about 240 million metric tons of carbon dioxide equivalent of methane to the atmosphere and this represents one of the highest anthropogenic sources of biomethane(Simonyan & Fasina, 2013). Since methane is the second highest contributor to global warming after carbon dioxide(Tauseef *et al*., 2013; Zheng *et al*., 2015), it is necessary to explore ways in developing systems to capture as much of the anthropogenic methane as possible and convert them into use. There is a lot of advantage in the capture and utilization of methane: it is clean as a source of energy when compared to natural gas(Tauseef *et al*., 2013), which is predominant in Nigeria and creates major pollution crises in Niger Delta Regions.
The aim of this research project is to explore the prospects of using the inner tube digester to produce biomethane from cow slurry which can be used in developing countries for providing energy to the rural poor. The effect of inoculating the cow slurry in the digester to produce more biomethane was equally investigated. The materials and ease of construction of the digester from locally sourced materials and how the methane can be captured for domestic purposes, in this case, was highlighted.

1.4 Anaerobic Digestion: Steps associated with the generation of methane
Anaerobic digestion is the bacterial fermentation of organic substances in the absence of oxygen. The process leads to the decomposition of complex biodegradable organics in a four-step process (Kevin, 2015) (Fig. 1). The anaerobic digestion of organic material in municipal solid waste or from cow slurry provides renewable energy in the form of biogas (Mata Alvarez, 2003; Kevin 2015) and can also create a means of recycling valued mineral nutrients back to agricultural land (Lukehurst *et al*., 2010). To optimize the latter requires source separation of targeted organics, as the material arising from mechanical pre-treatment, has a high level of contamination, with heavy metal concentrations above the recognized values for agricultural land used in food crop production (Zhang, 2012).

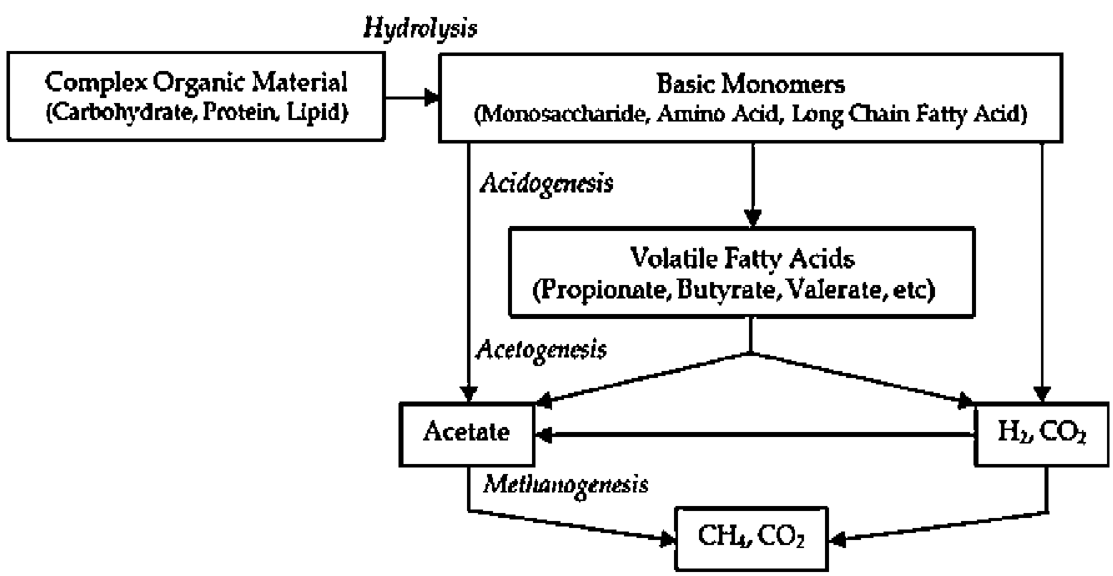


Figure 3.: Steps of the Anaerobic Digestion Process(Tauseef *et al*., 2013)

Food waste from both domestic and commercial sources have been a major source of feedstock for biogas production due to its high biochemical methane potential (Zhang, 2012), though its high moisture content makes energy recovery through thermal treatment unappealing (Ahring, 2003).

2. METHODOLOGY

2.1 Materials

The research was conducted in laboratory using three lab-scale manually mixed mesophilic inner tube digesters which were fed on a daily basis for 30 day period. The results presented here were for the first 10-days trial. The laboratory-scale digesters each had a 6-litre substrate volume as content but with a total capacity of 12-litres and were constructed using the innertubes of automobile car tyres, acrylic tubes with gas-tight top and runner bungs as stoppers for the openings in the tubes.

2.1.1 Conventional Components of Biodigesters

There are several types of biodigester used in producing biogas from organic wastes that have been introduced and applied to various areas of use like in domestic and industrial applications. The most predominant being the large-scale communal type, e.g. Fixed dome and floating dome types(Tauseef *et al*., 2013). China and India were among the first countries which methodically developed biogas technology for rural communities. They equally experienced that large-scale biodigester frequently showed some glitches for rural application and use. Some of the reasons adduced were the high production cost and difficulty in maintenance by the households(Liu & Wu, 2016; Tauseef *et al.*, 2013). As an alternative to the common types of large-scale biodigester, an inner tube (for automobile tyres) biodigester has been conceptualized and constructed for small-scale household purposes in Nigerian rural areas. The original idea was from John L Fry, Innertube Methane Digesters for Fuel Gas and Fertilizer, developed in 1973 for households. Some globally recognized biogas digesters used in places like India, China, and other developing countries for producing biogas from animal manure normally have the following features:

- Digester: The slurry which is usually animal wastes mixed with water or other solid wastes is fermented inside the digester and biogas is produced through bacterial action(Tauseef et al., 2013). This research adopted this type of digester concept given the ease of construction, the availability of the materials for construction and the low-cost of the entire biodigester.

- Gas holder or gas storage dome: The biogas here is collected in the gas holder, which holds the gas until the time of consumption (Tauseef, *et al*, 2013).
- Outlet pipe: In the outlet pipe the digested slurry is discharged into the outlet tank either through the outlet pipe or the vent provided in the digester.
- Mixing tank: The feedstock material (dung) is collected in the mixing tank. Enough water is added, and the material is thoroughly mixed until a homogeneous slurry is formed for the anaerobic digestion process.
- Inlet pipe: In the inlet pipe type, the feedstock is emptied into the digester through the inlet pipe/tank for the process.
- Gas pipeline/hose: The gas hose transports the gas to the point of application, such as a heating or cooking stove or a lamp. Cow slurry is the most common feedstock for biogas digesters, but substantial amounts of manure produced by buffalos, poultry, and pigs, are used, too (Table 1).

Table 1. Biogas Potential of Livestock Manure(Tauseef *et al*., 2013)

Animal fresh	**Total manure (kg/head/day)**	**Total solid (TS) (kg/head/day)**	**Biogas yield factor (m^3/kg of dry matter)**	**CN**	**VS (% of manure)**
Cow	20	4.0	0.20 – 0.50	18 – 25	13
Buffalo	25	4.5	0.15 – 0.32	18 – 25	-
Pigs	1 – 5	0.6	0.56 – 0.65	13	12
Sheep Goats	1.8	0.6	0.37 – 0.61	29	-
Poultry	0.1	0.03	0.31 – 0.54	-	17
Horses	2.4	7.1	0.20 – 0.30	24 – 25	-
Rabbits	0.2	0.1	0.36	-	

2.1.2 Experimental Procedure of the biodigester

The research project was conducted using a lab-scale manually mixed mesophilic biodigesters, which was constructed and fed daily. The lab-scale biodigesters each had a 12-litre capacity but 6-litres projecting volume (for headspace considerations) and were constructed of acrylic (Perspex) tubes with air-tight, and waterproof tyre tubes. The inner tubes of car tyres were locally sourced from tyre shops around the community. The top part of the digester was fitted with a gas outlet tube made from acrylic, an inlet feed port sealed with a rubber bung, and an effluent port sealed with a rubber bung where the digestate is released. The figures 5 and 6 shows the complete draft and layout of the inner tube digesters as it was designed and setup. Given the prevailing weather condition, the temperature of the system was raised at 36 ± 1 °C by concentrating two 1000 watts halogen lamps on the biodigesters at a height of about 1.5 metres to keep the temperature of the biodigesters at the optimum gas production level. The lamps provided the much-needed thermal energy required to keep the biodigesters at an optimum temperature level for 7 hours daily and the thick blanket was used to cover the digesters through the night, to maintain or retain most of the heat generated from the lamp. The values from the temperature probes showed that part of the heat was retained at night when the halogen was put out to reduce the energy billings. The artificial heating (parasitic energy) (Kevin, 2015) was equally necessary to simulate the average Nigerian type of temperature from a solar source, where the ambient temperature is usually higher than the ambient temperature of the lab where the research was carried out.

2.1.3 Household Continuous- Feed Methane Biodigester

There are several types of biodigester used in producing biogas from organic wastes that have been introduced and applied to various areas of use like in domestic and industrial applications. The most predominant type being the large-scale communal type, e.g. fixed dome and floating dome types(Tauseef *et al*., 2013). China and India were among the first countries which methodically developed biogas technology for rural communities. They equally experienced that large-scale biodigester frequently showed some glitches for rural application and use. Some of the reasons adduced were the high production cost and difficulty in maintenance by the households(Liu & Wu, 2016; Tauseef *et al.*, 2013). As an alternative to the common types of large-scale biodigester, an inner tube (for automobile tyres) biodigester has been conceptualized and constructed for small-scale household purposes in Nigerian rural areas. The original idea was from John L Fry, Innertube Methane Digesters for Fuel Gas and Fertilizer, developed in 1973 for households. The biodigester was made from tractor scrap innertubes, acrylic (Perspex), bicycle innertubes, PVC Pipes, shown in Figure 4, below. The small-scale biodigester was suitable for the household purpose and quite affordable to be installed individually in each household with access to solid waste like cow slurry.

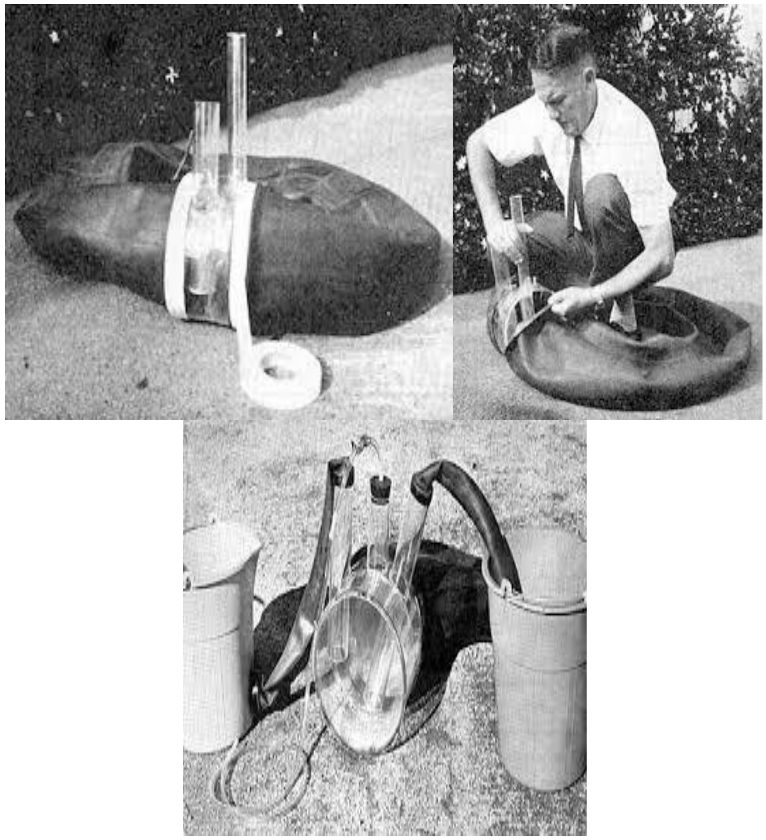
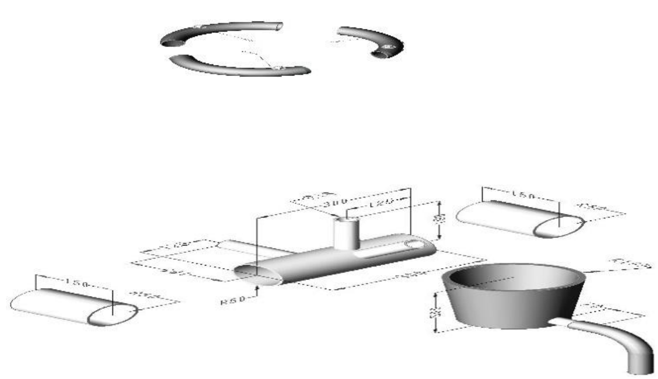


Figure 4. Innertube Digester; Methane Digesters for Fuel Gas and Fertilizer(Fry *et al*., 1973)

The newly conceptualized digester was designed and constructed from similar materials like automobile car tyre innertubes (butyl rubber), acrylic (usually referred to as Perspex in Nigeria). See Figures 5,6, for the array of the design and construction of the simplified model of a low-cost innertube digester. The biodigester was constructed taking into consideration the availability and low costs of the materials rural communities in Nigeria. The Biodigester can be fed continuously using food wastes and other semi-solid waste or biodegradable biomass, unlike John L Fry's digester that was strictly used for cow slurry. Household users can take the effluent as ready-to-use biofertilizer in addition to the biomethane gas for their daily cooking and heating purposes.



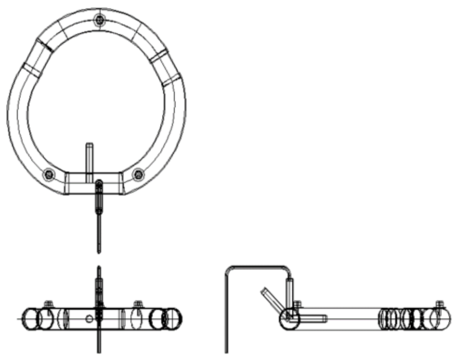


Figure 5. Arrays of the AutoCAD Design of the 12 litres Innertube Digester

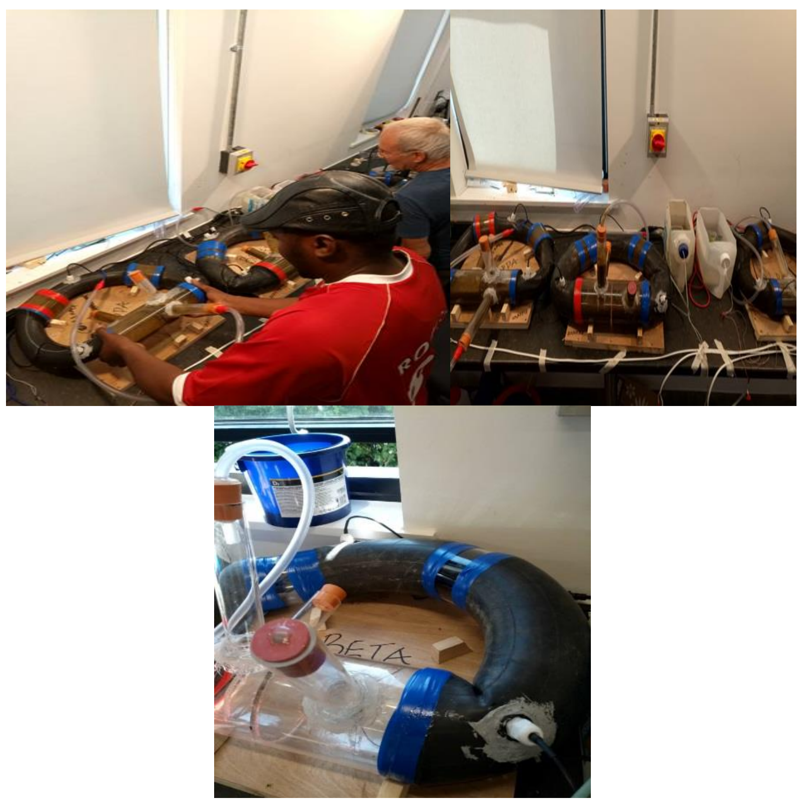


Figure 6. Arrays of the 12 litres innertube digesters been tested

2.1.4 Feeding Regime

A continuous feeding operation was realized by daily removal of digestate through an outlet tube in the other section of each digester, followed by substrate addition through the inlet tube. The lab-scale digesters were of the same design and the same mixing regime and Hydraulic Retention Time (HRT) was to be observed for a 30-day period(Kevin, 2015). In all the cases biogas production was measured using tipping-bucket gas counters with continuous data logging (Y Zhang, Walker, Banks, & Environment, 2010) using the Rasberry Pi kit and phyton coding.

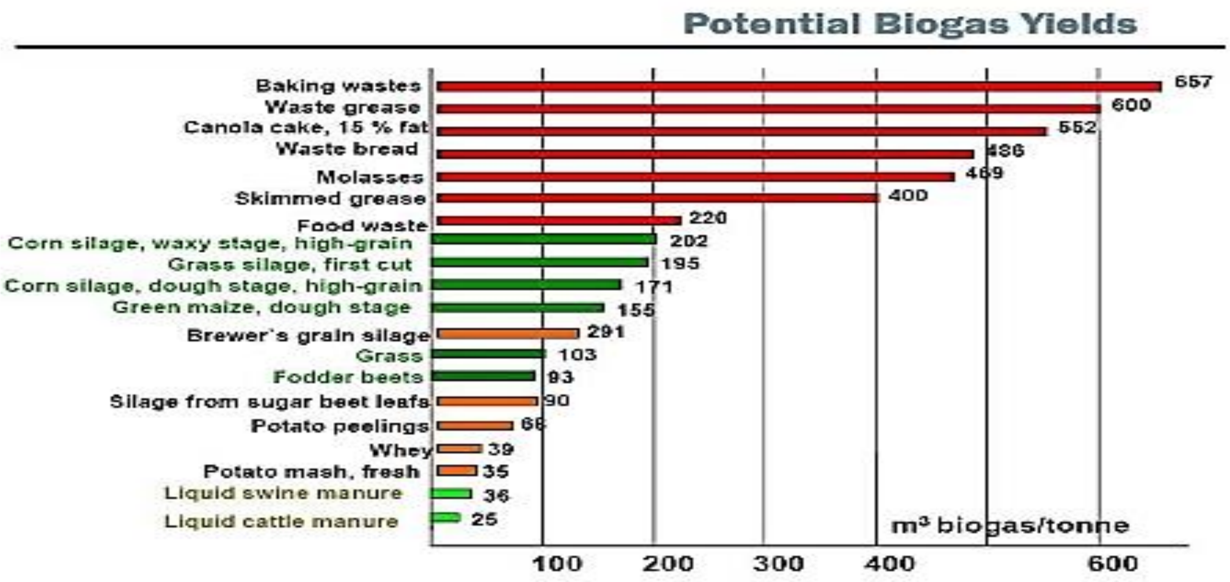


Figure 7. Potential Biogas Yield(Tauseef *et al*., 2013)

2.1.5 Mixing Mechanism: Parasitic Energy Demand

The major requirements of the anaerobic digestion process are thermal energy to maintain temperature (as in the case of using the halogen lamps) and pumping/mixing energy to distribute and homogenise substrate(Kevin, 2015). In the case of these digesters, the manual mixing by hand was adopted looking at the prevailing energy crisis in Nigeria and rural communities globally. Most rural homes lack access to constant electricity and it became obvious that these digesters may not get the required parasitic mixing energy from electricity. Hence, manual mixing is adopted given the fact that the materials of construction of the digesters are flexible (butyl rubber) and elastic. Since most anaerobic digestion systems are used to generate electricity using a Combined Heat and Power (CHP) unit(Kevin, 2015), excess heat is often readily available in most sophisticated systems, so the parasitic energy required to heat will not be considered further as far this project is concerned.

2.1.6 Data Logging of The Bioprocess: Using Raspberry Pi and Sensors

Operative monitoring and control are important to ensure process stability while optimizing process performance and the economics of the system (Kevin,2015), particularly if the organic loading rate is high(Latif, Ghufran, Wahid, & Ahmad, 2011). Certainly, there is a need for effective monitoring and control if the mixing system is to be optimized for biogas production. As a general case, monitoring and control systems vary depending on the application or use(Ounnar, Benhabyles, & Igoud, 2012). Research and Development require adaptable process instrumentation whereas on-site system needs robust and automated process instrumentation solutions (Kevin,2015). In a more complex biodigester, a more sensitive, comprehensive and reliable approach for data logging is adopted, whereas a small single-feedstock rural AD plant may survive with simple titration augmented by the occasional visit by a consultant(Y Zhang *et al*., 2010). Though the cost of monitoring equipment is becoming cheaper thereby improving the affordability of monitoring and control for smaller operations, the robustness and simplicity will always be key requirements when deployed in the potentially harsh environment of a farm. To save cost and ensure a simple data logging process is achieved to evaluate the performance efficiency of the lab-scale digesters, the biogas production was measured using tipping-bucket gas counters with continuous data logging(Y Zhang *et al*., 2010) connected to the Raspberry Pi kit and phyton coding used to interpret the readings of the temperature probes (inserted into the digesters) and gas volumes. The simple codes used was effective in reading the volumes of gas produced and the temperature from the sensor probes. See figure 8, for the set up used for the bioprocess data logging. Many sensors produce pulsed outputs with a switching action. This circuit and code combination for gas production as shown below are very useful;

GPIO.cleanup() #reset GPIO port GPIO.setmode(GPIO.bcm)#Broadcom pin notation GPIO.setup(17,GPIO.IN)#setup GPIO 17 as input pinstate=GPIO.input(17)#read the pin

A Simple circuit diagram for the connection used on the raspberry pi breadboard for the DS18B20 temperature probes is shown in figure 8.

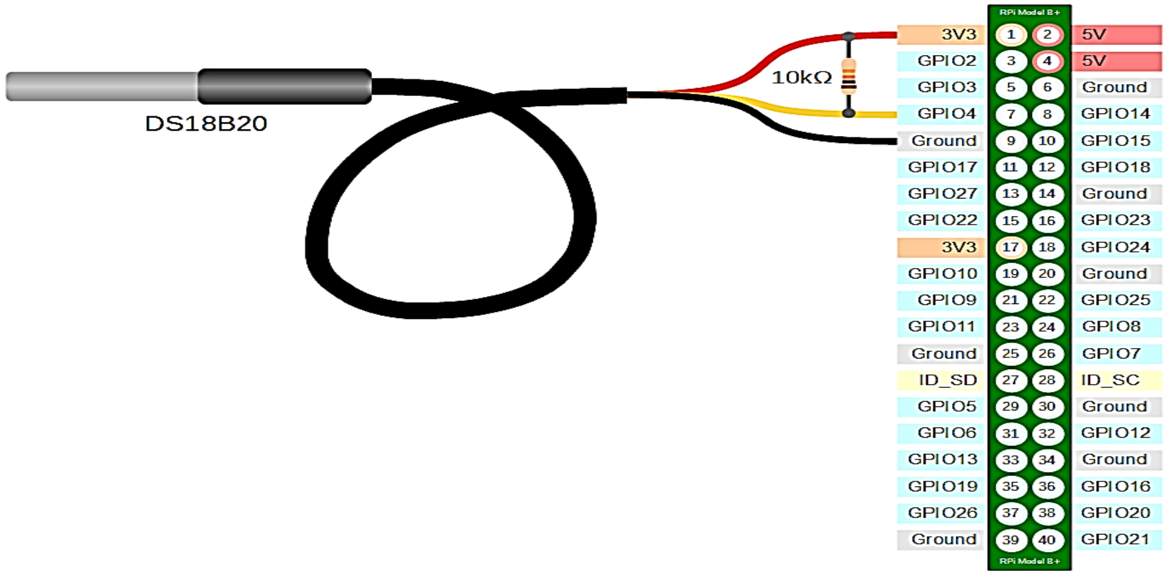


Figure 8. Circuit Diagram for the typical DS18B20 Temperature Probe(DS18B20, 2018)

The temperature sensor circuit diagram for the lab-scale biodigesters was built as outlined in figure 8, and the codes written, run on the Python script.

2.1.7 Other Bioprocess Optimization Metrics Used

The practicality of the different metrics that can be measured varies(Catron, Stainback, Dwivedi, & Lhotka, 2013) but key values are usually the pH, alkalinity, Volatile Fatty Acid (VFA) concentration and biogas flow rate and composition of the substrate(Budhijanto, Purnomo, & Siregar, 2012). Biogas production is an easy way to measure reactor performance but does not indicate the chemical stress experienced by the digester(Kevin, 2015). The biogas production of the digester was measured using tipping-bucket gas counters with continuous data logging(Y Zhang *et al*., 2010) connected to the Raspberry Pi kit and phyton coding used to interpret the pulse readings and gas volumes. The pH of the substrate was also relatively easy to monitor using a standardized and calibrated double junction pH meter (pHTestr 30).

2.1.8 Cattle slurry

Over the period of this research two 60 litres, drums of cattle slurry were obtained from Chynoweth Dairy Farm, Truro, the United Kingdom. It was then homogenised and stored in the bioresource refrigerator under the cold chain. Table 1 shows the typical characteristics of the cow slurry material and the biogas potential. To determine the moisture content and total solids of the cow slurry before mixing with deionized water (1:1), there was a need to oven drying and desiccation.

2.1.9 Inoculum

The inoculum for the 12-litre laboratory-scale trial digesters was taken from a 30-litre drum that is equally used at the farm at Truro, the UK. The inoculum was free from any large particles and easy to use in mixing with the cow slurry (1:1) to form the digestate. One of the 12-litre digesters were inoculated with the combination of 6-litres digestate (inoculum and cow slurry) to give a composition of 1:1, under a mesophilic condition at the Renewable Energy Engineering Facility, at the University of Exeter, the UK. The inoculum was provided by Chynoweth Dairy Farm at Truro in Cornwall. A digested dairy manure inoculum was selected due to the high levels of biomass it contained, the reliability of the source and the instantaneous digester start-up that the inoculum enabled(Yue Zhang, Banks, & Heaven, 2012).

2.2. Digester Operation and Monitoring

The model laboratory-scale digesters were fed in parts with a mixture of inoculum and Cow Slurry, at a ratio 1:1 on a Volatile Solid basis(Yue Zhang *et al*., 2012). Two more digesters were fed with cow slurry (the same ratio as the first digester) and Inoculum only in the proportion of 1:1 on a fresh weight basis as calculated based on the moisture content and total solids (TS) content with respect to their relative quantities in the UK waste stream(Kevin, 2015; Yue Zhang *et al*., 2012). To ensure homogeneity the substrates in the digesters were thoroughly mixed manually by hand-agitation which reduced the total solids content from 94% to around 20%. The choice of manual mixing was to reduce the cost of parasitic energy(Kevin, 2015) required for mixing and to simulate the mixing technique that is predominantly available in Nigeria or Africa where the model digester is originally designed to be used. The third digester which was fed only on inoculum and acted as a control, for the evaluation of the entire process. The total Organic Loading Rate (OLR) for all digesters was 6 kg VS m^{-3} day^{-1} throughout the trial. The solids and liquid retention times were coupled and hydraulic retention time (HRT) of 30 days and maintained. The digestates were removed with the aid of calibrated syringes through the effluent tube after which they are discarded or used as biofertilizer when needed. Fresh substrates were fed to the digester in the same quantity as the effluent taken out. See figure 9, for part of the bioprocess carried out.

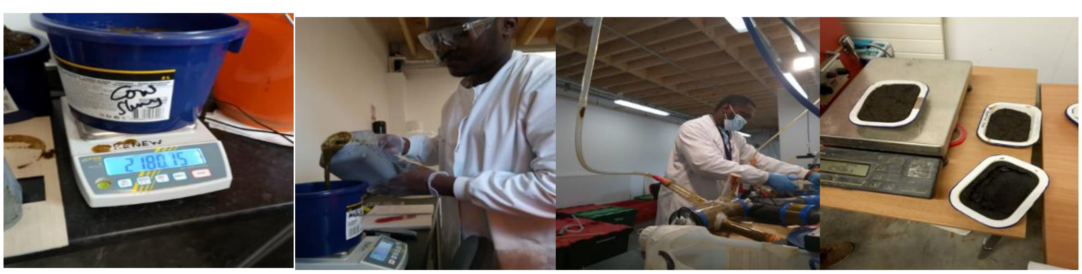


Figure 9: Bioprocess: Loading the biodigester with the feedstock

The operating regime of the entire system was maintained for 30 days with the possibility of extending to measure another parameter which is not under study in this paper. All digesters (namely Alpha, Beta, Cappa) were monitored daily for biogas production, temperature and pH. All gas volumes reported are corrected to Standard Temperature and Pressure (STP) of 0 ^{0}C, 101.325 kPa.

3. RESULTS AND DISCUSSIONS

3.1 Carbon and Nitrogen content

The Carbon to Nitrogen (C/N) ratio plays an important role in the AD and biogas production process. A C/N ratio that is either too high or too low will inhibit biogas production(Tauseef *et al*., 2013). The C/N ratio of the substrate after inoculation was calculated and found to be 24.7 for the dairy manure. The suitable range of the C/N ratio was 20–30 for anaerobic digestion processes, and the optimal C/N ratio suggested for gas production is 25(Tauseef *et al*., 2013; Yue Zhang *et al*., 2012).

Table 3. The Volume of Biogas Produced from the Tipping Counter (Pulse/ml)

Time (Days)	Alpha biogas production Pulse/130mL	Beta biogas production Pulse/120 mL	Cappa biogas production Pulse/104mL
1	4	31	5
2	2	69	4
3	1	53	0
4	0	45	0
5	4	59	9
6	7	67	4
7	6	52	5
8	6	63	10
9	7	64	9
10	3	1	2

Table 4. The Volume of Biogas Produced (mL)

Time (Days)	Daily Alpha biogas production (mL)	Daily Beta biogas production (mL)	Daily Cappa biogas production (mL)
1	520	3720	520
2	260	8280	416
3	130	6360	0
4	0	5400	0
5	520	7080	936
6	910	8040	416
7	780	6240	520
8	780	7560	1040
9	910	7680	936
10	390	9720	208

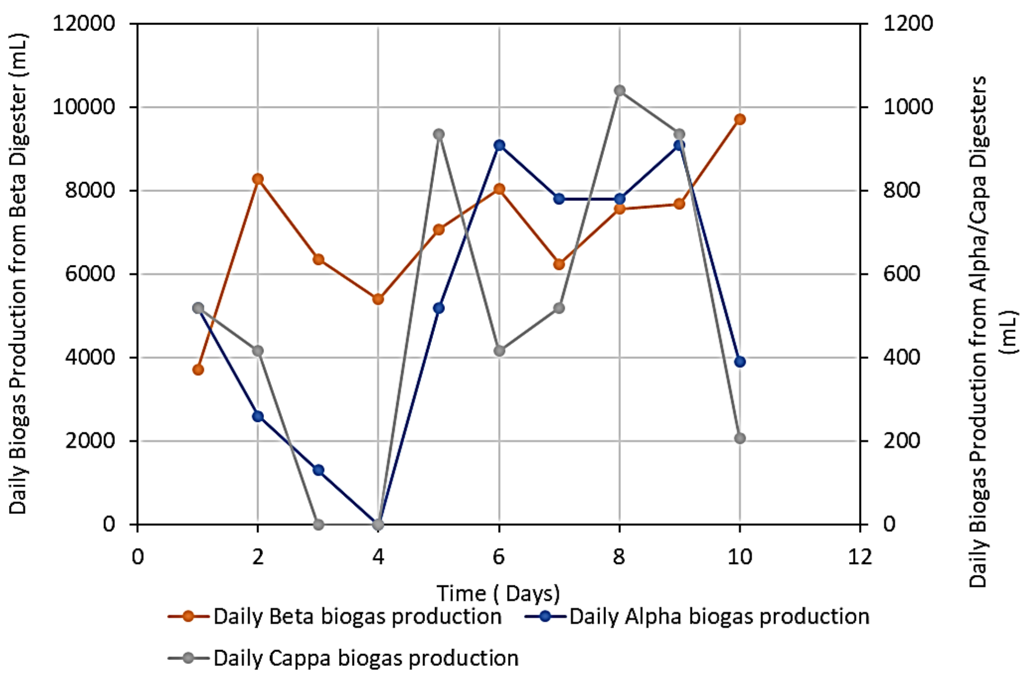


Figure 10. Daily biogas production (mL)

3.1 The Effect of Inoculating the Innertube Digester

A suitable nutrient content in the inner tube biodigester is very important for the AD process of cow slurry. The essence of using inoculum in one of the digesters (Beta Digester) was not only to provide active microorganisms but also to serve as an active source of nutrients. The inoculum satisfies the demand for macronutrients, micronutrients and nitrogen for the anaerobic digestion process without the addition of chemicals(Kevin, 2015; Yue Zhang *et al*., 2012). These nutrients essential for cell growth and the methanogens require special micronutrients for optimum gas production(Kevin, 2015). The macronutrient (Na, K, Ca and Mg) content in the inoculums was enough for the metabolic activities of the microorganisms(Yue Zhang *et al*., 2012). The results from the bioprocess show that the concentrations of K and Ca in the Beta digester were higher than in non-inoculated digester containing only cow slurry (Cappa Digester).

According to Zhang *et al*., 2011, the micronutrients contained in bioreactors were the key factors for improving anaerobic digestion. The results from the volume of gas produced and the charts buttress these points (See figure10 & 11). After inoculation for the first 10 days, the digested cow slurry in the Beta Digester clearly shows from the charts in figures 10 & 11 and results shows that it had a higher concentration of micronutrients than when it is not mixed with the inoculum, the Cappa Digester(without inoculum). The biogas production rate and volume from the inoculated Dairy Manure (Beta Digester) were the highest of the three digesters (Alpha, Beta Cappa). The Alpha Digester (Inoculum only) like the Cappa Digester, did not produce a substantial amount of biogas like the inoculated digester. The chart shows that under the same set of conditions (Temperature, Insulation, Volume, Hydraulic Retention Time, feeding regime) the inner tube digester containing the inoculated cow slurry (Beta-Digester) had the most effective and consistent methane gas production level among all the digesters. The higher concentration of micronutrients contained in the Beta Digester because of inoculation resulted in an improved performance than seen with the other digesters(Gu, Chen, Liu, Zhou, & Zhang, 2014).

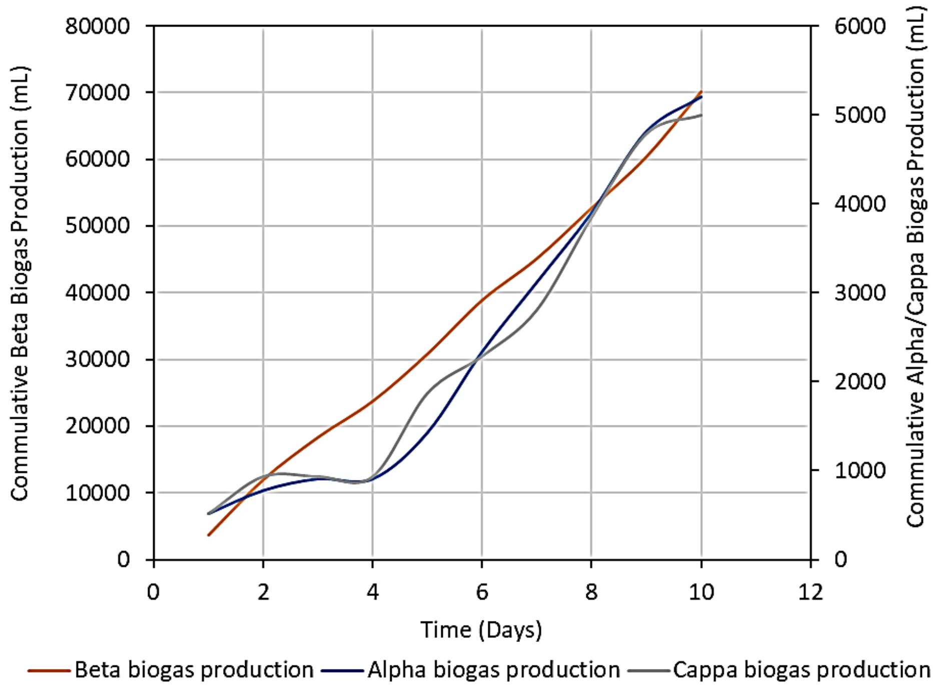


Figure 11. Cumulative Biogas Production (mL)

3.3 Methane Gas from the Inoculated Digester

The gas produced from the inoculated Beta digester can be scrubbed to produce pure methane which could be used for the purposes under studys. Looking at the chart for the cumulative biogas production rate, it is obvious that the Beta-Digester can be upgraded by the capacity to produce more gas (methane) for household use.

4. CONCLUSION

Biogas production takes a considerably long time to be stable. In developing countries, especially India, Nigeria, Ghana, and other Southeast Asian countries methane capture from manure has been encouraged by using biogas plants which are predominantly household anaerobic digesters handling manure of livestock held by an average-sized family. While this project is exploring the possibility of direct application on the field or households, it is important for it to be subjected to conventional trial and error experiments as seen in the lab-scale digester. This research project at this level only concerns itself with developing an innertube biodigester from automobile car tyre tubes for the quantitative optimization of continuous biodigester performance from an inoculated cow slurry. The purposes of the optimization efforts in biogas production using the tipping counter and raspberry pi are not only to obtain the highest conversion of the cow slurry but also to achieve the highest possible selectivity in simple materials for biodigesters construction. Improvements on this model and the bioprocess optimization of the digesters will be presented in another publication of this project. The common feature of this digester, described in figure 5 & 6, is that they employ no heating or continuous or excessive mixing due to which anaerobic digestion proceeds at a very slow rate. But this model adopted keeps the costs of the system down and makes them net energy producers, thereby making them a source of much-needed energy in the villages. The simplicity also makes their operation easy, enabling even illiterate farmers to use them effectively. There is a need to promote this form of bioenergy capture system throughout the developing world.

5. ACKNOWLEDGEMENTS

This research was funded by the Tertiary Education Trust Fund (TETFUND) under the Supervision of Auchi Polytechnic, Auchi, Edo State, Nigeria. The immense support of the Rector of Auchi Polytechnic, Auchi, Dr Sanusi Momodu Jimah is appreciated.

6. REFERENCE

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Prospects and Challenges of Food Quality Inspection and Evaluation in Nigeria using Hyperspectral Imaging

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ABSTRACT

For the problems of food quality in Nigeria to be solved, and the expectation of high quality food products that conform to safety standards to be met, there is need for the utilization of accurate, non-destructive, fast and objective quality determination instruments in the inspection and evaluation of food and agricultural products during handling processes and commercial operations. One of the emerging technologies that are currently utilized in the food industry and research for the above purpose, with very high efficiency is the hyperspectral imaging system. However, information on its utilization in the Nigerian industries and food research, appears to be quite unavailable. This paper discusses this imaging system and its applications in the food industry. It identifies the exposition of hidden deteriorations and infections as well as enhancement of computer-aided food technological operations and research as some of the prospects, and outlines lack of training of experts in remote sensing and unavailability of state-of-the-art facilities in the field as well as lack of high quality standards for foods being consumed in the country and allowance of uninspected, unevaluated and adulterated products to enter the market, as some of the challenges of applying hyperspectral imaging in food quality inspection and evaluation in Nigeria. Others challenges include the tendency to abandon projects by Government, unavailability of funding, lack of interest and poor investment in researches that can be conducted using the technology. The paper suggests that the Standard Organization of Nigeria (SON) in collaboration with the Nigerian Institute of Food Science and Technology (NIFST) and the Nigerian Institution of Agricultural Engineers (NIAE) should establish and enforce high quality standards for foods being consumed in the country. The installation and utilization of hyperspectral imaging systems in food industries in the country should be a requirement for registration. Hyperspectral imaging facilities should be made available and operational at all points of entry of foreign foods into the country. Researches in the field of imaging technologies beginning from remote sensing and computer vision, should be heavily funded.

Keywords: Hyperspectral imaging, multispectral imaging, remote sensing, computer vision, food quality inspection and evaluation, Nigeria

1. INTRODUCTION

A typical human eye will respond to wavelengths in the range of 390-750nm (Cecie, 2005). Human eye and its receptor for Red-Green-Blue colours constitute the limitation of manual inspection of food quality. Manual sorting and grading is based on traditional visual quality inspection performed by local farmers, which is tedious, time consuming, slow and non – consistent in outcome. Sun et al. (2003) observed that the basis of quality assessment is often subjective with attributes such as appearance, smell and colour, examined by human inspectors.

Francis (1980) noted that human perception could easily be fooled. It is important to discover the possibilities of adopting faster systems, which will save time and be more accurate in sorting and grading of agricultural and food products. One of such reliable method is the automated computer vision system. A cost effective, consistent, superior speed and accurate sorting can be achieved with machine vision sorting and grading system. Thus, there is increasing evidence that machine vision is being adopted at commercial level for sorting, grading of fresh products, and detection of defects such as cracks, dark spots and bruises on fresh fruit (Locht et al., 1997).

Series of studies have been conducted in recent years to investigate the application of remote sensing technologies in sorting and grading of fresh agricultural and food products. Computer vision (Batchelor and Searcy, 1989) stands out among its remote sensing counterparts such as Geographic Information System (GIS) and Global Positioning System (GPS). Yam and Spyridon (2003) used a simple digital imaging method for measuring and analyzing colour of food surfaces and found that the method allowed measurement and analysis of colour that is essential in the investigation of microbial attack. Payne and Shearer (1990) developed a machine vision algorithm for grading of fresh market produce such as tomato according to colour and damage, while Alchanatis et al. (1993), used a neutral network based classifier and colour machine vision instead of the conventional use of black and white cameras and geometric features for automatic classification of tissue culture segments of potato plantlets.

Infrared (IR) light is electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 0.74 µm to 300 µm. This range of wavelengths (Liew, 2006), corresponds to a frequency range of approximately 1 to 400 terahertz (THz). Different regions in the infrared such as near-infrared (NIR), short wavelength infrared (SWIR), mid wavelength-infrared (MWIR) and long wavelength-infrared (LWIR) can be used to remotely extract hidden information of an object using a vast portion of the electromagnetic spectrum and specific frequencies across the spectrum. These are termed hyperspectral and multispectral imaging, respectively.

Hyperspectral imaging (Schultz et al., 2001) is a remote sensing technology that collects and processes information from across the electromagnetic spectrum. It has been an area of active research and development with the images being only available to researchers. With the recent appearance of commercial airborne hyperspectral imaging systems, the technique is being positioned to enter the mainstream of remote sensing. Spectral imaging divides the spectrum into many more bands. This technique of dividing images into bands can be extended beyond the visible. Hyperspectral sensors view objects using a vast portion of the electromagnetic spectrum and utilize the unique ‘finger prints’ that the objects leave across the electromagnetic spectrum, referred to as spectral signatures to make possible the identification of materials that make up the scanned objects. A typical example is when spectral signature for oil helps mineralogists to find new oil fields. Multispectral imaging is also a remote sensing technology that captures image data at specific frequencies across the electromagnetic spectrum. The wavelength may be separated by filters or by the use of instrument that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, such as infrared. Multispectral imaging can allow extraction of additional information that the human eye will fail to capture with its receptors for red, green and blue. It was originally developed for space-based imaging with the images normally obtained by remote sensing radiometers (Chamberland et al., 2005). Usually, satellites have three or more radiometers (Landsat has seven). Landsat, as a satellite for multispectral imaging acquires one digital image (in remote sensing, called a scene) in a small wave length region, ranging from 0.4μm to 0.7μm called red-green-blue (RGB) region, and going through to infrared wavelengths of 0.7μm to 10 or more wave length bands classified as near infrared (NIR), middle infrared (MIR) and far infrared (FIR or thermal). A perusal of literature showed that investigations involving the applications of hyperspectral imaging in any field of endeavor in Nigeria, appears to be lacking. Food quality inspection and evaluation is one of the areas in which the technology finds useful application. This paper therefore discusses the potentials, prospects as well as challenges of applying hyperspectral imaging in food quality inspection and evaluation in Nigeria.

2. INSTRUMENTATION

The image acquisition tool for a computer vision system used for the determination of tissue damage of fresh-cut vegetables consisted of Nikon DIX digital camera, a Pentium PC with Windows 2000 operating system, a lighting chamber and an IEEE1394 fire wire PCI interface. Eight 15watt cool white fluorescent lamps were positioned at an angle to ensure uniform illumination on the photo platform without producing shadows in the images (Luo and Tao, 2003). The imaging equipment for identification of faecal and ingesta contamination on poultry carcasses consisted of a focusing lens, a prism-grating-prism spectrograph, a high resolution CCD camera, computer (Pentium II, 500MHZ) and associated optical hardware (Park et al., 2001). For spectral imaging system, a 30.5-cm (12-in) integrating sphere was used as a spatially-uniform target. For spatial calibration of the hyperspectral imaging system, thin vertical lines were printed on a transparent film with a 1-mm centre-to-centre spacing. Spectralon panels from Labsphere Inc. were used to calibrate and validate the hyperspectral imaging system to reflectance values. Processing was scheduled so that the time between slaughter and imaging was less than 10min. A laser beam was used to align the fibre-optic line lights and a digital line meter was used to measure light intensity and distribution on the carcasses (Lawrence and Windham, 2003).

2.1 Components and Analysis of Hyperspectral Imaging Systems

The principal components of a hyperspectral imaging systems are objective lens, illumination unit, spectrograph, CCD camera, conveyor, acquisition system and computer. Hyperspectral imaging acquires spectral images at wave lengths ranging from 400 – 1000nm. Diffuse illumination of the sample is carried out by tungsten – halogen or LED source (Xing et al., 2007). The light reflected from the target enters the objective and then spread into its component wavelength.

Commercial instruments are available for multipurpose bioluminescence and fluorescence imaging (e.g. Xenogen Corporations IVIS 200 R, CRI Inc's. Maestro R), but again are largely restricted to 2D planner imaging. A recent software addition to the IVIS 200 systems allows 3D reconstruction from spectral data but is restricted to data from a single view from the animal surface and is based on a simplified homogeneous submodel of light propagation.

2.2 Image acquisition

Computer vision systems are affected by the level and quality of illumination as with the human eye. The performance of the illumination system greatly influences the quality of image and plays an important role in the overall efficiency and accuracy of the system. Some of the devices or sensors used in generating images include scanners, ultrasound, x – ray and near infra – red spectroscopy. However, in machine vision, image sensors used are the solid state changed coupled device (CCD) camera technology (Narendra and Hareesh, 2010, Mahendran et al., 2012).

The hyperspectral and multispectral technology options are recent technologies with digital cameras, which eliminate the additional component required to convert images taken by photographic and CCD cameras or other sensors to readable format by computer processors (Narendra and Hareesh, 2010).

2.3 Image processing and analysis

Image processing and image analysis are recognized as being the most important part of computer vision (Lawrence et al., 2003). Image processing, in imaging science is any form of single processing for which the input is an image, such as a photograph or video frame; the output of image processing may be either an image or a set of characteristics or parameters related to the image. Most image – processing techniques involve treating the image as a two – dimensional signal and applying standard signal processing techniques to it. The acquisition of images (producing the input image in the first place) is referred to as imaging. Image analysis is the extraction of meaningful information from images; mainly from digital image processing techniques. The task of image analysis can be as easy as understanding a bar coded tags or as sophisticated as identifying a person from their faces. Computers are available for the analysis of large amounts of data, for tasks that require complex computation, or for the extraction of quantitative information.

It is good to note the human visual cortex as an excellent image analysis apparatus, especially for extracting higher – level information, and for many applications – including medicine, security and remote sensing – human analysts still cannot be replaced by computers. For this reason, many important image analysis tools such as edge detectors and neural networks are inspired by human visual perception models.

Computer image analysis largely contains the fields of computer or machine vision, and medical imaging, and makes heavy use of pattern recognition, digital geometry, and signal processing. This field of computer science was developed in 1950s at academic institutions such as the MIT A.I. Lab, originally as a branch of artificial intelligence and robotics.

Image acquisition and image pre-processing are categorized as low-level processing, while the intermediate and the high level processing stages as classified by Sun (2000) and Raji and Alumutu (2005) in Figure 1, are further processing stages required when integrating the pre-processing stages into an application device such as a sorter and grader.

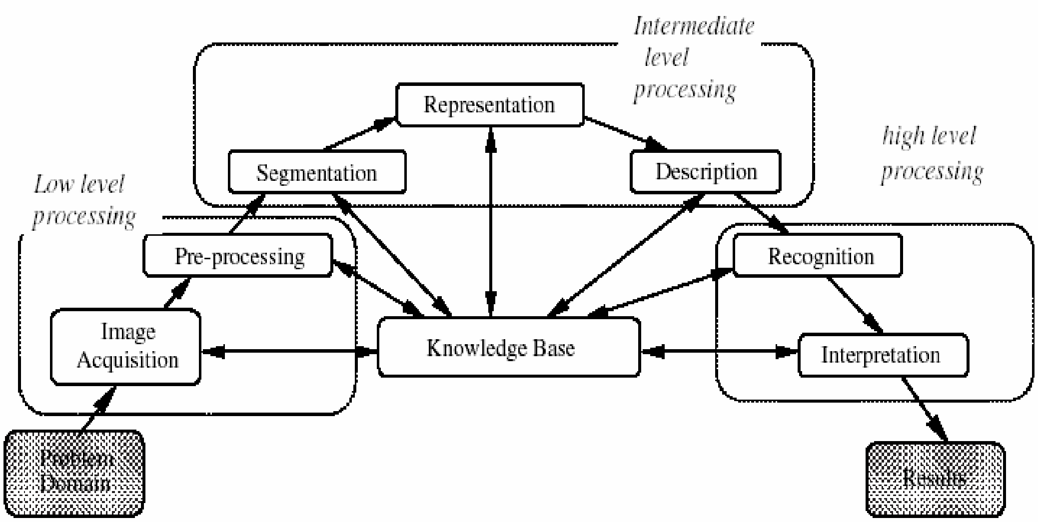


Figure 1: Different levels in the image processing
(Source: Sun, 2000, Raji and Alamutu, 2005)

3. FOOD QUALITY DETERMINATION

Food quality is the standard of food; its preference, degree of satisfaction, how good or bad it is or may end up to be. Consumers' acceptance of food is increasingly being dependent on the extent of food quality, which is subject to human perception. Traditionally, the measure of food quality had been limited to appearance, smell and colour, taste and flavour, texture and nutritive value. The food processing industry in developed nations is constantly searching for automated methods in the area of quality inspection and evaluation.

Production based on the quality of the raw materials goes beyond optimizing the value of the raw materials, to enabling the provision of products with well-defined qualities for recipe optimization, an example of which is defining the fat content of pork trimmings used for making different sausages. Next, documentation of product quality enables efficient flow of products into different markets for example fish that have higher fat content obtain a higher price in Japan than in Europe.

3.1 Studies on applications of hyperspectral and multispectral imaging techniques in food quality and safety inspection and control

The potentials of hyperspectral and multispectral imaging technology for application in various areas of food quality inspection, evaluation and control have been discussed by many investigators. Areas that were addressed include meat quality and safety assessment (Kozan et al., 2016), in-line food sorting with band selection for optimal classification (Gruna et al., 2010), food quality, safety and authentication (Kim et al., 2001, Kim et al., 2004, Wang and Paliwal, 2007, Amigo et al., 2013 and Kamruzzaman et al., 2014, Alonso et al., 2013).

Hyperspectral and multispectral imaging have been used as tools for food safety surveillance such as the determination of physical, chemical and biological contaminants in food, detection of meat and bone in feed stuff as well as organic residues on food processing equipment (Feng and Sun, 2012). Hyperspectral imaging techniques comprising of near infrared hyperspectral imaging, fluorescence hyperspectral imaging and Raman hyperspectral imaging or their combination proved a very powerful tool for food surveillance. Blasco et al. (2007) sorted citrus fruits and identified defects using hyperspectral and multispectral imaging techniques. Images of the same fruit were captured using three different systems: visible (VIS) and near infrared (NIR) reflectance, and ultra violet induced fluorescence (UVFL). Two (VIS-and NIR-sensitive) were used to capture fluorescence and visible images, which consisted of three monochromatic images of RGB wavelengths (Lorente et al., 2012). Basically the colour image acquisition system consisted of a colour camera; a lighting system composed of fluorescent tubes and polarized filters to prevent dark spots on the scene. The lighting system was made up of incandescent lamps. To avoid the interference of visible information, a 700nm cut-band filter was coupled to the camera lens. The fluorescent images were acquired using the same colour camera that was employed to capture the colour images. In this regard, fruits were illuminated using black light fluorescents tubes that emit radiation with a wavelength between 350nm and 400nm, and a peak at 370nm. Once the images have been segmented (Blasco et al., 2007), a collection of region of interest (supposedly sound peel and defects) were identified. Shape analysis using different techniques was also applied. Combined with the algorithm are visible and non-visible information to detect dangerous blemishes that can spread a fungal infestation and thus hinder the fruits from being commercialized. The defects found on the fruits were described as those that only affect the fruit appearance such as oleocellosis (disease of magarine), chilling injury, sooty mould (mould caused by black dust given off by fire), phytotoxicity (degree at which toxic substances become poisonous to plants), scales (diseases caused by scale insects), scarring (forming of mark of former attachment to plants), thrips (tiny sucking insects), and other defects with great economic importance such as anthracnose (fungal disease of plant), stem-end injury, green mould (decay caused by Penicillium digitatum) and medfly (Ceratitis capitata) egg deposition (Blasco et al., 2009a). Their sizes vary from large defects, such as anthracnose or chilling injury, to small ones like scales or medfly. The colour also differed from one to another and probably ranged from the white of stem-end injury, the silver or grey orange or green colour of P.digitatum or the brown colour of oleocellosis to the black of anthracnose.

Blasco et al. (2007) showed that about 65% of defects could be properly identified using colour information only. Once the morphological (structure of citrus fruit) parameters described had been introduced, the correct classification rate reached 82%. By bringing in NIR and UVFL images in the analysis, the success rate increased to 86%. However, above the numerical results, the greatest increase was achieved in the identification of anthracnose and green mould (95% and 97% respectively) which are dangerous defects that could spread diseases to sound fruits. Figure 2 shows images of an advanced decaying fruit acquired with the different vision systems.

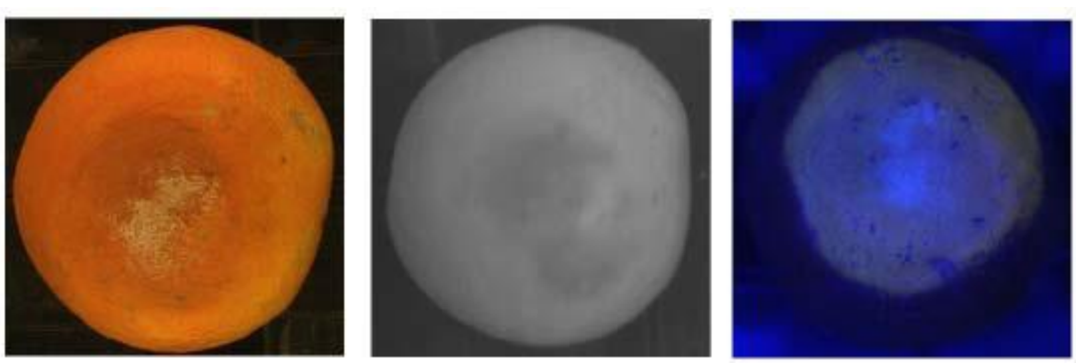


Figure 2: Images of an advanced decay damage acquired using the three acquisition systems. From left to right, Visible Image, NIR Image and UVFL Image (Source: Blasco et al., 2007)

Gomez-Sanchis et al. (2013) examined the feasibility of detecting green decay in citrus fruits in the early stages of infection, by avoiding the use of UV illumination and employing hyperspectral vision system based on liquid crystal tunable filters (LCTF) similar to the one used by Evans et al., (1998) and Wang (2010). The system consisted of a monochrome (in shades of one colour or black and white) camera with a high level of sensitivity between 320nm and 1100nm. It was configured to capture 551*551 pixel images with a resolution of 3.75 pixels/mm. Two LCTF were used, one sensitive to the visible between 460nm to 720nm (Varispec VIS07) and the other sensitive to the near infrared from 730nm to 1020nm (Varispec NIR07). Fruit sample was illuminated separately by indirect light from halogen lamps inside a hemispherical aluminum diffuser. Thereafter, the effect of the reflection of light over spherical objects was corrected following the procedure of Gomez-Sanchis et al. (2008a). A manual fast filter changer was designed that holds and guides the tunable filters, so that images of the same scene could be captured at visible and near-infrared wavelengths without having to move the camera (Gomez-Sanchis et al., 2008b). Images were acquired manually by placing the fruit in the inspection chamber and then presenting the damage to the camera. The hyperspectral images were composed of 57 monochrome images of each fruit. Mandarins cv. "Clemenules" (Citrus clementina Hort. ex Tanaka) were selected because of their economic importance in Spain. Fruits were chosen from the packing line of a trading company. A total of 200 fruits were used: 150 were inoculated with a suspension of Penicillium digitatum spores with a concentration of 10^6 spores/ml (Palou et al., 2001); the rest were inoculated with water for control purposes. The fruits were preserved for three days in a controlled environment at 25°C and 99% relative humidity. After this period, all the inoculated fruits presented a circulated area of decay with a diameter between 10mm and 25mm. The colour of the damage was similar to the colour of sound skin around it, thereby making it difficult for human inspector to detect. The success rate reached 92% and 95% when using the 57 bands and 20 bands respectively. The bands selected for use were 460, 480, 520, 560, 590, 600, 620, 630, 680, 730, 740, 760, 800, 820, 870, 880, 950, 960, 980 and 1010nm. The use of more than these 20 bands did not increase the success rate to any important degree, the increment being about only 1% after including all 57 bands. Figure 3 shows the result of the segmentation of a decaying fruit.

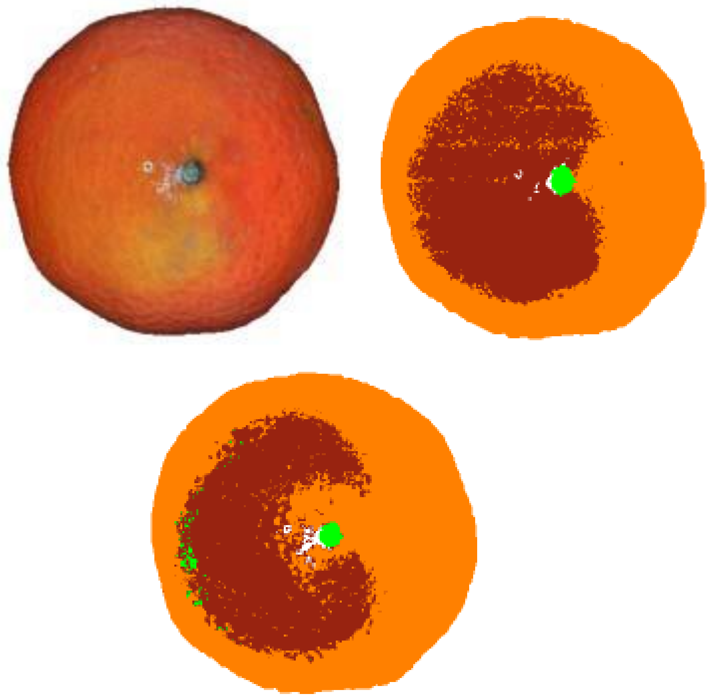


Figure 3: Image of a fruit with decay damage with segmentation from middle to right (Source: Gomez-Sanchis et al., 2008)

In general, the best results were obtained with the non-linear classifier, the success being 90% for all classes. Beef tenderness is an essential quality attribute for consumer satisfaction (Naganathan et al., 2008). The current beef quality does not incorporate a direct measure of tenderness because there is currently no accurate, non-destructive method for predicting tenderness available to the beef industry. Naganathan et al. (2008) developed and tested a visible/near infrared hyperspectral imaging system for predicting tenderness of 14 day aged, cooked beef. Hyperspectral images of fresh rib eye (cut of meat) steaks acquired at 14 day post mortem were used. A hyperspectral imaging system consisting of a Charge Coupled Device (CCD)-based digital video camera and a spectrograph was used. The system scanned a single-spatial line of target object, and the spectrograph disperses light from each line element or pixel to a spectrum. The camera acquired the image of a steak through a view port. With hyperspectral imaging, a spectrum for each pixel can be obtained and a gray scale or tonal image for each narrow band can be obtained. After imaging, the steaks were cooked in an impingement (striking) oven with a moving object. Slice Shear Force (SSF) values (Figure 4) were obtained following the procedures presented by Shackelford et al. (2001). Typical spectral signatures of lean and fat pixels and images of beef steaks at selected wavelengths are presented in Figures 5 and 6, respectively. Out of 111 samples, the number of tender, intermediate and tough samples were 94(84.7%), 12(10.8%) and 5(4.5%), respectively. Thus, this classification method has some potential in predicting beef tenderness.

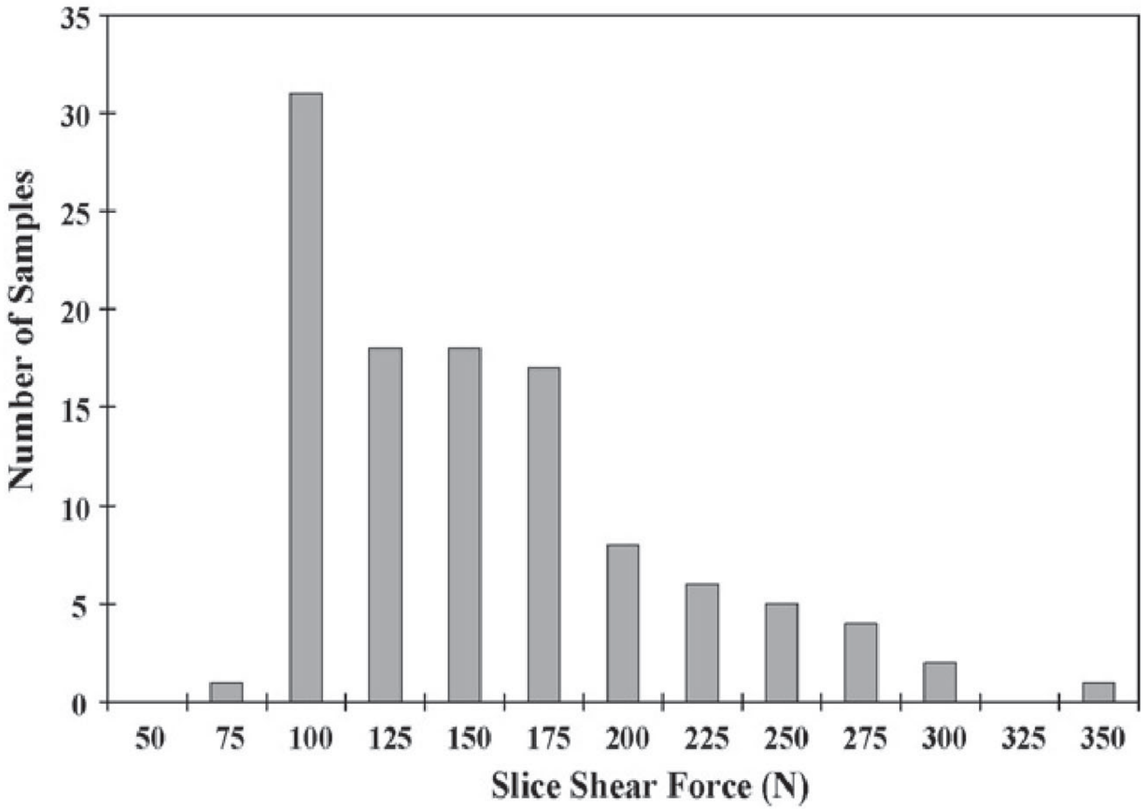


Figure 4: Sample distribution of beef rib eye steaks based on slice shear force (SSF) measurement. (Shackelford et al., 2001)

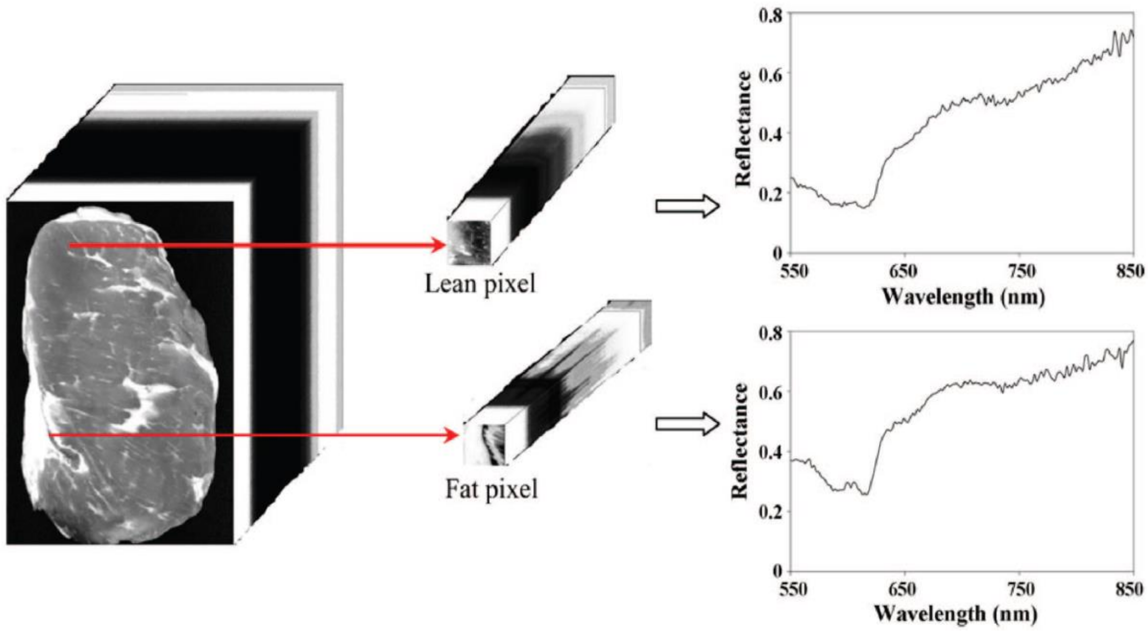


Figure 5: A hyperspectral image of a beef-steak showing typical spectral signatures of lean and fat pixels (Source: Naganathan et al., 2008)

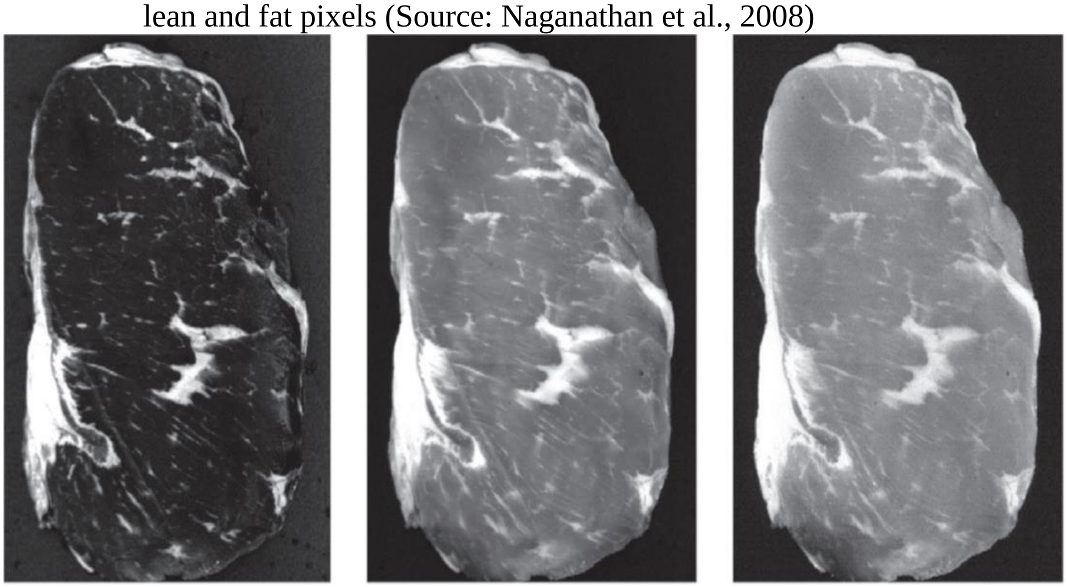


Figure 6: Images of beef steaks from left to right, at selected wavelengths 600nm, 700nm and 800nm respectively (Source: Naganathan et al., 2008).

Kumar et al. (2012) demonstrated the use of airborne hyperspectral and multispectral imaging in rapidly detecting the trees infected with citrus greening disease in citrus groves. Comprehensive ground trothing confirmed the accuracy of the imaging techniques. Cheng et al. (2014) studied colour distribution in grass carp fillets during cold storage using hyperspectral imaging, and reported that the quantitative calibration model between spectral data extracted from hyperspectral imaging and measured colour reference values, established using Least Squares Support Vector Machine (LS-SVM) applied to the whole spectral range gave the best results. LS-SVM and Multiple Linear Regression (MLR) using Success Projection Algorithm (SPA) and Genetic Algorithm (GA) selected wavelengths showed excellent performances in the prediction of Total Volatile Basic Nitrogen (TVBN) and K values in grass carp fillet during chemical spoilage (Cheng et al., 2016), and poor results for Thiobarbituric Acid Reactive Substances (TBARS) values. LS-SVM model using GA selected wavelengths showed good reliability and was considered best for simultaneous determination of TVBN, TBARS and K values of grass carp fillet. Visualized maps of chemical indicators obtained are shown in Figure 7.

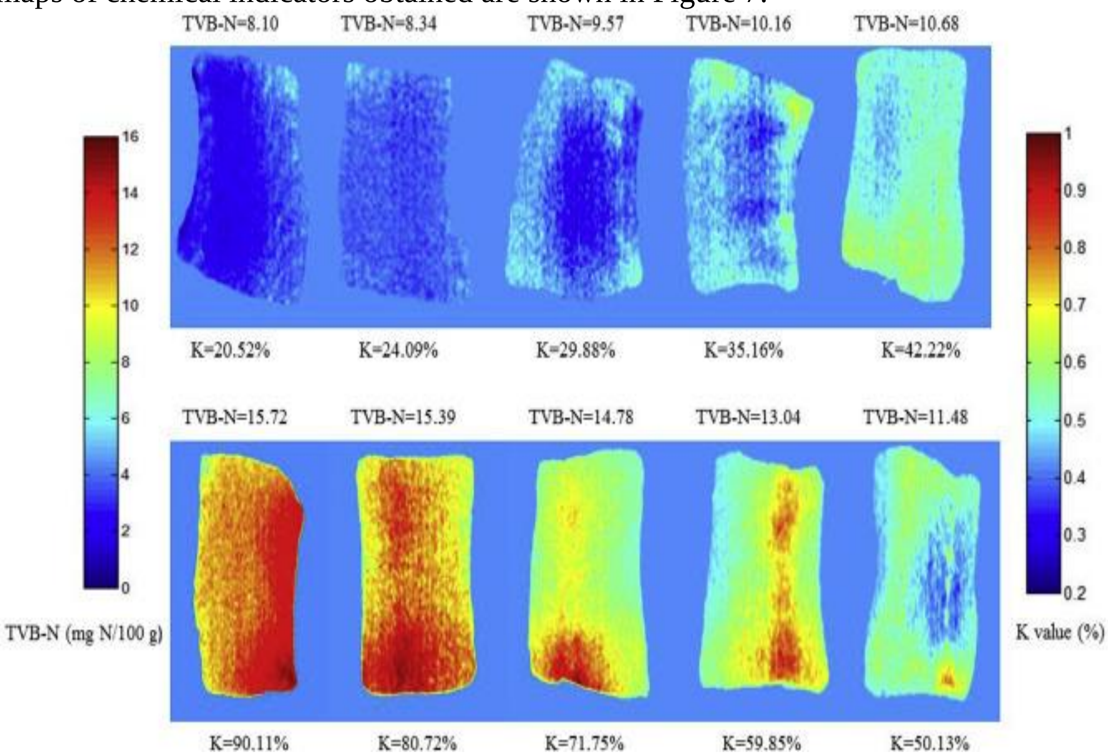


Figure 7: Visualized distribution maps of chemical indicators in grass carp fish fillets stored at 4 ± 1 °C for 0, 2, 4, and 6 days

Source: Cheng et al. (2016)

Early rottenness caused by penicillin (Zhang et al., 2015) and bruises in apples (Kim et al., 2001, Huang et al., 2015) have been detected using hyperspectral imaging in the full region (325-1100nm) spectra. Independent Component Analysis (ICA) and simple thresholding methods were used to segment and classify the rottened from the sound, while segmented Principal Component Analysis (PCA) was used to detect bruises. Results showed an overall accuracy of 97% for rottenness detection and 90.4-94.7% for bruise detection under different imaging conditions. Yang et al. (2014) used hyperspectral and multispectral imaging techniques to detect frass on mature red tomato with 99% accuracy.

Real time water holding capacity of red meat (Kamruzzaman et al., 2016), blue berry fruit maturity stages (Yang et al., 2014), skin defects in bicolored peaches (Li et al., 2016), fecal contamination of apples (Kim et al., 2005), maize kernel hardness classification (Williams et al., 2009), quality of lamb meat (Kamruzzaman et al., 2012), undesirable substances in food and feed (Fernandez Pierna et al., 2012), ingesta and fecal contamination on poultry carcasses (Lawrence et al., 2003), sprouts and damages due to midge in wheat kernel (Singh et al., 2009), quality and sensory attributes of pork (Barbin et al., 2012), compositional analysis (Benson, 1993), moisture content, total soluble solids and acidity in strawberry (ElMasry, et al., 2007) and lettuce discoloration (Mo et al., 2015) have all been investigated and detected with very high level of accuracy using hyperspectral and multispectral imaging and different analytical tools and algorithms. Also studied are apple fruit firmness (Peng and Lu, 2007), vegetable soybean (Wan et al., 2012), maturity parameters of mango (Sivakumar et al., 2006), internal defect in pickling cucumbers (Ariana and Lu, 2008), pickling cucumbers (Lu and Ariana, 2008), weed in processing tomato (Zhang and Slaughter, 2010), Salmonella enteritidis and typhimurium on agar plates (Seo et al., 2014) and cucumber chilling damage (Cheng et al., 2004). Other food quality and safety control measures to which hyperspectral and multispectral imaging technologies have been applied with good successes include: assessment of apple fruit quality (Noh and Lu, 2007), identification of secondary metabolites in medicinal and spice plants (Baranska et al., 2004), ripeness classification of pear (Khodabakhshian and Emadi, 2017), prediction of pork and beef marbling (Hung et al., 2014, Aredo et al., 2017) and beef tenderness assessment (Saadatian et al., 2015).

Dos Mohammed et al. (2000) carried out quality inspection of bakery products using colour based vision system, Ngadi and Liu (2010) presented an excellent discuss on hyperspectral image processing techniques and Liu and Ngadi (2013) clearly reviewed the application of the technology to food quality and safety control. Wu and Sun (2013) provided an excellent review on the advanced application of hyperspectral imaging in food quality and safety analysis. Other excellent reviews on application of hyperspectral and multispectral imaging techniques in agricultural and food handling, processing, quality inspection, assessment, evaluation, safety and control include: Bull (1992) – sensing techniques for images of agricultural and food material, Mahesh et al. (2015) – classification and quality monitoring, Huang et al. (2014) – recent developments on food quality and safety assessment, He and Sun (2015) and Cheng and Sun (2015) – microbial contamination, ElMasry et al. (2012) and ElMasry and Nakauchi (2016) – food quality sensing and evaluation and Gowen et al. (2007) and Qin et al. (2013) – food safety and quality evaluation. Bauriegel and Herppich (2014) reviewed the application of hyperspectral and chlorophyll fluorescence imaging in early detection of plant diseases, while Wang et al (2014) addressed fruit quality.

4. PROSPECTS OF HYPERSPECTRAL AND MULTISPECTRAL IMAGING IN FOOD QUALITY INSPECTION AND EVALUATION IN NIGERIA

Prospect is simply the possibility that something will happen, chances of being successful, and possibility of being used in the future, by virtue of successful researches carried out. It could be an idea, research work or technology that might presently appear only as a tool of study with a promising future to solve real life problems.

Incorporating the emerging technologies of hyperspectral and multispectral imaging into the agricultural sector of Nigeria by first investing in researches on the appropriate methods and means of application will be of immense benefit to the country. The nation's markets are littered with unnoticed disease infected fruits which are later sold to consumers who being unable to detect that the products are spoilt, consume them and become poisoned. Using the hyperspectral imaging facility, the decay in citrus fruits which would not be detected by manual inspection, can be captured and revealed by the images. Also, many substandard and contaminated grains, flour, baked, canned, meat, fishery and poultry products find their ways into the market in Nigeria, because of inefficient methods of quality inspection employed – the human eye cannot see through a metal can or beef, neither can the normal sampling technique be able to accurately cover the whole population of product being examined. Hyperspectral and multispectral imaging inspection of products will be of help in detecting the unhealthy or contaminated ones, thereby facilitating their removal from the lot.

Other gains of the imaging technique of quality inspection and evaluation include availability of optimized technologies for increased productivity, faster and more efficient operation procedure, production of more consistent product quality, greater product stability and accuracy and safety. The techniques can be used in the detection of the presence of hair in imported dry milk and flour and presence of toxic materials in imported fertilizer, level of deterioration, outbreak of disease in poultry and cattle, presence of pathogens in liquid milk and adulteration in drugs.

Application of multispectral inspection of citrus fruit, using the NIR and UVFL images only in the analysis has been found to have the success rate raised to 86%. Success rate in the identification of anthracnose and green mould reached 95% and 97% respectively. The potential to increase sensitivity and ability to discriminate using the combination of imaging with spectroscopy in the form of spectral imaging technology covering both the multi - and – hyperspectral ranges seems promising (Geladi et al., 2004a&b). This technology makes use of light reflection at usually a large number of different wavelengths for giving out a spectral image containing both spatial and spectral information at the same time for an object.

Current state-of-the-art vision systems for quality and process control in the fish processing industries are typically limited to traditionally trichromatic (Red Green Blue) imaging. However, the aquaculture and fish processing industries are definitely areas where the added information in a spectral image can be exploited to improve the general quality and or reduce production cost, for example, assessment of fat and water content distribution in fish fillets (ElMasry and Wold, 2008), determination of freshness of cod fish (Sivertsen et al., 2011), detection of nematodes in cod fish fillets (Wold et al., 2001; Heia et al., 2007; Sivertsen et al., 2010) and detection of melanin spots in Atlantic Salmon fillets (Mathiassen et al., 2007).

The introduction of these sophisticated and novel technologies will enable the evaluating of pork freshness and beef tenderness, which would be sold immediately, to be carried out. Enormous amount of meats from abattoirs are usually sold daily in Nigeria. These products might be spoilt, but cooked and eaten without any earlier discovery, only for them to end up constituting a source of harm to consumers. The harnessing of these technologies will also make way for a time in the future when the level of food production will become optimum and limitations of technical knowhow due to economic preference for manual labour would have been improved upon in this country. They will be useful for the ever increasing marketing of food products in Nigeria.

The use of these technologies will enable the planning of marketing and utilization or processing of food and agricultural products to more durable forms to prevent spoilage to be enhanced. The technologies will also encourage the sale and consumption of high quality food and agricultural products. Food and marketing industries will be encouraged to engage more cost effective and profit reliable production strategies.

5. CHALLENGES FACING THE APPLICATION OF COMPUTER VISION IN DEVELOPING NATIONS

Application of computer vision technologies in the food industry has grown with stability over the years in developed countries. The major challenge of this technology is socio-economic. In Nigeria, where in most parts, there is economic preference for manual skill; research on computer vision is limited. Figure 8 shows the result of searching in the Web of Science data base for the total number of papers published between the year 2002 and 2006 that consist of topics related to food and computer vision. The Figure shows a clear movement that reflects an increasing interest in the field. Figure 9 shows the countries where the papers in Figure 8 were produced. In the Figure, it can be observed that among the top 15 countries, and in the 9th position is Chile, the only country from Latin America, and really, it is the only one from a developing region that is involved or included. And it is necessary to note that in the case of Latin America, the food industry is a principal economical sector. Yet, research activity in the application of computer vision to food products is limited in the region constituted of developing countries. For example, the amount of publications in the region of Latin America that appears in ISI-indexed journals is just modest. Only Chile and Brazil appear among the top 20 countries.

Not seen in the Figure, Brazil is the other Latin American country that appears in the list, in the 20th position of the rank. This rank suggests that leaving aside Chile and Brazil, research and development in computer vision applications for the food industry in Latin America or developing countries appears not to be a priority.

Worldwide there is an extensive list of publications on the applications of computer vision technologies to food industry. A special issue of the Journal of Food Engineering (Vol.61, No.1, 2004) was dedicated to and consists of several articles on specific applications of computer vision to food processing. None of the papers published in that Journal appeared to have come from Africa and Nigeria.

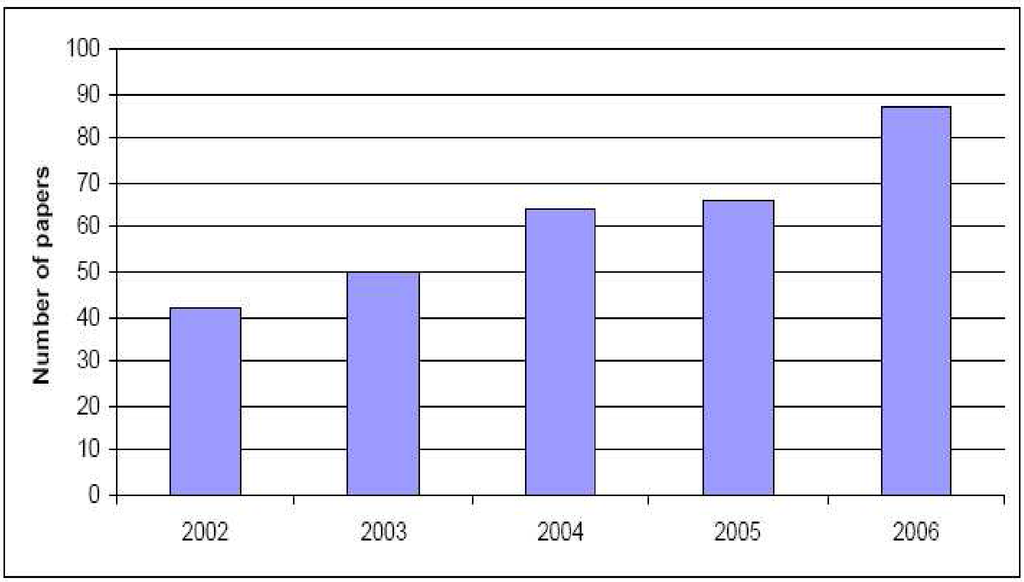


Figure 8: Number of papers registered in the Web of Science related to computer vision in food

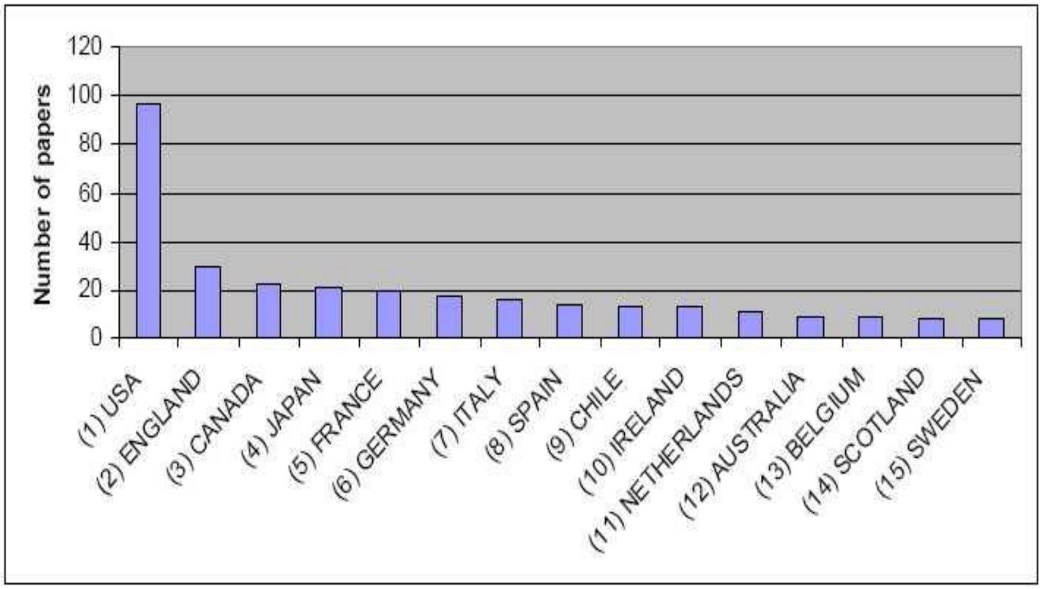


Figure 9: Rank of countries with more papers registered in the web of science related to computer visions in food

6. CURRENT CHALLENGE OF HYPERSPECTRAL IMAGING IN AFRICA

The purpose of this discuss is to challenge Nigeria into seeing the need to incorporate hyperspectral and multispectral imaging into its National technological and food processing and storage sector, despite the fact that a country such as Malawi has not fully utilized nor accessed hyperspectral imagery, even though it has the opportunities of promotions from most international agencies. It is every government's wish to have new technologies but developing countries are failing to cope with technological trends since such countries cannot meet up with the requirements due to limitations in finances and capacity (Mkondo, 2008).

Lack of resources and finances are not the only hindering factors, there is paucity of trained man power in the field and if available, there is lack of belief and confidence in local technical experts by government since the trend has been to wait for an external source to provide solutions to problems in various industrial sectors of the economy. In Nigeria, abandonment of projects is quite common and there appears to be no single project oriented towards hyperspectral and multispectral remote sensing activities in food industry. International agencies that are promoting image spectroscopy in least developed countries appear to be scarce and there are very few hyperspectral sensors that can be purchased due to fund diversion practices, even if there is an international agency that is ready to promote the technology. Malawi that tried, cannot afford such technology since inception and implementation of new technology comes at higher cost. An international agency donating projects becomes disappointed due to lack of proper maintenance, which leads to most

projects stumbling in developing countries. Nigeria cannot sustain hyperspectral remote sensing technology if the country cannot manage spectral libraries related to collection and storage of data, laboratories and spectra for reflectance of manmade and natural phenomena which are of great scientific applications.
The economic status of a country like Malawi leads to a poverty level that enables the international institutions to be the ones that will decide on the type of image processing techniques and remote sensing methodology to use in carrying out activities. An example is when working with an American agency that cannot let a beneficiary access European datasets. Hyperspectral remote sensing is a very welcome technology but countries like Malawi are still concerned with advanced image processing, complex calculations, image enhancement and access to remotely sensed datasets (Mkondo, 2008) and where Nigeria stands in is yet to be known.

Developed countries have access to remote sensing data both in hyperspectral and multispectral formats but Nigeria does not have a remarkable presence in international space science activities. It will be good practice for countries like Malawi and Nigeria to base their remote sensing decisions on their national policies, but the political will to carry projects through is a factor that is very important. For example, Malawi has been convinced about the value of remote sensing applications but the pricing of imagery is relatively high. Although it is now claimed that the prices of imagery has gone down, it is still difficult to cost and determine hyperspectral image coverage.

6.1 Hyperspectral and Multispectral Imaging Technological Capacity

Hyperspectral and multispectral imaging technologies are no easy to use technologies. The procedures and required software algorithms have not been developed to the extent where a country like Nigeria can apply them. There are a lot of spectra that can be downloaded but such spectra cannot be easily accessed and does not cover least developing countries like Malawi. A country like Nigeria requires remotely sensed data that can support food and agriculture, resources management, economic activities and inventory of natural resources and topography. . The main challenge facing Malawi is the use of remotely sensed data in various applications and the capacity to meet the remote sensing technological requirements. For a small country like Malawi and a giant of Africa like Nigeria whose mapping and remote sensing activities are limited to a few experts and under the mandate of government, there is a great need to help such countries to have a great change for management, processing and access to satellite imagery (Mkondo, 2008). There is need to enhance the capacities of developing countries like Nigeria to launch into the use of these technologies, and engage their various technological applications so as to reduce gaps in coping with trends in this information age.

6.2 Instrumentation Challenges

6.2.1 Spectrograph

A crucial component of an hyperspectral based imaging system is the imaging spectrograph. A spectrograph is equipment used to record spectra. The spectrograph cannot operate effectively at low efficiency and requires a high efficiency aberration corrected convex diffraction grating. The development of a family of Hyperspec^{TM} spectrograph using a patented off-axis configuration with a high efficiency aberration corrected convex diffraction grating has been successfully developed by Head wall photonics in the United States of America (USA). No country in Africa, including a technological nation such as South Africa and Nigeria - the so called giant of Africa – is fully into optimization of such component.

Fecal contamination on poultry carcasses in Nigeria's local meat market is not a bothering issue. Hyperspectral based imaging system that would facilitate the minimization of stray light and the absence of aberrations in on-line food monitoring, which have the tendency to retain the fidelity of the spectral image throughout the spectral region due to the very low image distortion is not available to measure small regions of contamination on these carcasses in Nigeria.

6.2.2 Push-broom measurement systems

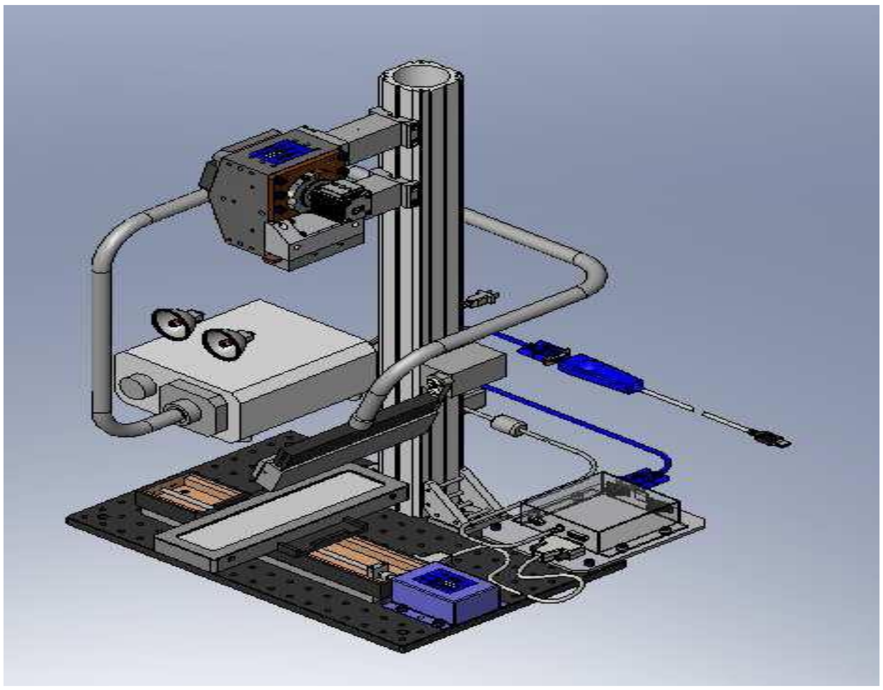
Hyperspectral detection methods are faced with the challenge of the availability or development of methods that combine the hyperspectral optical system with some methods of suitably moving the samples (food) and capturing the hyperspectral data. Two of Push-Broom measurement systems that have been developed in the USA and which have never being considered in Nigeria's remote sensing are shown in Figure 10. The first image (Figure 10a) is a push-broom based 'Starter Kit' developed for hyperspectral methods applicable in food, drug and pharmaceutical monitoring at Head wall Photonics USA.

Figure 10b is a push-broom based system developed for the same purpose at the United States Department of Agriculture (USDA) in Beltsville, MD by Moon Kin's group. Both systems use a moving stage and a high intensity light source optimized for the regions and measurements of interest.

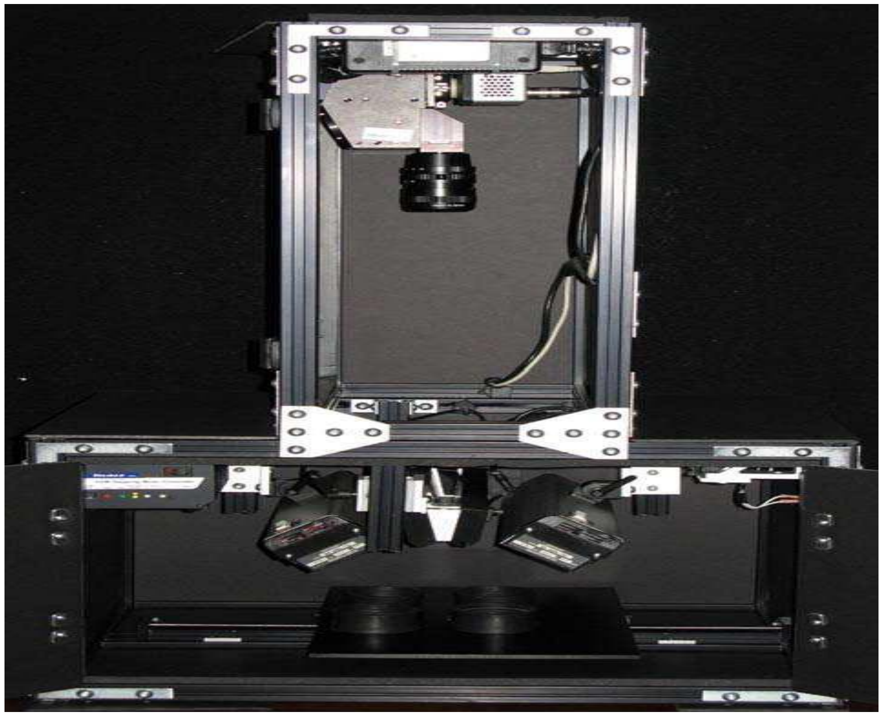
Software development is crucial to the correct operation of these push-broom measurement systems. The capturing of high frame rate images in real-time, together with the development of real-time spectral image manipulation algorithms require that particular attention be paid to software development for the push-broom measurement system.

6.2.3 Pan and tilt measurement systems

A pan and tilt system that directly scans a scene has been faced with challenges in field measurement applications. The acquisition of images in the pan and tilt system has been limited by poor coordination of camera movement and the unit has also been challenged in the measurement of spectral images by naturally illuminated object. The optimized system uses an uncooled CCD camera with 7.4μm square pixel. Image acquisition depends on the coordination of camera movement with camera frame triggering an acquisition as the Pan and Tilt Stages move in an angular direction. This optimization has been achieved by Head Wall Photonics, USA. A major challenge is that Nigeria as a developing nation is not giving much attention to technological improvement. Instrument developers appear not to have been making marks in the country's technological drives.



(A)



(B)

Figure 10: Push–Broom Hyperspectral Imaging System, A: Hyperspec™ Starter Kit and B: USDA Designed Hyper spectral Imaging System

6.2.4 Illumination in hyperspectral imaging

Optimum illumination is crucial in the design of an optimized hyperspectral measurement system. A hyperspectral imaging system design can be hindered in operation by optical losses in the optical element of the measurement system and the choice of camera which is the ultimate component responsible for the detection efficiency. The motorized push-broom systems have challenges of being near-field of action in image scope and also challenge of the designer having some control of the choice, opto-mechanical design and the spectral content of the lighting. Opto means vision. The optimization of the system is necessary but very far from developing countries including Nigeria.

6.2.5 Signal to noise in hyperspectral imaging system

The operation of a hyperspectral imaging system at high speed places challenge on the signal to noise ratio. The expected performance of the analyzer operating with direct sun light as the source of illumination and the technical specifications of a typical hyperspectral measurement configuration for the moment a sample is illuminated at specific wavelength are factors that can hinder the signal to noise ratio.

6.2.6 Challenge of food samples

The hyperspectral scanning of food samples in real-time places a particular challenge to the instrument designer. The final measurement can be affected by such parameters as variation in spatial features, presence of skin bleaches, variation of surface reflectivity, and its variation with surface orientation.
The design of the illumination system is crucial in such measurement applications and the illumination assemblies on hyperspectral imaging systems require adjustment to allow illumination to be optimized. Head Wall Photonics, USA, has also optimized the design of the illumination system assemblies to be adjustable in order to allow the illumination to be optimized for each particular application of interest. An organization such as Head Wall Photonics that is so much concerned about the optimization of technology to a better state is seriously lacking in Nigeria.

6.2.7 Spectral region

The feature that primarily determines the spectral regions is detector material and design. Typically imaging detector faces the challenge of the need of cooling to achieve optimum performance levels under real-time imaging conditions, and the farther the detector cut off is in the IR, the more unavailable cooling becomes.
Most hyperspectral sensor systems, including the design of the imaging optics and the hyperspectral imaging spectrographs are not very efficient, and optimization around the wide spectral regions provided by the detector material is needed. Noise limited measurement is a challenge and requires optimization over narrower regions. Head Wall Photonics, USA has been facilitating the optimization of hyperspectral based measurement systems and it cannot be predicted with the rate at which Nigeria technological interest is going, if this would become possible in the next decade.

6.2.8 Complex discrimination algorithms

The model available for compressing vast quantities of data is a simple detection algorithm, though extremely effective one for the particular measurement presents a challenge. More complex algorithms using chemometrics and neural network are a future challenge in USA as the physical and chemical detection appears more challenging. The consideration of these in the future is not promising in Nigeria.

6.2.9 Costs of selected hyperspectral and multi spectral imaging system

Hyperspectral imaging equipment for the UVA, Visible and NIR is quite expensive; typically between $2000 and $20,000 equivalent to NGN740000 and NGN7400000 in Nigeria currency respectively. These systems use a focusing lens, prism-grating-prism and collimating lens.
The Normalized Difference Vegetation Index (NDVI) was developed to differentiate between vegetation and non-vegetation figures. The NDVI technique requires an imaging system with a combined cost of $3500.

6.3 Challenges of Hyperspectral and Multispectral Imaging Application in Food Quality Inspection and Evaluation in Nigeria

Spectral imaging technology covering both multispectral and hyperspectral ranges are actively academic research tool for application oriented research in a variety of fields, and are yet to be developed into a tool for solving real life problems in a variety of applications ranging from airborne remote sensing to online quality control of food. Nigeria, as a developing country is still yet to fully embrace computer vision system, a lesser technology compared to spectral imaging technologies. The major problem of computer vision has been one of socio-economic effect, which increases unemployment of manual labor, when the number of operators needed in a processing line is replaced with machines. This is not suitable in Nigerian agricultural sector where manual skill is more economically preferred to the least mechanized system of farming (Tractor farming) due to poor economy, mostly among local farmers which constitute a large part of Nigeria's farming hands.

Nigeria was not included among the top 15 countries, where papers on computer vision had been published. If such a nation as China was not included in the ranking, how can one have anything to say about Nigeria that is yet to begin to participate in carrying out research in the field? The future of computer vision in food quality inspection in Nigeria appears uncertain, how much more that of spectral imaging technology. A small African country like Malawi has been convinced about the value of remote sensing applications, even though challenged by the price of imagery which is relatively high. Nigeria, an acclaimed giant of Africa cannot be said to have been fully convinced, since the negligence placed on research and technology is a known truth. The attempt to address the present research and technical challenges of hyperspectral imaging technology application and the need for spatially and spectrally optimized systems is yet to be made. The push-broom measurement systems, pan and tilt measurement systems, challenge of food samples , illuminations, signal to noise ratio, appropriate spectral regions, simple detection algorithm and more complex discrimination algorithms (to be considered in the future) need to be optimized collectively to achieve a fully functioning and accurate measurement system. This is based on the real-time food inspection requirement of hyperspectral scanning that has led to the development of spatially and spectrally optimized system. Nigeria is very far from adopting this technology, and consideration of optimization appears to be unimaginable.

Finance is an inherent problem of the agricultural sector in Nigeria. The United States Navy offered a contract on computer vision valued at $63,000,000. Spectral imaging equipment is quite expensive; worth between NGN740000 and NGN7400000. The nation is faced with the challenge of improving its agricultural economy. The high costs of automated vision systems and spectral imaging technologies worldwide cannot be over emphasized.

7. CONCLUSION

The fundamental and technological applications of hyperspectral and multispectral imaging technology in food and agriculture were reviewed, and the possibilities and benefits of using these technologies in food quality inspection and evaluation in Nigeria discussed.

In other climes, the success rate reached using the spectral imaging technology covering both hyperspectral and multispectral imaging ranges in food quality inspection and evaluation was close to 100%. The identification of anthracnose and green mould using multispectral imaging of fresh citrus had results increasing to 95% and 97% accuracies. The classification efficiencies for the feces and ingesta without dilution and diluted up to 1:5 were greater than 97.3% and 95.5 respectively. The effectiveness of a spectral imaging technology identifying adulterated samples was very high. The major challenge of using the spectral imaging technology in food quality inspection and evaluation in Nigeria was found not to only be lack of resources and finances but also the lack of belief and confidence in local technical experts by government due to the common dependence on international sources to provide solutions to problems in developing countries. The abandonment of government projects in developing countries like Nigeria after their time lapse was also noted.

Hyperspectral and multispectral technologies were found not to be easily used because the detailed knowledge of the operational procedures as well as the algorithms employed are still alien to investigators in such a country as Nigeria, and as such, their application in food quality inspection and evaluation is yet to be addressed. Successful use of hyperspectral imaging for food quality inspection, control and safety assessment in real-time in Nigeria, was also noted to be accompanied by challenges of instrumentation in the acquisition of spectral images at extremely high speeds, thereby leading to the requirement of optimization of the signal to noise ratio. Computer vision equipments were found to be too costly and unaffordable to peasant farmers with the price of imaging systems covering both the hyperspectral and multispectral regions reaching far above half a million Naira.
It is hereby suggested that the Standard Organization of Nigeria (SON) in collaboration with the Nigerian Institute of Food Science and Technology (NIFST) and the Nigerian Institution of Agricultural and Biological Engineers (NIABE) should establish and enforce high quality standards for foods being consumed in the country. This will enable the handlers to seek the use of more efficient and accurate methods of food quality inspection, evaluation and control which hyperspectral and multispectral imaging technologies provide. The installation and utilization of hyperspectral and multispectral imaging systems in food industries in the country should be a requirement for registration and operation in the country. Hyperspectral and multispectral imaging facilities should be made available and operational at all points of entry of foreign foods into the country. This will enable the influx of adulterated products to be checked. Research in the field of these imaging technologies beginning from remote sensing and computer vision, should be heavily funded, to enable investigators commence studies and follow up on the developments in the field.

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Development of a double feeder sweet potato slicing machine

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ABSTRACT

A double feeder sweet potato slicer was designed and fabricated to slice various sizes of sweet potatoes. Problems with sweet potato products manufacturers are the wastage of vegetables and uneven thickness of the slices resulting in the low quality and there is a productivity loss in the manufacturing of chips in the market due to non-availability of the proper tools. A sweet potato slicer was designed, fabricated and evaluated. The machine consists of three main units, namely the hopper, slicing unit and power transmission unit. The machine consists essentially of a hopper where peeled sweet potatoes are put, cutting disc coupled to a horizontal shaft which when in operation undergoes rotating motion and a 0.5hp electric motor. The horizontal shaft derives its motion through a mechanism coupled to an electric motor via gears for primary speed reduction and regulation. The machine was evaluated based on the following parameters which includes; throughput capacity and slicing efficiency. Test evaluation results showed that the size and weight of the samples significantly affected the slicing efficiency of the machine. The slicing efficiency of the machine increased with increasing size and weight of the sweet potatoes. The slicing efficiency ranges from 86.14% to 91.08%. The throughput capacity of the machine increased with size and weight of the potatoes ranging from 125 to 165kg/hr.

Keywords: Sweet potato; slicing efficiency; throughput capacity; double feeder slicing machine, Nigeria

1. INTRODUCTION

Potato slicing is labour intensive. Proper mechanization is required in order to meet up with the demand for its various products. Reducing the size of food raw materials is an important operation to achieve a definite size range (Henderson and Perry, 1980). The need to mechanize potato slicing is enormous as the manual method of potato slicing done in households and by rural farmers has a number of undesirable attributes and this has drawn the attention of national agricultural research to devote utmost interest and resources to engineering in operations. The sweet potato (*Ipomoea batatas*) is a dicotyledonous plant that belongs to the morning glory family, *Convolvulaceae*. Its large, starchy, sweet-tasting, tuberous roots are a root vegetable. The sweet potato is only distantly related to the potato (*Solanum tuberosum*) and does not belong to the nightshade family, *Solanaceae*. Sweet potato (*Ipomoea batatas*) can serve as animal feed and as the source of many other products (Picha, 1986). Industrially, potatoes could be used for the production of starch, alcohol and fermented beverages (Sharma, 2016). Sweet potato roots are rich sources of crude protein, minerals, carotenoids and anthocyanin (Picha, 1985). Sweet Potatoes are edible agricultural food material which provides rich sources of staple carbohydrate with high moisture content characteristic, groom in the field scale in tropical regions like Nigeria and West Africa at large. They are bulky and difficult to transport to distant processing sites, factory and market. It is widely demanded in the production of potatoes chips, animal feeds as well as other starchy food products. But due to its high moisture content, it is susceptible to spoilage during storage, by being attacked by microbial agents and some physiological factors which is a major challenge to farmers after harvest.

Therefore, the potato needs be processed into some form of dried product with longer shelf-life which could be achieved by slicing which is a form of size reduction of the product in order to enhance quick and effective drying, hence preservation and quality. Size reduction also facilitate cooking, frying in hot oil or roasting which is the most widely practiced traditional processing of potatoes for human consumption in Nigeria. The operations involved in the processing of potatoes include washing, peeling, slicing, drying, milling (FAO, 2012).

Due to uneven thickness of the slices arising from improper tools, a lot of wastage of these crops is happening, leading to low productivity and other miscellaneous damages to the crops (Ehiem et al., 2011). To ease the slicing process for domestic and industrial use, a double feeder sweet potato slicing machine was necessary to greatly reduce drudgery, bulkiness reduction, increase surface area, enhance drying rate, easy handling, increase income, enhance the shelf-life of the product, ease transportation, improve human and livestock nutrition as well as increase in market opportunities (Kamaldeen and Awagu, 2013) .

2. MATERIAL AND METHODS

2.1 Material selection

The materials used were agricultural produce and machine parts. Considering the agricultural product, sweet potato (*Ipomea batatas*) was used in the test and evaluation of the performance of the machine. The construction material for the double feeder potato slicer was selected based on sets of design specification. Material selection and construction was also influenced by availability, mechanical properties and cost of the materials including logistics. A number of factors were considered in the design of the double feeder potato slicing machine which included the physical and mechanical properties of the materials for construction. Due to the nature of the selected crop, a device for slicing is expected to be thin and sharp. It must be able to penetrate the crop and the materials for construction must neither contaminate the crops nor be corroded when in contact with water. Stainless steel materials were therefore used for fabricating components which are directly in contact with the crops being sliced.

Other considerations in designing the machine include, cutting resistance of the crops, moisture content, thickness of slices, speed of cut, maximum power requirement, power source and contamination.

2.2 Design analysis and calculation

The design analysis was carried out to determine the parameters necessary for the selection of appropriate grade and size of materials for the fabrication of the various machine components.

2.2.1 Electric motor power

The power required to slice the potato was derived as follows;
Slicing shear force, $F = 166.57N$ (determined by experiment from the hardness of the sweet potatoes)
Work done (*W*) = Slicing shear force x Distance moved by the blades on the cutting disc

$$W = F \times d \quad (1)$$

d = Distance moved by the blades on the cutting disc = Half the length of the blade = 20cm
Power (*P*) = $^{Workdone}/_{time\ (t)}$
t = Time required to slice a potato = Time experimentally determined to slice potato = 2*sec*

$$P = W\ /\ t \quad (2)$$

To ensure that the electric motor is able to drive all the machine moving parts, slice the potatoes efficiently, and to avoid any underestimation, I selected 0.5*hp* electric motor.

2.2.2 Gears

A reduction gear system was used to transmit power to the cutting disc at reduced speed and increased torque. This enables the disc to exhibit rotary motion thereby slicing the potato. The objective of the gear analysis is to determine the diameter of the gears that will produce the speed required to slice the potato. The gear ratio is given by Khurmi and Gupta (2006) as;

$$\frac{T_2}{T_1} = \frac{N_1}{N_2} \quad (3)$$

$$N_2 = \frac{N_1 \times T_1}{T_2} \quad (4)$$

Where;
N_1 = Speed of pinion (rpm) = Speed of electric motor
N_2 = Speed of gear (rpm)
T_1 = Number of teeth on pinion
T_2 = Number of teeth on gear
The mean torque experienced by the gear, T_{mean} can be calculated from;

$$T_{mean} = \frac{P \times 60}{2\pi N_2} \quad (5)$$

2.2.3 Shaft design

The objective of main shaft analysis is to determine the minimum value of shaft diameter that will withstand the torsional and bending load exerted on it. Shaft design involves determination of correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading condition.

The types of loading on the shaft are bending load, weight and reaction on the shaft, torsional load imposed from the energy input. The forces acting on the shaft when in operation are:

1. Weight of gears
2. Torsional load from gears

To estimate the diameter of the shafts used in the machine, we use the Maximum Shear Stress Theory. This theory according to Khurmi and Gupta (2006) is appropriate for shafts subjected to combined bending and twisting moments, as it is the case with the shafts in this machine. The shaft used in the machine is made of mild steel.

Weight of cutting discs are 3kg and 3.5kg respectively. Weight of the gear is 1.5kg.

The shaft is subjected to Combined Bending and Tensional Stresses. The equivalent twisting moment is:

$$T_e = \sqrt{(K_m \times M)^2} + (K_e \times T)^2 \qquad (6)$$

K_m = Combined Shock and fatigue factor for bending = 1.5

K_e = Combined Shock and fatigue factor for torsion = 1.0

T = Twisting Moment of gear shaft in Nm, T_{mean}

M = Bending moment of gear shaft in Nm,$M = 43.95Nm$, from the bending moment diagram

And the equivalent bending moment is:

$$M_e = \frac{1}{2}\left[(K_m \times M) + \left(\sqrt{(K_m \times M)^2} + (K_e \times T)^2\right)\right] \qquad (7)$$

According to Khurmi and Gupta (2006), the torsion equation and bending equation are given as:

$$T_e = \frac{\pi d^3}{16} \times \tau \qquad (8)$$

$$M_e = z\sigma, z = section\ modulus = \frac{\pi d^3}{32} \qquad (9)$$

$$d = \sqrt[3]{\frac{16T_e}{\pi \times \tau}}$$

$$d = \sqrt[3]{\frac{32M_e}{\pi \times \sigma}}$$

The diameter of the shaft was deduced from these equations above. One shaft was involved in the development of the machine. The shaft is connecting the gear to the cutting disc. After the fabrication of the machine it was tested for performance during operation. The performance efficiency for the sweet potatoes slicing machine was done on the basis of its throughput capacity and slicing efficiency.

2.3 Throughput capacity of the sweet potato slicer

Throughput capacity was defined as the ratio of the quantity of sliced materials collected from the machine outlet to the time taken.

Throughput capacity, $S_c = \frac{W_s}{T} = \frac{Weight\ of\ potatoes,kg}{Time\ taken,sec}$ (10)

Where;

S_c = Throughput capacity, kg/h

W_s = Weight of sliced material, *kg*

T = Time taken, sec

2.4 Slicing efficiency of the sweet potato slicer

The slicing efficiency (α) was defined as the weight of all slices minus weight of damaged slices to the weight of all slices multiplied by 100%.

$$\alpha = \frac{L_i - L_o}{L_i} \times 100\% \quad (11)$$

Where;

α = Slicing efficiency of slicing, %

L_i = Weight of all sliced potatoes, g

L_o = Weight of damaged sliced (unsliced) potatoes, g

2.5 Principles of operation and performance evaluation of the machine

The sweet potato slicing machine (see Figure 1), consists of the following components, namely; hopper, cutting disc, shafts, discharge outlet, slicing chamber, slicing chamber lid, frame, presser, blades, gears, bolts, connecting power supply units and electric motor. The electric motor provides the primary rotary motion required to power the machine. The motion and torque from the electric motor are transmitted to the cutting disc via gears and shafts. The cutting discs in the slicing chambers are vertically positioned. The peeled sweet potatoes are fed manually into both hoppers and reach the slicing blades on the cutting disc by gravity. The sliced potato through the critical gaps between the cutting disc plate and the blades (this determines the thickness of the sliced potato) through the exit channels into the receiver. After the fabrication of the machine, it was tested for performance during operation. The performance efficiency for the sweet potatoes slicing machine was done on the basis of its throughput capacity and slicing efficiency (see Table 1). The evaluation was carried out by feeding the machine manually for three (3) consecutive times varying the sizes. The sliced products obtained from the machine outlet was collected and separated into two groups, that is, sliced potatoes and un-sliced potatoes. The mass of each category was determined by an electronic balance. The time taken for each test run was recorded with stopwatch.

3. RESULTS AND DISCUSSIONS

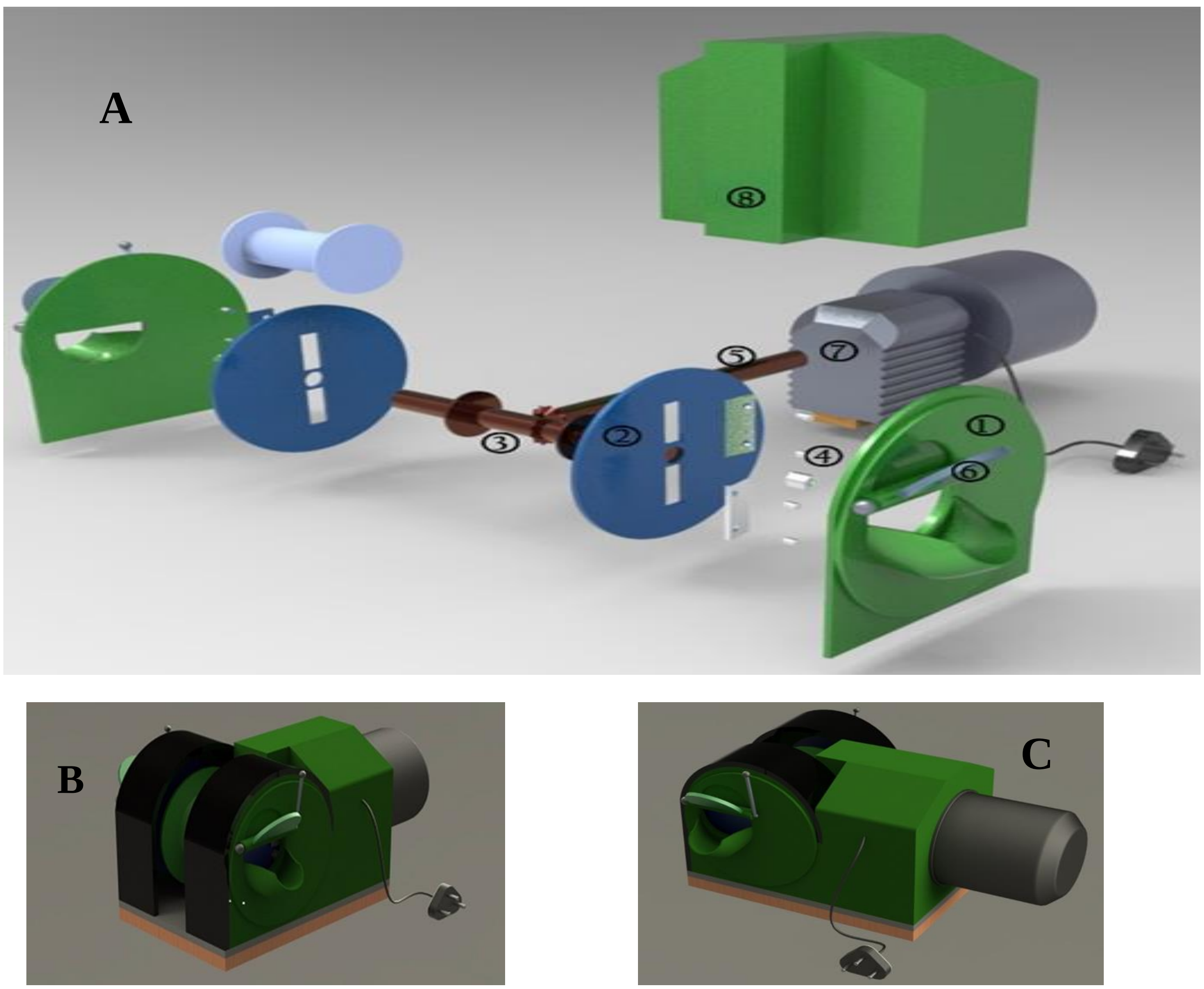
The sweet potato slicing machine was evaluated based on the following parameters; throughput capacity and slicing efficiency using some kilograms of sweet potatoes. The results obtained from the evaluation are presented in Table 1. To operate the slicer, the presser is pushed all the way down the hopper to feed the sweet potatoes in the hopper to the slicing chamber. The operating rpm of the slicer is good enough to be maintained for as long as is needed to complete the desired slicing job. It was found that the prototype slicer has a capacity of 125 to 165kg/hr which is about the same as for a multi-crop slicing machine powered by a three-phase, 1400rpm, and 2kW electric motor. The quality of the product from the prototype in terms of the uniformity of the sliced potatoes is just as good as that from the multi-crop slicing machine.

Table 1 Test results.

Mass of potatoes, kg (L_i)	Mass of unsliced potatoes, kg (L_o)	Mass of sliced potatoes, kg (L_i - L_o)	Time taken, sec (T)	Throughput capacity, kg/hr ($S_c = L_i/T$)	Slicing efficiency, % (α)
0.087±0.005	0.012±0.002	0.075±0.003	2.46±0.15	126.89±1.07	86.14±1.19
0.097±0.006	0.016±0.001	0.082±0.006	2.76±0.11	127.06±5.20	84.23±0.77
0.119±0.009	0.014±0.001	0.105±0.007	3.10±0.22	137.68±3.35	88.22±0.62
0.153±0.005	0.016±0.001	0.137±0.005	3.62±0.02	152.61±4.59	89.35±0.17
0.173±0.020	0.017±0.002	0.156±0.018	3.82±0.23	162.68±9.99	90.21±0.29
0.167±0.010	0.016±0.001	0.151±0.010	3.72±0.13	161.63±5.25	90.24±0.11
0.232±0.004	0.024±0.001	0.208±0.004	5.17±0.07	161.67±1.13	89.53±0.03
0.261±0.013	0.026±0.002	0.235±0.013	5.97±0.36	157.81±3.69	90.03±0.91
0.273±0.006	0.024±0.001	0.248±0.005	6.23±0.06	157.46±1.88	91.08±0.08

The slices gotten are 2mm and 5mm thick. Thus, the performance of the sweet potato slicing machine compares very favourably with that of the multi-crop slicing machine, while costing much less to own and operate. Noteworthy also is the fact that the machine is manually fed but automatically slices the potatoes as it reaches the cutting disc in the slicing chamber. Due to cost and availability of materials, plastics were used in place of mild steel in the fabrication of this machine. This did not affect the operation of the machine. And the beauty of it is that they are not required to have any specialized skill or knowledge to own, operate and maintain the machine.

The runs were performed thrice and the averages as well as standard deviation were obtained. From the test results (see Table 1), it is shown that the difference in weight and sizes have significant influence on the throughput capacity and efficiency of the machine. The slicing efficiency ranges from 84.23% to 91.08%. However when the quality of the sliced products is examined at different sizes, the larger the sizes of the sweet potatoes, the larger the throughput capacity and its efficiency. It was also observed that the larger potatoes gave a longer unbroken products. It was deduced that the size of the sweet potatoes signficantly affected the mass of the potatoes, i.e., as the size increases, the mass increases. This may be as a result of texture, fibre content and moisture content that resulted to high capacity for sweet potatoes.



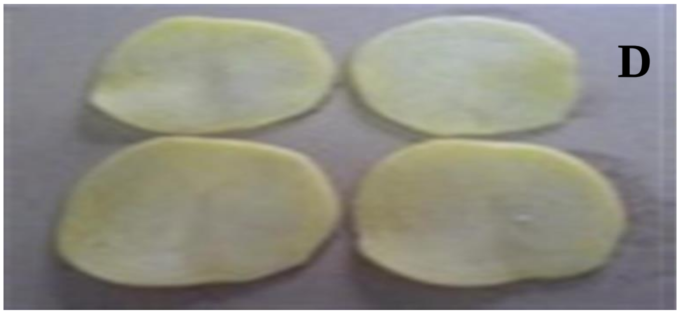


Fig. 1 Sweet potato slicing machine (exploded view-A, side view-B, back view-C, Sliced output from the slicer-D)

Note: case cover with hopper (1), cutting disc with stainless steel blade (2), gears for toque transfer and speed reduction (3), bolts (4), gear shaft (5), presser (6), 0.5hp electric motor (7), housing cover plate (8)

4. CONCLUSION

A double feeder sweet potato slicing machine was successfully designed and fabricated using locally available construction materials and technology. Test results with the machine in slicing samples of sweet potato indicated satisfactory performance with efficiency between 84 to 91%. Results showed that the size and weight of the samples significantly affected the slicing efficiency and throughput of the machine. The slicing efficiency of the machine increased with increasing size and weight of the sweet potatoes. The slicing efficiency increases with the size and weight of the potatoes and it ranges from 84.23% to 91.08%. The throughput capacity of the machine increased with size and weight of the potatoes ranging from 125 to 165kg/hr. it can be concluded that the mechanization for sweet potato processing is feasible as it will help to curb the drudgery of sweet potato slicing.

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Modeling the relationship between grading, moisture content and screen apertures in groundnut decortication

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Abstract-Whole Groundnut kernels free of bruises attract foreign exchange earnings. The appropriate selection and the interactions between the processing parameters in groundnut decortication produces clean kernels. Therefore, the focus of this study was to establish mathematical equations in order to explore and predict the possible relationships between the process inputs (grading, moisture content and screen apertures) and the measured output (clean kernels, bruised kernels and split kernels) in decorticating three selected varieties of groundnut in-shell commonly cultivated in Nigeria with a view of maximizing their kernel quality. The varieties were Samnuts 10, 14 and 18. In doing this, individual relationships were explored one at a time by keeping other process parameters constant to ensure clear interpretations. The relationships between grading, moisture content and screen apertures versus the response (efficiency of clean, bruised and split kernels) were approximated using a linear and nonlinear (quadratic or polynomials) functions. Regression analysis and design expert software (multivariate) were used to develop the mathematical models that describe the relationships between these inputs and the measured outputs.

Keywords: mathematical modeling, Groundnut Decortication, Process inputs, measured output

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is one of the world's principal oil seed crops that is rich in protein and has a high energy value. Groundnut is also an important food crop in many areas of semi-arid tropics (FAO, 1994). It is cultivated for its kernels, oil and hay for livestock (Nigam *et. al.*, 1999). Improvements in groundnut productivity and processing for a qualitative output are also crucial because of its potential to regain and increase export earnings. Growth in agriculture has generally been linked to development in other sectors which invariably contributes to poverty alleviation (Khan, 1999). Like most developing countries, majority of the rural dwellers in Nigeria depends on agriculture. In order to reduce poverty, agricultural sector must be revitalized. This will increase rural employment, trade and purchasing power for smallholder farming families, strengthen the economic capacity of rural women and improve household nutrition. It thus plays a key role in the agriculture-dependent economies of West Africa where its marketing and trade served as the major sources of employment, income and foreign exchange (Rai *et al.,* 1993; Revoredo and Fletcher, 2002; Ntare *et al.,* 2008).

Production of groundnut in Nigeria has immensely contributed to the economic development being one of the most popular commercial crops. Nigeria produces 41 % of the total groundnut production in West Africa (Echekwu and Emeka, 2005; FAOSTAT, 2010). Until 1969, Nigeria was the third largest exporter of groundnut in the world after India and China. Groundnut sector provided the basis for the agro-industrial development and contributed significantly to the commercialization and integration of the national rural sectors (Ntare *et al*, 2007).

However, groundnuts exported into Europe during the years of bumper harvests in Nigeria and other Sub-Saharan African countries (SSA) was done majorly in-shell because of high incidence of aflatoxin contamination on decorticated kernels is carcinogenesis. Aflatoxin is associated with bruises and breakages of kernels. This reduced the net profit of both the farmer and produce agent. Kernel quality as a method of measuring marketability is very essential in successful agricultural production as poor quality produce is characterized by gradual decline in value and vigour (Hartmann *et al.,* 1990). A good quality kernel has high economic value, better germination and free from disease and insect attack.

The greatest potential for providing clean decorticated kernels is the development of mathematical models that will predict the relationships between process input and measured output in order to obtain maximum kernel quality such that profit could be maximized for the production to be sustained. Such models could be utilized for the design and development of suitable home-processing equipment in order to reduce bruises and breakages on the decorticated kernels to meet the standards of the importing countries and in turn serves as leverage for creating jobs for the teaming unemployed youth population.

2. METHODOLOGY

Using the process modeling technique in design expert software, data obtained for clean, bruised and split kernels while decorticating the three selected groundnut varieties were model. The aim is to find a functional relationship that can adequately relate process input (grading, moisture content and sieve size) and process output (clean, bruised and split kernels).

Multiple regression analysis was used to develop the mathematical relationships between the respective independent variables (moisture content and screen apertures) that would predict the quality of kernel recovered from each grade of the three groundnuts in-shell varieties being decorticated in the study. The mathematical models being developed were basically focused on predicting the rate of clean kernel recovery.

Linear and quadratic mathematical models were tested for each grade of the three groundnut varieties in order to obtain possible relationships and then select the best relationships (models). The relationships between the combination of the independent variables and the response/dependent variable (clean kernels) were also established for each grade of the three groundnut varieties.

Residual plots for the selected models of each grade of the three groundnut varieties were developed to indicate the relationships on the effects of clean kernels recovery on each combination of the independent variables. Microsoft Excel Statistical Package (2010) was used to develop the residual and surface response plots.

2.1 Experimental procedure

Three groundnut varieties were selected for the study. They were Samnuts 10, 14 and 18. Each of the three groundnut in-shell varieties were graded into three different grades according to its geometric size with the aid of the developed grader. Each grade from the three varieties was then subjected to three moisture regimes (8, 10 and 20 %) and was decorticated with all the three screens (8, 10 and 12 mm) constructed. The initial decorticating trials for each variety were conducted with ungraded samples of all the grades at the chosen moisture content regimes to serve as control. All decortications were replicated three times in order to minimize error. The measured parameters studied were clean, bruised and split kernels and the process conditions (factors of interest) employed are grading, moisture content and screen apertures. These factors were varied at various levels and their effects on the quality of the clean kernels were studied and measured via three varieties of groundnut in-shell.

2.2 Procedure for model development

Multi-variable (multivariate) method of modelling was adopted. Microsoft Excel Statistical Package (2010) was used for the regression analysis to establish relationships that exist between the independent and dependent/response variable (clean kernels recovery). The data used for these analyses were arranged into linear and quadratic terms as shown in Table 1. Regression models of linear, interactions, quadratic, linear plus quadratic, linear plus interaction and full quadratic were derived from these arrangements as the case may be. Based on the *F*-values, the *P*-values for each variable, coefficient of determination, (R^2), and the adjusted R^2 values, best models were selected for each groundnut grade. Plots of observed and predicted values of clean kernels recovery were used to select the best model based on the highest values of R^2 using Microsoft Excel

Statistical Package (2010). Since maximizing kernel quality is the goal of this study, clean kernel recovery was considered as dependent variable (or response variable). Similarly, generalized mathematical models showing the relationships between clean kernels recovery and the independent variables of each grade of the three groundnut varieties were developed using regression analysis. Plots of the observed against predicted values of clean kernels recovery for the respective grades of the three groundnut varieties were also presented.

Table 1: Format used for multi-variable relationship modelling

Clean Kernels (Y)	**Linear**		**Interaction**	**Quadratic**	
	MC	**SA**	**(MC×SA)**	**(MC)²**	**(SA)²**
$\boldsymbol{Y_1}$	MC_1	SA_1	MC_1SA_1	$(MC_1)^2$	$(SA_1)^2$
$\boldsymbol{Y_2}$	MC_2	SA_1	MC_2SA_1	$(MC_2)^2$	$(SA_1)^2$
$\boldsymbol{Y_3}$	MC_3	SA_1	MC_3SA_1	$(MC_3)^2$	$(SA_1)^2$
$\boldsymbol{Y_4}$	MC_1	SA_2	MC_1SA_2	$(MC_1)^2$	$(SA_2)^2$
$\boldsymbol{Y_5}$	MC_2	SA_2	MC_2SA_2	$(MC_2)^2$	$(SA_2)^2$
$\boldsymbol{Y_6}$	MC_3	SA_2	MC_3SA_2	$(MC_3)^2$	$(SA_2)^2$
$\boldsymbol{Y_7}$	MC_1	SA_3	MC_1SA_3	$(MC_1)^2$	$(SA_3)^2$
$\boldsymbol{Y_8}$	MC_2	SA_3	MC_2SA_3	$(MC_2)^2$	$(SA_3)^2$
$\boldsymbol{Y_9}$	MC_3	SA_3	MC_3SA_3	$(MC_3)^2$	$(SA_3)^2$

where:
Y_{1-9} **-** Clean kernels recovered,
MC_{1-3} – Moisture content at 8, 10 and 20 % levels,
SA_{1-3} – Screen aperture of 8, 10 and 12 mm

3. RESULTS AND DISCUSSION

3.1 Modelling clean kernel recovery

The regression model for clean kernels recovery from the three grades of the groundnut varieties (Samnuts 10, 14 and 18) considered in this study. The ANOVA and regression output for the selected models for grades I, II and III samples of three groundnut varieties were shown in Tables 1 – 12. From the regression output, the relationship between clean kernels recovery (dependent/response variable) and the combinations of the two independent variables (moisture content and screen aperture) in linear, quadratic and interaction terms were derived. The selected equations were based on the significant higher *F*-values, coefficient of determination, R^2, the number of significant variables with respect to their *P*-values. Other models were rejected based on the insignificant levels of *F*-values in some cases.

Similarly, regression and appropriate equation models for clean kernels recovery from the three grades of Samnuts 10, 14 and 18 having highest R^2 value are as presented in equations 1 – 7:

i) Grade I

Samnut 10:

$$CK = 53.73 - 3.807MC - 3.108SA + 0.04921(MC \times SA) + 0.09417\, MC^2 + 0.581SA^2 \quad \ldots \ldots 1$$

Samnut 18 :

$$CK = 11.18SA - 0.728MC - 0.50.02 \quad 2$$

ii) Grade II

Samnut 10:

$$CK = 0.511MC + 24.36SA - 62.96 + 0.177(MC \times SA) - 0.08908MC^2 - 1.150SA^2 \quad \ldots \ldots \ldots \ldots \ldots 3$$

Samnut 14:

$$CK = 21.77SA - 22.09 - 1.593MC + 0.149(MC \times SA) - 1.130SA^2 \quad 4$$

Samnut 18:

$$CK = 82.87 - 0.720MC - 13.90SA + 1.161SA^2 \quad 5$$

iii) Grade III

Samnut 10:

$$CK = 8.495MC + 32.28SA - 113.64 + 0.552(MC \times SA) - 0.454MC^2 - 2.270SA^2 \quad \ldots \ldots \ldots \ldots \ldots . \quad 6$$

Samnut 14:

$$CK = +2.742MC + 37.88SA - 78.43 + 0.732(MC \times SA) - 0.314MC^2 - 2.844SA^2 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 7$$

Where, CK= Clean kernel, MC= moisture content, SA= Screen Aperture

3.2 Plots of observed and predicted values of clean kernels recovery

The plots of the observed against predicted values of clean kernels recovery from grade I, II and III samples of Samnuts 10, 14 and 18 were presented Figures 1 – 7. The plot shows that the residuals were in a linear, quadratic and interaction manner on the graphs suggesting that the variance of the original observations were constant. The higher level of variance (R^2) that accounted for clustered graph indicated smaller and unbiased differences between observed and predicted values of clean kernels recovery; hence a well fitted regression model for prediction. This also indicated that the terms in the model developed were adequate, hence a well fitted regression line/models for prediction. The plots also revealed that an increase in screen aperture would lead to higher values of clean kernels recovery. It also revealed slight decrease in clean kernels recovery when moisture content increases. However, higher clean kernels recovery resulted from a combination of larger screen aperture and increase in moisture content.

The plots also revealed that increase in screen aperture would lead to lower values of clean kernels recovery probably because a larger percentage of the pods would pass through the screen undecorticated due to the smaller size of the grade. Similarly, it was observed that slight increase in clean kernels recovery would be realized with increase in moisture from 8 – 10 % mainly because the smaller pods will swell thereby reduce the chances of passing undecorticated. However, a right combination of increase in screen aperture and moisture content produced slightly higher clean kernels recovery.

4. CONCLUSION

Mathematical model equations that could explore and predict the possible relationships between moisture content and screen aperture on one hand and kernel quality in terms of clean kernels recovery for the three varieties of groundnuts in-shell were developed. The relationship existing between the performances indices were found to be adequately expressed by regression equations using linear and non-linear (quadratic or polynomials) functions.

It could be generalized that the consistencies in obtaining higher values of coefficient of determination, R^2, in multi-variables modelling also confirmed a direct relationship between clean kernels recovery and independent variable (moisture content and screen aperture). It should also be noted that the fittings expressed in equations 1 – 7 holds true if the values of moisture content of the decorticated groundnuts and screen apertures of the decorticator are greater than zero.

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Table 1: Analysis of variance for selected quadratic model for the grade I groundnut in-shell (Samnut 10)

Source	*Sum of Square*	*Mean Square*	*F*	*Sign. F*	*Degrees of Freedom*
Regression	2118.5	423.70	421.70	0.000182	3
Residual	3.014	1.005			5
Total	2121.5				8
Other parameters					
R	R^2		Standard Error		No. of Observations
0.999	0.999		1.002		9

Table 2: Regression output for quadratic model for grade I groundnut in-shell (Samnut 10)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	53.73	0.06842*	19.26	-7.559	115.01	2.790
b1	-3.807	0.04608*	1.157	-7.490	-0.124	-3.290
b2	-3.108	0.450	3.584	-14.51	8.298	-0.867
b3	0.04921	0.296	0.03898	-0.07483	0.173	1.263
b4	0.09417	0.08928*	0.03797	-0.02668	0.215	2.480
b5	0.581	0.04642*	0.177	0.01734	1.145	3.280

*Significant at 95% confidence level.

Table 3: Analysis of variance for selected model for the grade I groundnut in-shell (Samnut 18)

Source	*Sum of Square*	*Mean Square*	*F*	*Sign. F*	*Degrees of Freedom*
Regression	3133.5	1566.7	456.39	3E-07	2
Residual	20.60	3.433			6
Total	3154.1				8

Other parameters			
R	R^2	Standard Error	No. of Observations
0.997	0.993	1.853	9

Table 4: Regression output for linear model for grade I groundnut in-shell (Samnut 18)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-50.02	1.87635E-05*	4.112	-60.08	-39.96	-12.16
b1	-0.728	0.000820*	0.118	-1.016	-0.440	-6.187
b2	11.18	9.91376E-08*	0.378	10.26	12.11	29.57

*Significant at 95% confidence level.

Table 5: Analysis of variance for selected quadratic model for the grade II groundnut in-shell (Samnut 10)

Source	*Sum of Square*	*Mean Square*	*F*	*Sign. F*	*Degrees of Freedom*
Regression	400.31	80.06	11.72	0.03491	5
Residual	20.49	6.831			3
Total	420.81				8

Other parameters			
R	R^2	Standard Error	No. of Observations
0.975	0.951	2.614	9

Table 6: Regression output for quadratic model for grade II groundnut in-shell (Samnut 10)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-62.96	0.299	50.21	-222.76	96.85	-1.254
b1	0.511	0.876	3.017	-9.092	10.11	0.169

b2	24.36	0.07988*	9.345	-5.376	54.11	2.607
b3	0.177	0.180	0.102	-0.147	0.500	1.741
b4	-0.08908	0.435	0.09902	-0.404	0.226	-0.900
b5	-1.150	0.08863*	0.462	-2.620	0.321	-2.488

*Significant at 95% confidence level.

Table 7: Analysis of variance for selected quadratic model for the grade II groundnut in-shell (Samnut 18)

Source	*Sum of Square*	*Mean Square*	*F*	*Sign. F*	*Degrees of Freedom*
Regression	2257.7	752.57	267.30	6E-06	3
Residual	14.08	2.815			5
Total	2271.8				8
Other parameters					
R	R^2		Standard Error		No. of Observations
0.997	0.994		1.678		9

Table 8: Regression output for quadratic model for grade II groundnut in-shell (Samnut 18)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	82.87	0.03596*	29.11	8.039	157.70	2.847
b1	-0.720	0.00107*	0.107	-0.994	-0.447	-6.762
b2	-13.90	0.06641*	5.942	-29.18	1.373	-2.340
b3	1.161	0.01124*	0.297	0.399	1.924	3.915

*Significant at 95% confidence level.

Table 9: Analysis of variance for selected quadratic model for the grade III groundnut in-shell (Samnut 10)

Source	*Sum of Square*	*Mean Square*	*F*	*Sign. F*	*Degrees of Freedom*
Regression	1659.6	331.93	12.84	0.03075	5
Residual	77.56	25.85			3
Total	1737.2				8
Other parameters					
R	R^2		Standard Error		No. of Observations
0.997	0.995		5.085		9

Table 10: Regression output for quadratic model for grade III groundnut in-shell

(Samnut 10)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-113.64	0.329	97.69	-424.53	197.24	-1.163
b1	8.495	0.244	5.870	-10.19	27.18	1.447
b2	32.28	0.174	18.18	-25.57	90.14	1.776
b3	0.551	0.06855*	0.198	-0.07804	1.180	2.788
b4	-0.454	0.09969*	0.193	-1.067	0.159	-2.357
b5	-2.270	0.08580*	0.899	-5.130	0.591	-2.525

*Significant at 95% confidence level

Table 11: Analysis of variance for selected quadratic model for the grade III groundnut in-shell (Samnut 14)

Source	*SS*	*SS%*	*MS*	*F*	*F Signif*	*Degree of freedom*
Regression	3219.6	95	643.92	11.63	0.03529	5
Residual	166.13	5	55.38			3
Total	3385.7	100				8

Other parameters

R	R^2	Standard Error	No. of Observations
0.975	0.951	7.442	9

Table 12: Regression output for quadratic model for grade III groundnut in-shell (Samnut 14)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-78.43	0.621	142.97	-533.42	376.56	-0.549
b1	2.724	0.772	8.591	-24.62	30.07	0.317
b2	37.88	0.250	26.61	-46.79	122.56	1.424
b3	0.732	0.08537*	0.289	-0.189	1.653	2.531
b4	-0.314	0.346	0.282	-1.211	0.583	-1.115
b5	-2.844	0.119	1.315	-7.030	1.343	-2.162

*Significant at 95% confidence level

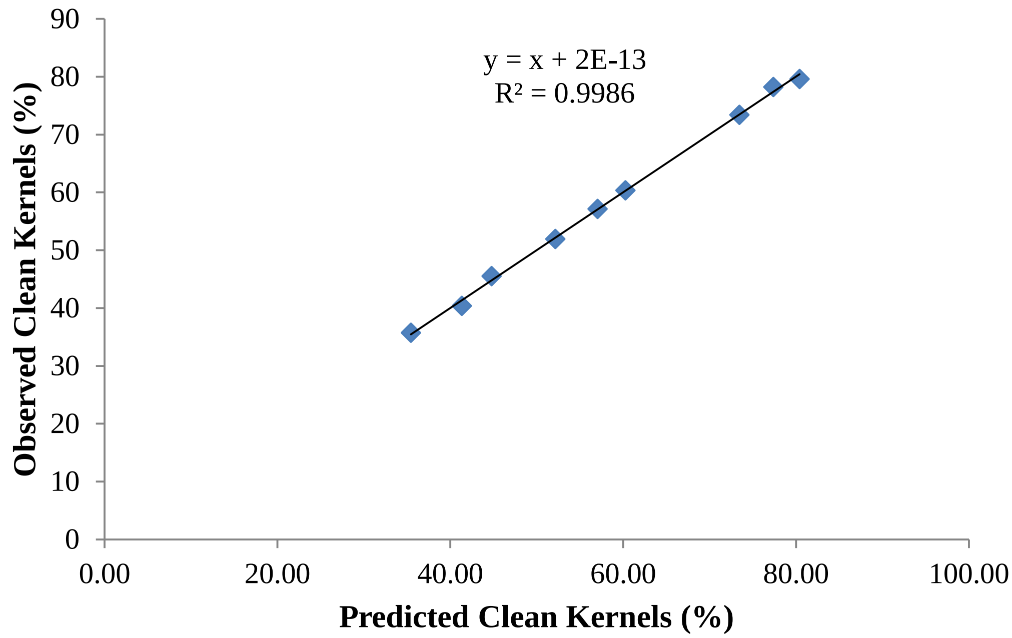

Figure 1: Observed versus predicted values of clean Kernels from multi-variable regression model for grade I groundnut in-shell (Samnut 10)

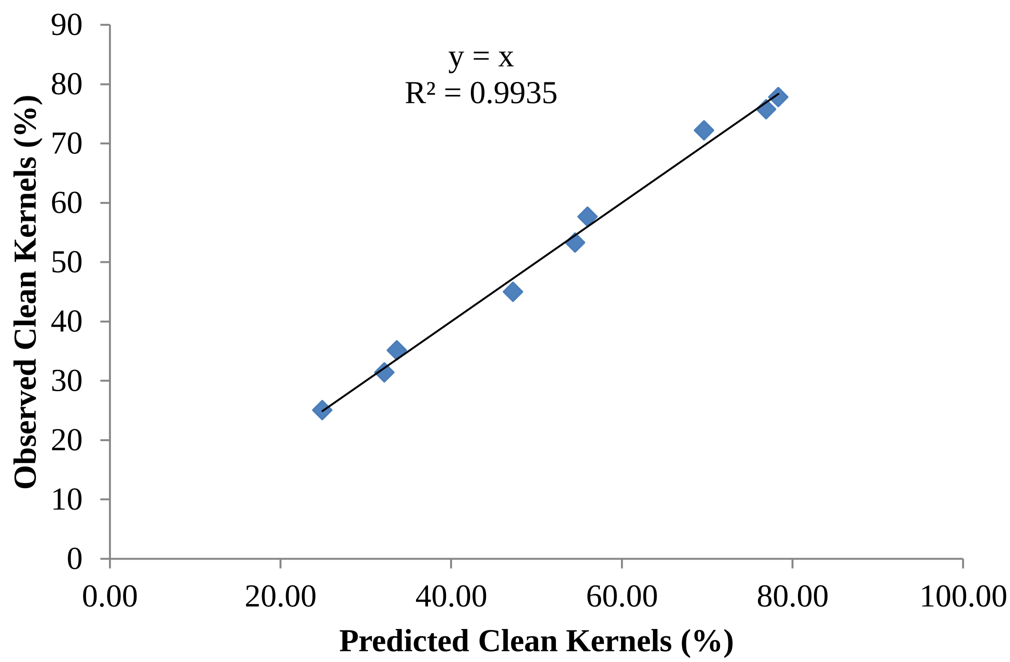

Figure 2: Observed versus predicted values of clean kernels from multi-variable

regression model for grade I groundnut in-shell (Samnut 18)

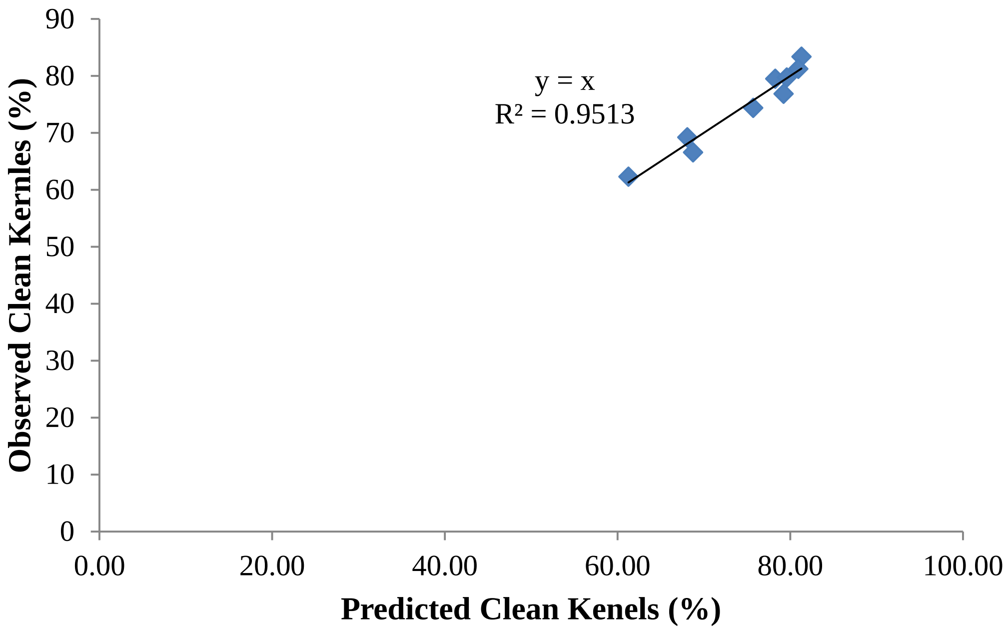

Figure 3: Observed versus predicted values of clean kernels from multi-variable regression model for grade II groundnut in-shell (Samnut 10)

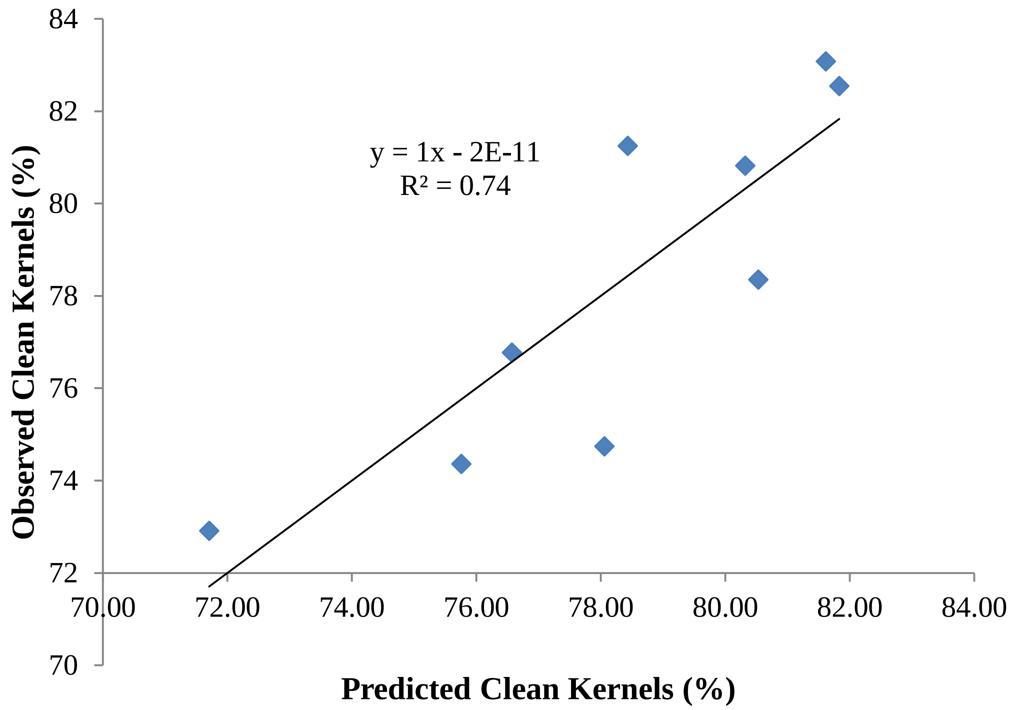

Figure 4: Observed versus predicted values of clean kernels from multi-variable regression model for grade II groundnut in-shell (Samnut 14)

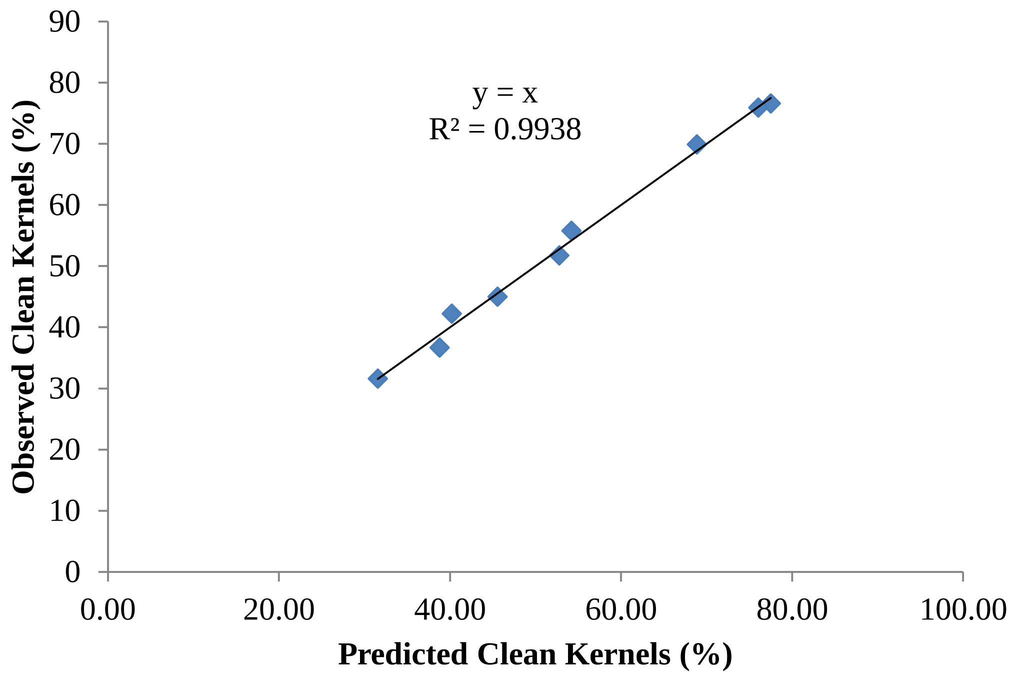

Figure 5: Observed versus predicted values of clean kernels from multi-variable regression model for grade II groundnut in-shell (Samnut 18)

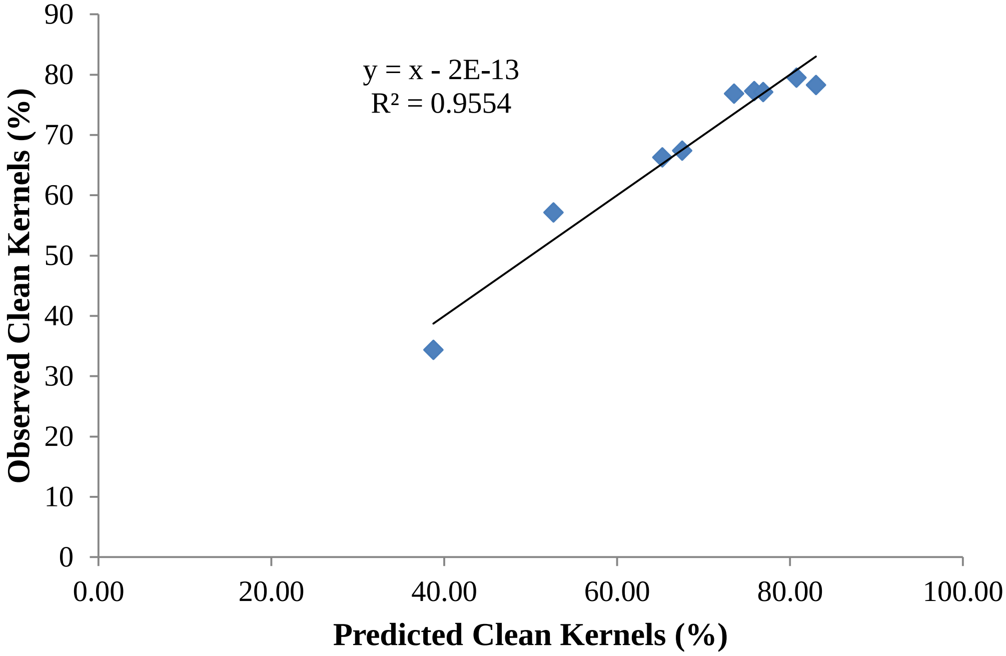

Figure 6: Observed versus predicted values of clean kernels from multi-variable regression model for grade III groundnut in-shell (Samnut 10)

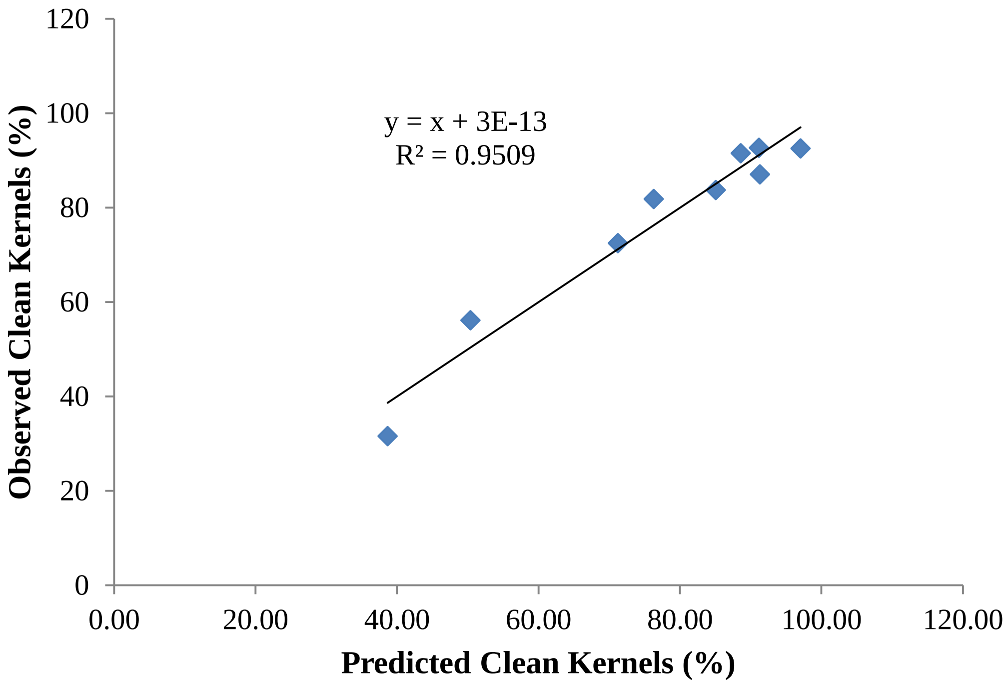

Figure 7: Observed versus predicted values of clean kernels from multi-variable regression model for grade III groundnut in-shell (Samnut 14)

Life Cycle Assessment of Local Rice Production and Processing System in Nigeria

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Abstract: The environmental impacts and energy usage associated with field production and processing were studied using life cycle impacts assessment tool with a functional unit of one kilogram (1kg) of rice. Energy productivity, efficiency and specific energy were computed and descriptive statistics were used for data analysis. The energy use pattern showed that rice production consumed an average total energy of 13270.99 MJ/ha with herbicide, insecticide, fertilizer, human labour, seed, diesel and machine hour equivalent to 52.01, 0.75, 20.19, 0.72, 8.83, 14.21, and 3.29% respectively. The energy productivity, Specific energy and energy efficiency were 0.3 kg/MJ, 3.7 MJ/kg and 3.9 respectively. A total of 11289.16 MJ (85.1%) indirect energy, 1981.83 MJ (14.9%) direct form of energy, 12004.1 MJ (90.45%) non-renewable energy and 1266.89 MJ (9.55%) renewable energy forms were used in rice production. The average total energy used for milling 500kg of rice was 776.1MJ with diesel, water, human labour, electricity and machine hour equivalent to 58.1, 8.9, 3.0, 15.7, and 14.3%, of the total energy used respectively. The energy productivity was 0.48 kg/MJ. These finding imply that rice production in the study area is mostly dependent on non-renewable and indirect energy forms, rice milling was observed to be dependent on direct and non-renewable energy forms especially diesel energy, also the high impact score of global warming is due to the high emission of CO_2 gas from fuel and combustion during field operation of rice.

Keywords: Life Cycle Assessment, Energy use, Specific Energy, Energy Efficiency

1. INTRODUCTION

Rice (*Oryza spp*) is the most widely cultivated cereal and also among the world's most important staple food crop with more than half of the world's population (IRRI, 2009) relying on it as the major daily source of calories and protein. It is planted by seeds using broadcasting method mostly between March and April, the cycle of rice is 190 days, and they begin to sprout usually a week to 30 days. The rice plant can grow to 1.8m (3.3-5.9ft) tall, depending on the variety and soil fertility. It has long/ slender leaves 50-100cm (20-39in) long and 2-2.5cm (0.79-0.98in) broad. All agricultural activities including production and processing of rice either take input from the environment or releases output into the environment, such inputs and outputs have several impacts on the environment. It is therefore of the utmost importance to access effects of inputs and outputs of various agricultural processes and production systems on the immediate environment through Life Cycle Assessment (LCA) tool. The LCA is a technique to assess each impact associated with all the stages of a process or production system from raw material processing, manufacturing, distribution, uses, repair and maintenance and disposal or recycling (Jekayinfa, *et al.,* 2013a; 2013c) which can best be achieved by compiling an inventory of relevant energy and environmental releases. It could be deduced that energy input into production and processing systems is one of the crucial data needed to achieve LCA therefore, the need for critical and optimal analysis of such input into the system arises to ensure optimal use and management of resources (Svoboda, 1995). The LCA of various agricultural products have been determined including: wheat production and processing (Jekayinfa *et al.,* 2015a); cassava starch production (Olaniran *et al.,* 2016); cassava flour production and processing (Olaniran *et al.,* 2017).

ISO 14040 (2006) stated that LCA comprises of four main stages: goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation. In the same vein, most inputs into agricultural production and processes leads to more environmental effects varying from acidification to global warming. Common categories of assessed damages or effect to the environment are global warming (greenhouse gases), acidification (soil and ocean), smog, ozone layer depletion, eutrophication, habitats destruction, desertification, land use as well as depletion of minerals and fossil fuels (Jekayinfa *et al.,* 2013c; European Commission, 2016). Energy is a highly important resource for human and industrial activities; it exists in many forms and can be classified as renewable and non-renewable. For effective optimization of cost and inputs into production and processing, several energy inputs are consumed therefore, there is need for attention on energy utilization and process improvement studies. In the light of this, the LCA of rice production and processing from planting to post harvesting operation was studied.

2. MATERIALS AND METHOD

2.1 Procedures for data Collection

Life cycle inventory was established through survey and collection of life cycle data that are related to the product system from inputs to outputs (Aru and Ikechukwu, 2018). In this study, the data collection was conducted on the rice production and processing as follows:

i. Identification of inputs and outputs for each individual unit process
ii. Undertaking mass and energy balance for the entire process
iii. Quantification of amount of product, waste, material source and energy consumption
iv. Conversion of industrial scale data to the baseline of selected functional unit (1 kg of rice)

2.2 Energy Use

The data on energy use for both production (cultivation) of rice and processing were collected and divided into fossil fuel, electricity and biomass energy. When comparing the total energy required for different activities, the biomass energy was recalculated to its primary energy carrier (Quaak *et al.,* 1999, Jekayinfa, 2006; Jekayinfa and Bamgboye, 2003, 2004, 2006 and 2007; Jekayinfa, 2007; Jekayinfa and Bamgboye, 2008; Waheed *et al.,* 2008; Jekayinfa *et al.,* 2012; Jerald, 2013; Jekayinfa *et al.,* 2013b and 2013c; Jekayinfa *et al.,* 2015b), the energy consumption was measured in MJ.

2.3 Energy Efficiency, Specific Energy and Energy Productivity

These were obtained per hectare using mathematical relations (Eqn 1-4) as given by Singh and Mittal (1992), Khan *et al*. (2004), Ozkan *et al*. (2004), Canakci *et al*. (2005), Hatirli *et al*. (2005). Each agricultural input and output has its own energy equivalent value

$$\text{Energy efficiency} = \frac{\text{Total energy output (MJ/ha)}}{\text{Total energy input (MJ/ha)}} \quad (1)$$

$$\text{Energy Productivity} = \frac{\text{Rice output(kg/ha)}}{\text{Input Energy (MJ/ha)}} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Energy input MJ/ha}}{\text{Rice yield/output (kg)}} \quad (3)$$

$$\text{Energy productivity} = \frac{\text{milled rice output (kg)}}{\text{Energy input (MJ)}} \quad (4)$$

2.4 System Boundary

This involved collection and subdivision of all operations into unit processes by flows of intermediate products which perform one or more defined function (ISO 14040, 2006). The system boundary in this study includes various stages of production from cultivation to harvest and processing until the product is ready for final consumers as presented in Cradle to grave analysis presented in Figure 1.

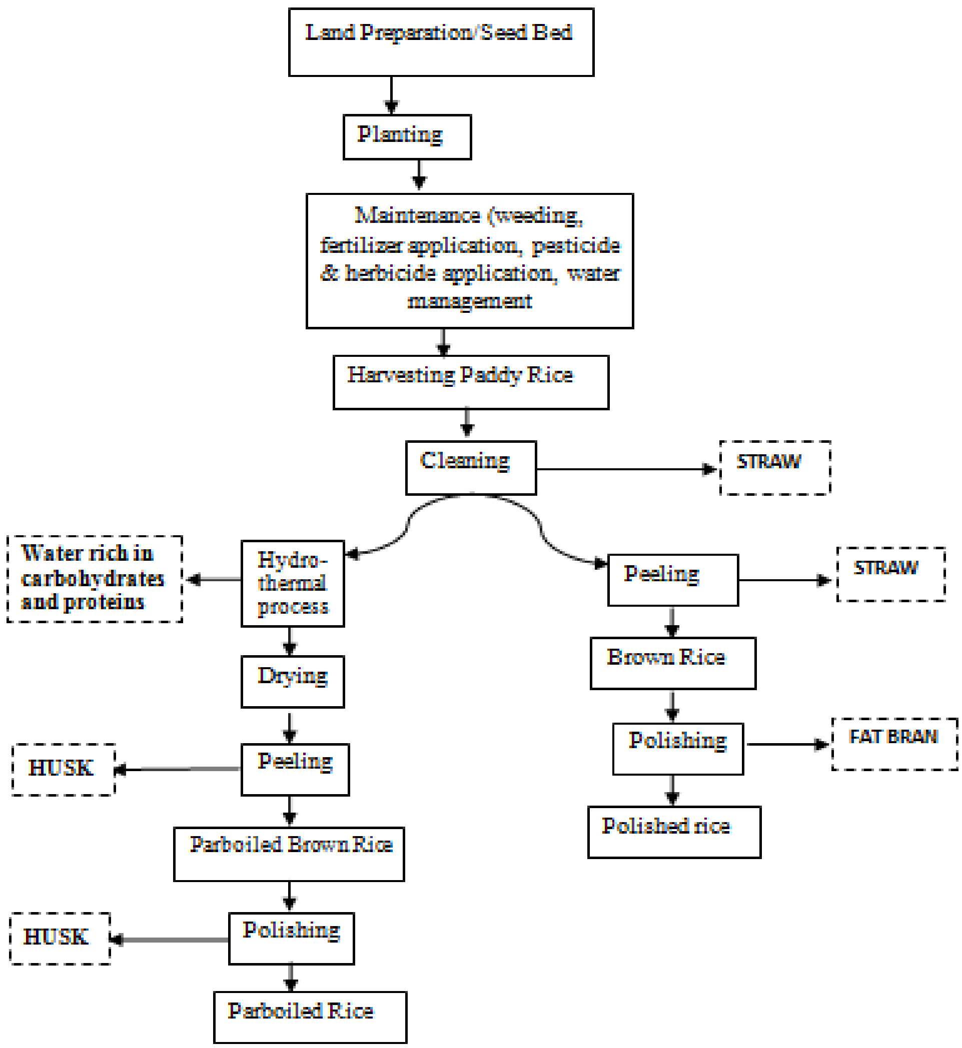

Figure 1: Flow Chart of Rice Production and Processing System

2.5 Functional Unit

A functional unit of one (1) kilogram of rice was used for the study which was limited to production of rice (land preparation, planting, maintenance, harvesting) and processing (parboiling and threshing). The flow chart showing rice production and processing system is presented in Figure 1 as given by Juliane *et al.* (2015)

2.6 Life Cycle Assessment Methodology

Four different Phases (Figure 2) according to the International Standard Organizations (ISO, 1997; Finnveden,1997; Jerald, 2013) were critically examined as follows:

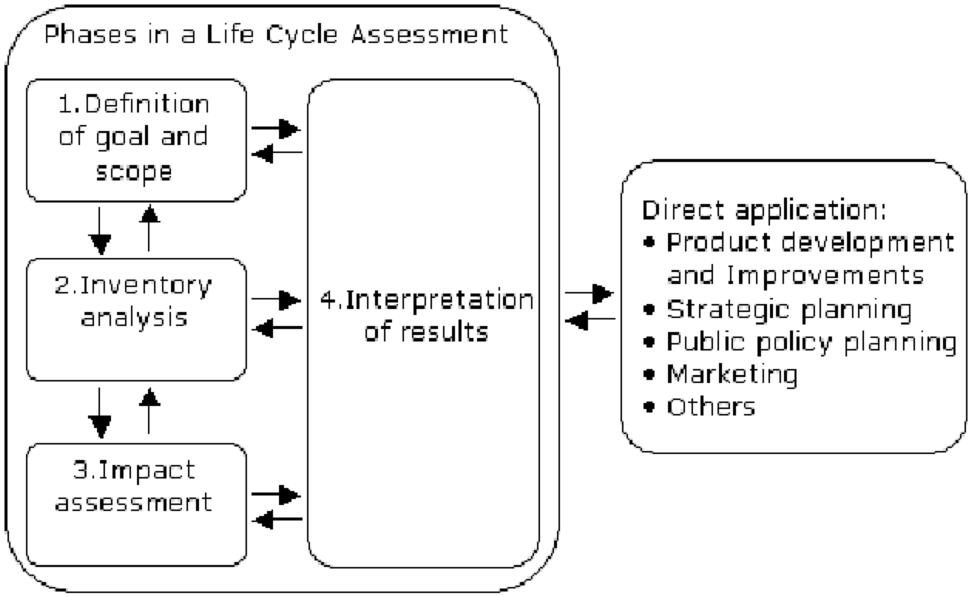

Figure 2: Stages of Life Cycle Assessment (Jerald, 2013)

i. **Goal and Scope Definition:** Studying and estimating various contributions and impacts of emission from the production and processing of rice to three major environmental impacts; global warming, acidification, eutrophication. This study was limited to the production of rice (field preparation, planting, harvesting, Drying, parboiling) and it's processing (De-husking, milling) however, transportation of rice is not included in the analysis due to lack of relevant data.

ii. **Inventory Analysis:** This step includes compilation and quantification of inputs, outputs and emissions of rice production and processing system throughout its life cycle. The data from rice cultivation to harvesting were reviewed and collected however, unavailable data were obtained from scientific databases and a summary of processes included data sourcing, principles of allocation applied and site specific inventory data. Questionnaires, interviews and environmental reports were used.

iii. **Impact Assessment:** The life cycle impact assessment aimed to examine the product system from an environmental perspective using impact categories and category indicators connected with life cycle inventory results. The environmental impacts were quantified in terms of a common unit, contributing elements and characterization factors. The used impact assessment categories in this study covered global warming arising from greenhouse gas emissions, acidification from acid gas emissions, and eutrophication as a result of nitrifying and phosphorus emissions (Martin *et al.* 2000; Jerald, 2013). The Life Cycle Impact Assessment (LCIA) included understanding and evaluating the significance and magnitude of the potential environmental impact of the product system (ISO, 1997; Jekayinfa *et* *al.*, 2013) which were grouped into impact categories and reported in terms of equivalent quantities of reference substances, for instance, CO_2 for climate change impacts, SO_2 for acidification, NO_3 for eutrophication. Three impact categories were considered in this study including: global warming, acidification and eutrophication (Frank, 2012; Jerald, 2013 and Jekayinfa *et al.*, 2013). Thus, this phase included the following classification (assigning different inputs and outputs to different impacts categories based on the expected types of impacts to the environment) and characterization (assessing relative contributions of each input and output to its assigned impact categories were assessed and the contributions were aggregated within the impact categories) (Thomassen and De Boer, 2005; Waheed *et al.*, 2007; Thomassen *et al.*, 2008, 2009).

iv. **Interpretation of findings**: Life cycle assessments are performed in order to systematically examine a products life cycle from raw materials to the final disposal of products. The findings of either the inventory analysis or the impact assessment, or both, were combined in line with the defined goal and scope to draw appropriate recommendations from the results

2.7 Life Cycle Inventory

Emission estimation methods specified in literature was used, characterization factors were used to convert values related to the functional unit into modeled environmental inputs and outputs data, aggregated inventory table for Life Cycle Assessment of rice production and processing were also obtained from literature. The life cycle inventory (LCI) assessment was done by the use of emission estimation methods specified in literature by *California air resources board institutional guidance for mandatory greenhouse gas emission reporting (2008)*, *Emission estimated techniques manual for combustion engines (2002) and direct emission from mobile combustion sources (2008) and reported by* Jimenez-Gonzalez and Overcash, (2000; 2001), Jimenez-Gonzalez *et al*. (2000) and Jekayinfa *et al.* (2013). The characterisation factors which were used to convert the values related to the functional unit into modeled environmental inputs and outputs data were also sourced from literature (Phong *et al*., 2010; Liang *et al.*, 2005; IPCC, 2006, 2007; ISO, 1997; ISO International Standard 14040, 2007; Oenema *et al.*, 2005, Jekayinfa *et al.*, 2013). The emission estimations used were stated in Equations5 -10 as follows:

1. C$o_2$emission from mobile and stationary engines

$$CO_2 emission\ (kg) = Fuel\ combusted\ X\ HHV\ x\ EF_{CO_2} \quad (5)$$

2. Co_2 emission from biomass

$$CO_2 emission\ (kg) = \mathrm{Heat} \times \mathrm{CCEF} \times 3.664 \quad (6)$$

3. $N_2o$and CH_4 emission from mobile engines

$$\mathrm{N_2O\ and\ CH_4\ emission\ (kg)} = \mathrm{A_s} \times \mathrm{EF} \quad (7)$$

4. $N_2O$and CH_4 emission from stationary engines

$$\mathrm{N_2O\ and\ CH_4\ emission\ (kg)} = \mathrm{Fuel} \times \mathrm{HHV} \times \mathrm{EF} \quad (8)$$

5. No_x, SO_2 and CO emission from mobile engines (fuel use basis)
   $$Emission = fuel \times LF \times EF_i \qquad (9)$$
6. No_x, So_2 and CO emission from stationary engines
   $$Emission = P_{kw} \times OP\ (hrs) \times EF_i \times [1 - \frac{ER}{100}]$$
   (10)

Where:

Fuel combusted = mass or volume of fuel used in kg or liters

HHV = Default high heat value supplied or calorific value (45MJ/Kg for Diesel fuel)

EF_{co2}= Emission factor for CO_2 in fuel =10.15kg/gal for diesel = 2.91 kg/kg(density =860kg/m^3)

Heat=Steam x B

Steam =Actual steam generated (kg)

B=Boiler design heat input/Boiler design steam output

CCEF=Default carbon content emission factor provided in kg C/MJ

A_s= Activity level (miles^2)

EF_i= Emission factor (kg/Kg) =8 x 10^{-6} ,4.5 x 10^{-4}, 9.84$10^{-3}$,1.05 x 10^{-2} and 1.14 x 10^{-3} forN_2O, CH_4, CO, NO_x and SO_2 respectively

LF= Load factor=0.55 for wheeled tractor

P_{kw}=engine power in kW

OP=Operating time of the engine (hours)

ER=emission reduction technology (wt%)

(1-ER/100)= 1.0,0.8 and 1.0 for CO,NO_x and So_2 respectively.

The emissions from fertilizer use were calculated as specified by Delucchi and Lipman (2003); Wood and Cowie (2004). Similarly, the emissions from insecticide and herbicide use were calculated from the methods specified by Rafaschieri *et al.* (1999). The emission of N_2O from Nitrogen use was calculated by a method used in previous studies (Delucchi and Lipman, 2003) and given as Equation (11).

Loss 1.00=+(0.0125×kg Nitrogen application) (11)

NO_x and CH_4 emissions were computed by assuming 20% of applied Nitrogen and 10 g/kg Nitrogen according to Delucchi and Lipman (2003).

(1– ER /100) 1.0, 0.8 and 1.0 for CO, NO_x and SO_2 respectively

ER emission reduction technology (wt%).

2.8 Statistical analysis

Analysis of variance by one-way ANOVA was performed to analyse the variation in environmental impact per kcal and per kg product, with the entire production and processing system as a factor. One-way ANOVA was also used to analyse the variation in environmental impact per kg product. Duncan's multiple range tests was used for multiple comparison of impact means of the entire production and processing system. Statistical analyses were performed using SPSS (IBM SPSS Statistics 20)

3. RESULTS AND DISCUSSION

3.1 Energy Use

It was observed that hydrothermal processing consumes the largest energy in the entire production and processing line for *Oryza sativa* excluding transportation with cleaning operations consuming the least energy in the cradle to grave analysis with an approximate energy loss of 4% for the entire system, these findings are in similar trend with Jerald (2013) report for Life Cycle Assessment of food processing by Solhee *et al.* (2018) in Environmental implications of Eco-Labeling for rice farming Systems. The energy consumption for the major unit operations for rice production and processing considered in this study is presented in Figure 3.

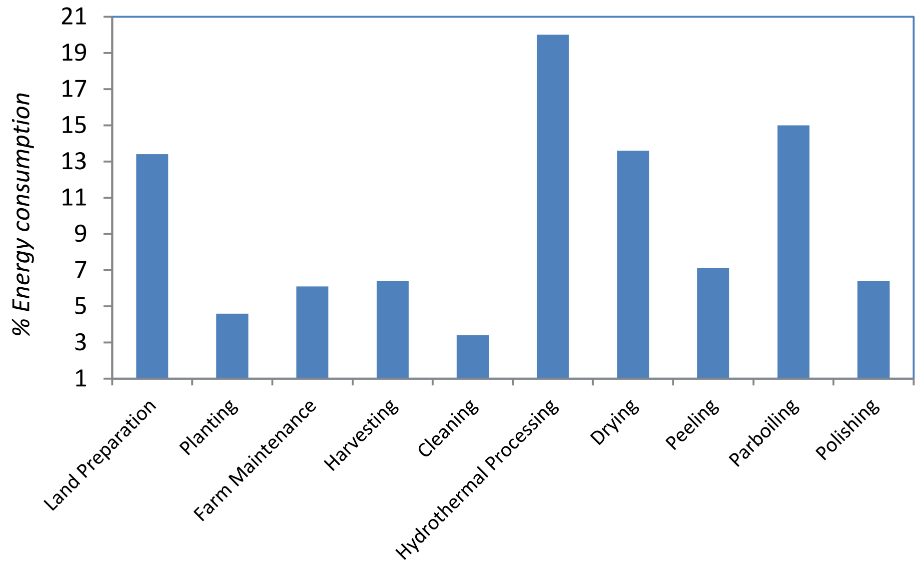

Figure 3: Percent Energy Use of Rice Production and Processing

NPK 15:15:15 brand is the most widely used fertilizer for rice production within the scope of the study. The energy equivalent for a kilogram of NPK fertilizer derived from ratio of the elements (N, P and K) in 50kg bag of the fertilizer gives 16.67 kg for each of the three elements N, P, and K. However, from literature, the energy equivalent for elemental N, P and K were 60.60 MJ, 11.10 MJ and 6.70 MJ respectively thus, the quantity of each element when converted to its energy equivalent was obtained as 1010.202, 185.037 and 111.689 MJ for N, P and K respectively giving a total of 1306.928 MJ. This implies that a 50 kg bag of NPK 15:15:15 fertilizer is equivalent to 1306.928 MJ of energy, while a kilogram of the fertilizer is equivalent to 26.14 MJ of energy. The energy use pattern per hectare of rice production is presented in Table 1, while the energy inputs in the forms of direct and indirect, renewable and non-renewable energy per hectare of rice production is presented in Table 2 and the total energy input in form of direct, indirect and renewable, non-renewable for milling 500kg of rice is presented in Table 3.

Table 1: Energy use pattern per hectare in rice production

Input	Quantity/ha	Total energy equivalent (MJ)	%
Human labour (hr)	48.7	95.45	0.72
Machinery (hr)	6.97	437.02	3.29
Herbicide (lit)	29	6902	52.01
Insecticide (lit)	0.5	99.5	0.75
NPK fertilizer (kg)	102.5	2679.2	20.19
Diesel (lit)	33.5	1886.38	14.21
Seed (kg)	79.69	1171.44	8.83
Total Energy Input (MJ)	-	13207.99	100
Energy efficiency	-	3.9	-
Energy productivity (kg/MJ)	-	0.3	-
Specific energy (MJ/kg)	-	3.7	-

Table 2: Energy inputs in the forms of direct and indirect, renewable and non-renewable energy per hectare of rice production

Energy forms	Total energy Equivalent (MJ/ha)	%
Direct Energy *a*	1981.83	14.9
Indirect energy *b*	11289.16	85.1
Total	***13270.99***	***100***
Renewable energy *c*	1266.89	9.55
Non renewable energy *d*	12004.1	90.45
Total	13270.99	100

Where: a is Human labour & diesel, b is fertilizer, insecticide, herbicide, machinery, & seed; c is Human labour and seed and d is Diesel, fertilizer, insecticide, herbicide and machinery.

Table 3: Total energy input in form of direct, indirect and renewable, non-renewable for milling 500kg of rice.

Energy forms	Total energy Equivalent (MJ/ha)	%
Direct Energy *a*	665.1	85.7
Indirect energy *b*	111	14.3
Total	***776.1***	***100***
Renewable energy *c*	92.8	12
Non renewable energy *d*	683.3	88
Total	***776.1***	***100***

Where: a is water, diesel, electricity and human labour, b is machinery, c iswater and human labour and seed and d is electricity, machinery, diesel.

3.2 Life Cycle Inventory (LCI)

Table 4 shows the detailed LCI of rice production and processing system. The impact category assessed by this study is limited global warming, eutrophication, and acidification as presented in Table 5 while the characterization factors and units used for the characterization of the emissions classified into impact categories is presented in Tables 6 and 7 respectively.

Table 4: Summary of Inputs, Outputs and Emissions for Production of 1 kg of Rice

Input/Output	***Amount***
Diesel (MJ)	4.8705E -02
Electricity (MJ)	6.3750E- 03
Energy used in transportation on diesel (MJ)	1.6550E -01
Rice husk (kg)	1.1156E – 01
Ammonium sulfate (kg)	2.5500E- 04
2,4 Dichlorophenoxy acetic acid (kg)	
Some environmental output emissions from fuel combustion	
Carbon dioxide CO_2 (g)	1.0927E + 02
Methane CH_4(g)	1.4706E – 01
Nitrogen dioxide N_2O (g)	8.8236E - 04
Carbon monoxide CO (g)	2.9412E – 02
Nitrogen oxides NO_X(g)	1.4706E – 01
Emissions due to electricity use	
CO_2 (g)	3.5818E + 01
CO (g)	9.6136E – 03
NO_X (g)	1.1810E – 04
SO_2 (g)	3.1720E – 05
Emission due to transportation	
CO_2(g)	1.7242E + 01
CH_2(g)	2.3205E- 03
CO (g)	4.6410E – 03
NO_X(g)	2.305E – 02
Emission due to rice husk combustion	
CO (g)	4.5702E – 01
NO_X(g)	1.6092E + 00
SO_2(g)	2.0598E – 01

Sakaorat *et al.*(2009)

Table 5: Classification of Results for the Production and Processing of 1 kg of Rice.

Environmental impact category	Emissions	Amount (kg)
Global Warming	CO_2	2.82882 E +00
	CH_4	2.75401 E -04
	N_20	4.8960 E-06
	CO	1.96702 E -03
	SO_2	2.2789 E-04
Acidification	NO_x	2.09897E-03
Eutrophication	NO_x	2.09897E-03
	N_2O	4.8960E-06

Table 6: Characterization Factors for the Production and Processing of 1 kg of Rice

Impact category	Contributing elements	Characterization	Unit
Energy use	Energy consumption	Factors	MJ
Global warming[a]	CO_2	1	
	CH_4	25	
	N_2O	320	gCO_3- Equivalent
	CO	2	
	SO_2	1	
Acidification[a]	NO_X	0.7	
	NH_3	1.88	gSO_2- equivalent
	NO_3	1	
Eutrophication	NO_2	1.35	
	NO_X	1.35	
	N_2O	2.85	
	NH_3	3.64	gNO^-_3 – equivalent
	N	4.43	
	PO^{3-}_4	10.45	
	P	32.03	

[a]Based on Denmarks LCA Handbook (Wenzl, 1997)

Table 7: Characterization Results for the Production and Processing of 1 kg of Rice

Environmental impact category	Total impact score
Global warming, $kgCO_2$-eq	2.83129E+00
Acidification, $kgSO_2$–eq	2.32686E-03
Eutrophication, $kgNO^-_3$ –eq	2.10387E-03

3.3 Discussion

The production and processing of rice is also associated with some unpleasant waste production to the environment which could not be quantified by the LCA tool and this include husk disposal, carbon monoxide discharge from vehicles transporting harvested paddy from farm to processing house, dust to the air and discharge of cleaning and waste water from parboiling to the environment.

The result of the characterization for production and processing of 1 kg of rice as shown in Table 4 indicates that global warming has the highest impacts score which is due mainly to high combustion of diesel in the production and processing of rice. About 90% of the of the global warming inputs to the production and processing line of rice are associated with carbon monoxide emission from internal combustion engine used for threshing, transportation and smoke from parboiling of paddy, and use of fertilizers. Also, carbon dioxide (CO_2) contributes to the high impact score of global warming and this is due to the incomplete combustion of the high carbon fuel. Diesel used as fuel or source of energy in the production of fertilisers, mobile field operations and stationary engines such as generators, dryers and threshers for the processing of the grains also contribute to global warming, a similar trend was reported by Jekayinfa *et al.* (2013); Jerald (2013); Solhee *et al.* (2018).

The world today is on a drive to reduce greenhouse gases, in order to reduce this harmful effect, the options include enhanced production technology such as minimizing the use of chemicals like pesticides and herbicides. Also, since NPK fertilizers are the most commonly used fertilizer in rice cultivation which also contribute global warming environmental impact (a similar trend was also reported by Solhee *et al.*,2018), a replacement of this fertilizer with manures and other organic and domestic wastes will be a very good alternative, pre-fermented compost from farm residues or addition of nitrate or sulfate containing more of nitrogen fertilizer to suppress methane gas production (Jerald, 2013) will be a better alternative. Moreover, encouraging the use of fuels derived from biological sources such as biodiesel in internal combustion engines instead of fossil fuels will in turn reduce the emission causing global warming.

Eutrophication is an impact on ecosystems from substances containing Nitrogen and Phosphorus. The impact score of eutrophication which is the pollution of the body of water from pesticides and herbicides to cause deficiency of oxygen comes after the high impact score of global warming while ozone layer depletion has the least impact score. The results of this study also support a recommendation for agricultural policies including direct payment for environmentally friendly farming, marketing for agro-food industries, and an environmental assessment of the agricultural sector.

4. CONCLUSION

The life cycle of rice production and processing was investigated with the assessment of the various potential impacts of inputs, output, and emissions to and fro the system. The energy input and output, energy efficiency in rice production and processing were estimated. Life cycle assessment has proved to be a useful tool to assess the environmental impacts of rice production and processing in Nigeria. The impact category assessed by this study is limited to global warming, eutrophication and acidification. The result of the characterization for production and processing of 1kg of rice indicates that global warming has the highest impact score and this is due to high combustion of diesel in the production and processing system. Carbon dioxide (CO_2) and carbon-monoxide contributes majorly to the high impact score of global warming and this is due to the incomplete combustion of the high carbon fuel used in rice production and processing; a good solution to this include the use of bio-fuel for internal combustion engines and compost manure for production of rice.

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Modeling Bioremediation of Spent-Hydrocarbon Polluted Afisols

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ABSTRACT

In the current work, statistical models were developed for the prediction of microbial biodegradation of spent hydrocarbons in polluted soils. A parcel of land measuring a square meter was contaminated with spent hydrocarbons; engine oil, gasoline and grease. Ten strains of microbes belonging predominantly to the genera; Pseudomonas sp. were found to be indigenous to the site. Their population was augmented by the bacteria Pseudomonas eschiridia. Environmental conditions at the site were improved by pulverization, moisturization, shading, and oxygenation with 500ml of hydrogen peroxide. Four evaluations were made from two bioreactors with two experimental runs each, making a total of four reactors namely, R_1B_2, R_1B_3, R_2B_2, R_2B_3. Initial contaminant concentration (Total Organic carbon Concentration) of 281.7mg/g of soil and initial microorganism population (TSS) of 960mg/g of soil was found. The result obtained from the graph and evaluations made gave rise to a typical model equations of the type; $C= C_0e^{-Kt}$. These relationships which describe the pattern of TOC depletion with time for the studied plots gave 12.93, 63.20, 202.8 and 164mg/g of soil/day after the 30th day for R_1B_2, R_1B_3, R_2B_2 and R_2B_3 respectively. It was estimated from the developed models that the degradation rates for R_1B_2 will be 2.2 X 10^{-18}mg/g of soil/day after 3years, assuming that environmental conditions remain reasonably the same. It was generally observed that the TOC Values tended to zero with time, which indicated that the state of stability (innocuous state) was gradually being achieved. From the findings of this work it is posited that, bioremediation of spent hydrocarbons from polluted urban and rural soils can be achieved using indigenous soil micro-organisms with or without bio-augmentation.

Keywords: Bioremediation, Modeling, Total Organic Carbon, Afisols, Chi-Square, Nigeria.

1. INTRODUCTION

Bioremediation is the process whereby organic wastes are biologically degraded under controlled conditions to an innocuous state, or to levels below concentration limits established by regulatory authorities (King *et al.*, 1997). By definition, bioremediation is the use of living organisms, primarily microorganisms, to degrade the environmental contaminants into less toxic forms. It uses naturally occurring bacteria and fungi or plants to degrade or detoxify substances hazardous to human health and/or the environment. Microorganisms may be indigenous to a contaminated area or they may be isolated from elsewhere (cultured for inoculation) and brought to the contaminated site (Ellis *et al.*, 2000). Contaminant compounds are transformed by living organisms through reactions that take place as part of their metabolic processes. Biodegradation of a compound is often a result of the actions of multiple organisms. According to Ellis *et al.* (2000), Bio-augmentation is the importation of microorganisms to a contaminated site. For bioremediation to be effective, microorganisms must enzymatically attack the pollutants and convert them to harmless products.

The quality of life on Earth is linked inextricably to the overall quality of the environment. In early times, we believed that we had an unlimited abundance of land and resources; today, however, the resources in the world show, in greater or lesser degree, our carelessness and negligence in using them. The problems associated with contaminated sites now assume increasing prominence in many countries. Contaminated lands generally result from past industrial activities when awareness of the health and environmental effects connected with the production, use, and disposal of hazardous substances were less well recognized than today. The problem is worldwide, and the estimated number of contaminated sites is significant. It is now widely recognized that a contaminated land is a potential threat to human health, and its continual discovery over recent years has led to international efforts to remedy many of these sites, either as a response to the risk of adverse health or environmental effects caused by contamination or to enable the site to be redeveloped for use.

The conventional techniques used for remediation have been to dig up contaminated soil and remove it to a landfill, or to cap and contain the contaminated areas of a site. These methods have some drawbacks. The first method simply moves the contamination elsewhere and may create significant risks in the excavation, handling, and transport of hazardous materials. Additionally, it is very difficult and increasingly expensive to find new landfill sites for the final disposal of the material. The cap and contain method is only an interim solution since the contamination remains on site, requiring monitoring and maintenance of the isolation barriers long into the future, with all the associated costs and potential liability. A better approach than these traditional methods is to completely destroy the pollutants if possible, or at least to transform them to innocuous substances. Some technologies that have been used are high-temperature incineration and various types of chemical decomposition (e.g., base-catalyzed dechlorination, UV oxidation). They can be very effective at reducing levels of a range of contaminants, but have several drawbacks, principally their "technological complexity, the cost for small-scale application, and the lack of public acceptance", especially for incineration that may increase the exposure to contaminants for both the workers at the site and nearby residents. Thus this has put

Bioremediation in a higher ranked position when compared to other remediation technologies (Bragg *et al.,* 1994).

Bioremediation is an option that offers the possibility to destroy or render various contaminants harmless using natural biological activity. As such, it uses relatively low-cost, low-technology techniques, which generally has a high public acceptance and can often be carried out on site. It will not always be suitable, however, as the range of contaminants on which it is effective is limited, the time scales involved are relatively long, and the resultant contaminant levels achievable may not always be appropriate. Although the methodologies employed are not technically complex, considerable experience and expertise may be required to design and implement a successful bioremediation program, due to the need to thoroughly assess a site for suitability and to optimize conditions to achieve a satisfactory result (Ibekwe *et al.,* 2006; Mohammed-Sichani *et al.,* 2017).

Because bioremediation appears to be a good alternative to conventional clean-up technologies, research in this field, especially in the developing countries is rapidly increasing and gradually phasing off other remediation technologies (Onyenjoro, 2011). Bioremediation has been used at a number of sites worldwide, including Europe (Bragg *et al.,* 1994; Atlas 1995a; Atlas 1995b; Jain *et al.,* 2011), with varying degrees of success, because of the cold climatic condition. Techniques are improving as greater knowledge and experiences are gained, and there is no doubt that bioremediation has great potential for dealing with certain types of site contamination. Soil bioremediation would be impossible without a model and many of the up to date models have been very advanced to be employed or bought by an average Nigerian. Some of the models developed for predicting and designing bioremediation technologies in Europe cannot be effectively deployed for other regions because of the site specificity of such models (Onyenjoro, 2011; Abdusalam, 2012a; Sanni and Emetere, 2016;). There is therefore need to develop effective models of bioremediation for each region concerned. The need to work up models that would make the transfer of bioremediation technology employable and workable for the Nigerian situation has necessitated the researchers to come up with the current work. Some researchers have attempted to develop numerical models for bioremediation in Nigeria (Abdusalam, 2012; Onyenjoro, 2011), however, these models involve complex mathematical equations, which can only be solved using advanced computer programs. A few researchers have also proposed the simplicity and adequacy of statistical models for bioremediation schemes (Agarry, 2017; Agarry and Ogunleye,2012); the results have been very promising and reliable, nevertheless, these statistical models are also site specific as they depend largely on the varying soil properties from region to region. The authors intend to test the novel idea of employing statistical models for the prediction of bio-remediation of contaminated Afisols in Makurdi geological formation, Benue State-Nigeria. Chen *et al.,* (2003) proposed a statistical method of modeling bioremediation, which is straight-forward, pragmatic and capable of enhancing its acceptance and use globally for soil remediation designs. The basic problem involved in the use of bioremediation in the cleanup of hazardous contaminant is that, it can only be effective where environmental conditions permit microbial growth and activity, its application often involves the manipulation of environmental parameters to allow microbial growth and degradation to proceed at a faster rate. Consequently this manipulation necessitates a "microcosmic" representation of a full execution of bioremediation program, which can then be solved statistically (Norris *et al.,* 1993).

2. METHODOLOGY

2.1 Site Description

The site used for the experimental work was an abandoned area used by Automobile mechanics in Makurdi metropolis-Nigeria. A stretch of land measuring $1m^2$ was carved out for the experiment. The soil, which is a poorly graded sandy soil has been under extensive contamination with fossil fuels of various kinds such as: used engine oil, used petrol, diesel and all sort of gases as a result of the activities of auto mechanics in the area.

Three stages were used for the execution of this research (Onyenjoro, 2011) viz:

- *Off Site Study*: A laboratory-based study was carried out to determine the biodegradability of chemical substances and the ability of the indigenous or introduced micro-organisms to degrade them; this stage was done off site.
- *On/Off Site Pilot Trial*: a pilot trial, both on site and in the laboratory was done to provide further data necessary for the design of the pilot-scale treatment scheme.
- *Proper Execution*: Pilot-scale bioremediation was conducted on site at a licensed facility approved by the Federal Ministry of Environment of the Nigerian Government.

The treatment was initiated by stimulating the isolated indigenous microbial consortium on the $1m^2$ area by churning the *poorly graded sandy-soil* (S_P) and mixing with few drops of hydrogen peroxide (H_2O_2). Then an aqueous solution of slurry was added to the experimental soil and left for 4 weeks. The experimental soil was already wet because of the wet season moisture and needed no additional wetting (Abdusalam *et al.*, 2009).

2.1.1 Laboratory tests**:** At the preliminary stages of the work, no laboratory tests were carried out on the model site as the concentration of the contaminants was previously known to be high.

2.2 Soil Sampling

A composite soil sample from the site was collected using stainless spatula and kept in sterilized polyethylene bags supplied by Sheda Chemical Laboratory, Abuja-Nigeria and taken to the same laboratory for tests at each sampling period. Sampling was carried out every five (5) days for six consecutive times in order to verify the total hydrocarbons remaining in the soil samples.

2.3 Scope of Treatment and Variables

2.3.1 Scope of Treatment

1. *Land preparation*: during land preparation for the experimental work, the following activities were necessary to create a favorable sphere of action for the micro-organisms: Digging and breaking of bulk particles into simple single grain particle and incorporation of the accurately pre-determined amounts and blends of microbes and chemical products to the experimental soils based on the extent of initial contamination of the soil with spent petroleum products.
2. *Activation of the bioremediation inputs*. A diluted portion of the concentrated products (H_2O_2 and other additives) were added to the microbial blends identified before incorporation into the contaminated experimental soils.
3. *Applying the bioremediation inputs* (strain of microbe): this was achieved by saturating the contaminated soil with water so that the bioremediation inputs could easily penetrate deep into and mix with the soil pollutants. The bioremediation inputs were tilled into the soil as much as possible using an improvised soil mixer. This was done to help, keep the ground moist but not to wash it away.

2.3.2 Treatment Variables:

Table 1 shows the values of the input variables used for remediation of the soil. The site was first *seeded* with a strain of Bacteria (*Pseudomonas enchiridia*) used as an "inducer" which was gotten from the remediation site of a similarly contaminated soil. A 1m^2 plot of land which served as the model site was sampled and taken to the laboratory for the isolation of indigenous micro-organisms, so as to identify the exact quantity and blends of the microbial consortium to be added to the experimental plot. The reason for the strip of one square meter area was to ensure cost effectiveness of the process. Initial moisture content of samples collected from site was found to be determined. The depth of contamination was varied from point to point around the 1m^2 area of site-sampled in the range of 10-15inches. The oxygen level was not of paramount necessity, as the site was aerated to supply more O_2 by sprinkling H_2O_2 liquid. The temperature of the site was also found to vary in the soil, while the type of contaminants used were, gasoline, diesel and spent engine oil. These contaminants were observed to be predominant on the actual site, based on the results of the preliminary laboratory experiments. For the purpose of the current work, the contaminants were collectively referred to as "Crude oil". Sieve analysis revealed that, the soil was a poorly graded sandy soil ($S_{p)}$.

2.4 Statistical Tests for Verification of Results.

The experimental input variables or treatment factors considered in the current work were depth of contamination (inches) and temperature (^{0}C), while the output or response variables tested for were the final pollutant concentration (mg/g) and time (days) which were used to calculate concentration and degradation rates. Chi-square test was used to analyze the significant differences at P = 0.05 (Chen *et al.,* 2003; Udom, 2008).

Table 1: The input parameters used for the remediation of $1m^2$ of site

Moisture Content (%)	Depth of Contamination (cm)	Oxygen Level (cm^3)	Temperature (^0C)	Type of Contaminant	Soil Type
13	10 – 15	90	30 – 33	Crude Oil	S_p

3. RESULTS AND DISCUSSION

3.1 Laboratory Test Results

Table 2 shows the results of the first-order kinetic constants for the three experimental runs, while Table 3 shows the list of indigenous microbes isolated from the site. Figures 1-4 show the 2 plots of the experimental data, whereas, Figures 5 to 8 show the plot of the first-order kinetic curve for each experimental plot. It was necessary to deduce the concentration rates from the plots, which were used subsequently for the statistical models/description of the degradation rates. From Table 2, it was observed that the kinetic constant and coefficient of determination decreased with increase in the food to micro-organism ratio. This was as a result of the reduced migration activities of the micro-organism as they had sufficient food available for metabolism. The coefficient of determination (R^2) was also observed to decrease with increasing F/M ratio. This observation is in tandem with those of Agarry (2017) and Odokuma and Dickson, (2003) who also observed that kinetics of micro-organisms treating crude-oil contaminated soils decreased as the F/M ratio increased. From Figures 1-8, it was found that the experiments fitted the first order kinetic curve in the order of $R_1B_2 > R_1B_3 > R_2B_3 > R_2B_2$.

Table2: First Order Kinetics for the Experimental Runs

Experiment	F/M Ratio (mg TOC/mg TSS)	Kinetic constant (k/day)	R^2
R_1B_2	0.5	0.041	0.92
R_1B_3	1.0	0.019	0.84
R_2B_3	2.0	0.015	0.80
R_2B_2	5.0	0.007	0.71

Table 3: List of species and strains isolated from crude oil contaminated site

Species	**Taxonomic group**	**Number of strains**
Chryseomonas chlororaphis	Bacteria	2
Chryseomonas luteola	Bacteria	8
Pseudomonas aureofaciens	Bacteria	8
Pseudomonas cepacia	Bacteria	2
Pseudomonas fluorescens	Bacteria	20
Pseudomonas mendocina	Bacteria	2
Pseudomonas sp.	Bacteria	8
Sphingomonas paucimobilis	Bacteria	2
Stenotrophomonas maltophilia	Bacteria	2
Candida famata	Fungi	14
TOTAL= 10 Species		**TOTAL= 68 Strains**

After tests for evaluating pathogenicity, 3 strains were excluded. Common biochemical tests were performed to identify the genus of isolated strains. The genus of those strains were identified as *Bacillus sp., Rhodococcus sp., and Citrobacter sp*. and thus they were not included in the above table.

The augmented strain (though foreign to the site) was the *Pseudomonas enchiridia* and thus it was not included in Table 3. From Table 3, it was observed that the predominant bacteria species was the pseudomonas flurescens, while the dominant fungi species isolated was candida famata. This suggest that the dominant species isolated from the study area are chiefly responsible for the degradation of crude-oil derived soil pollutants and are also tolerant to the toxicity exerted by the pollutants, hence their multiplicity as compare to the other species.

3.2 Weights of Isolated Bacteria from the Studied Bioreactors

The weights of isolated indigenous bacteria as related to the weight of soil, volume of oil, were used to compute the food to micro-organism (F/M) ratio for the various reactors studied as shown in Table 4. However, the weights of indigenous bacteria was found to be constant (500 mg) in all the bioreactors and run, irrespective of the food to micro-organism ratio and the volume of oil used.

Table 4: Setup of Bioremediation Experiments

Bioreactor	Weight of soil (g)	Volume of oil (ml)	Weight of indigenous isolated bacteria (mg)	Food-to-Microorganism ratio (F/M) (mgTOC/mgTSS)
R_1B_2	20	5	500	0.5
R_1B_3	20	10	500	1.0
R_2B_2	20	50	500	5.0
R_2B_3	50	50	500	2.0

R stands for run, B stands for bioreactor. Density of crude oil = 0.96gcm^{-3}

3.3 Model Development

The general formula of the first-order kinetic that was used to describe the rate of TOC reduction in the contaminated sites is as given in Equation (1).

$$\frac{dC}{dt} = -kt \tag{1}$$

Where:
t: time (day)
C: remaining TOC concentration (mgL^{-1}) at any time.
k: first order kinetic constant (1/day).
Integrating Equation (1) gives the first-order kinetics as shown in equation 2:

$$C = C_0 e^{-kt} \tag{2}$$

Where C_O is the initial TOC concentration (mgL^{-1}). Equation 2 thus becomes as follows:

$$\ln\frac{C_0}{C} = kt \tag{3}$$

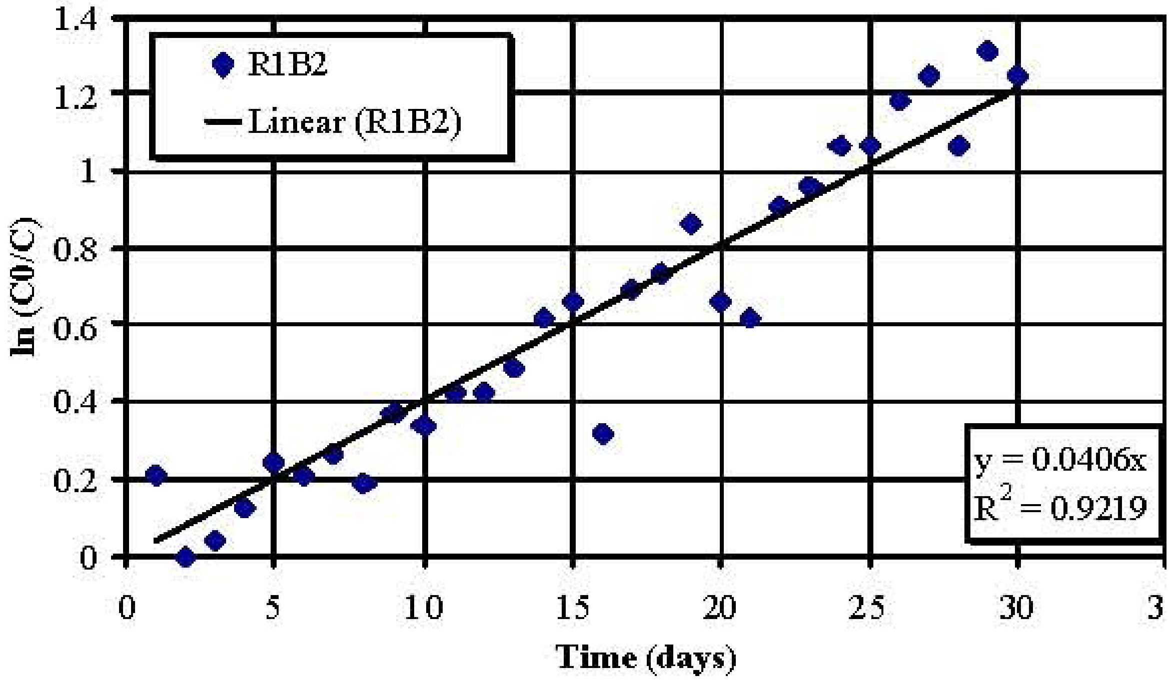

Fig. 1: Linearization of experimental data in R1B2

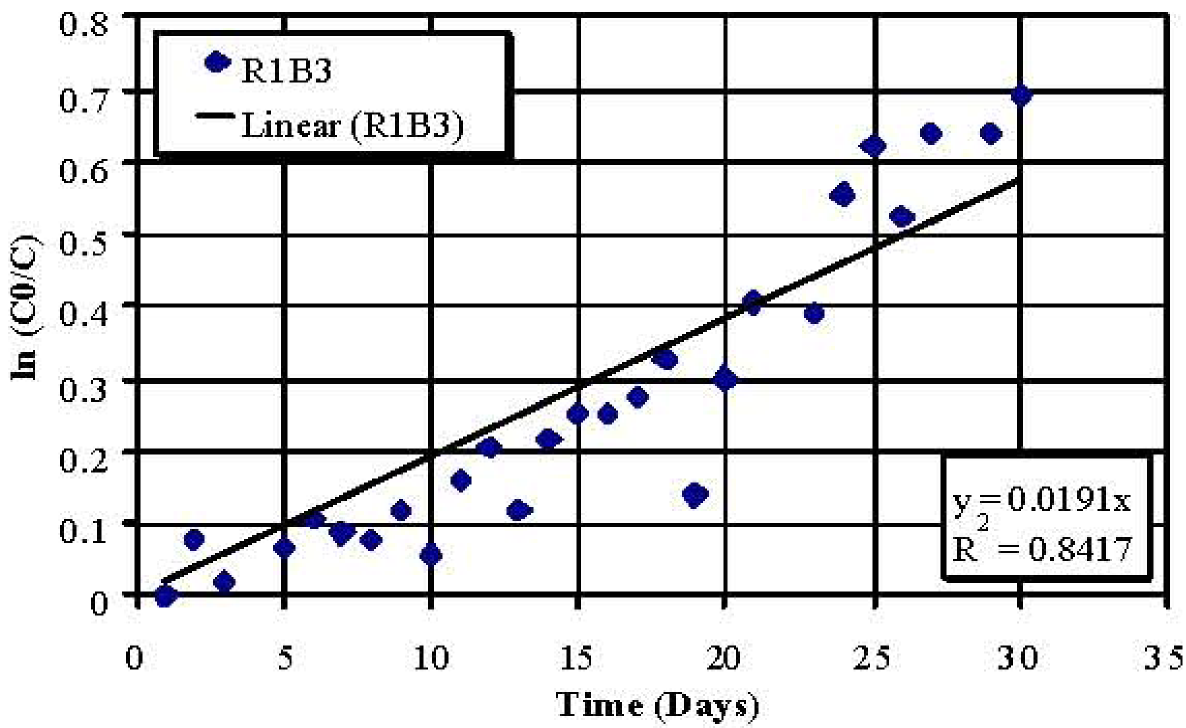

Fig. 2: Linearization of experimental data in R1B3

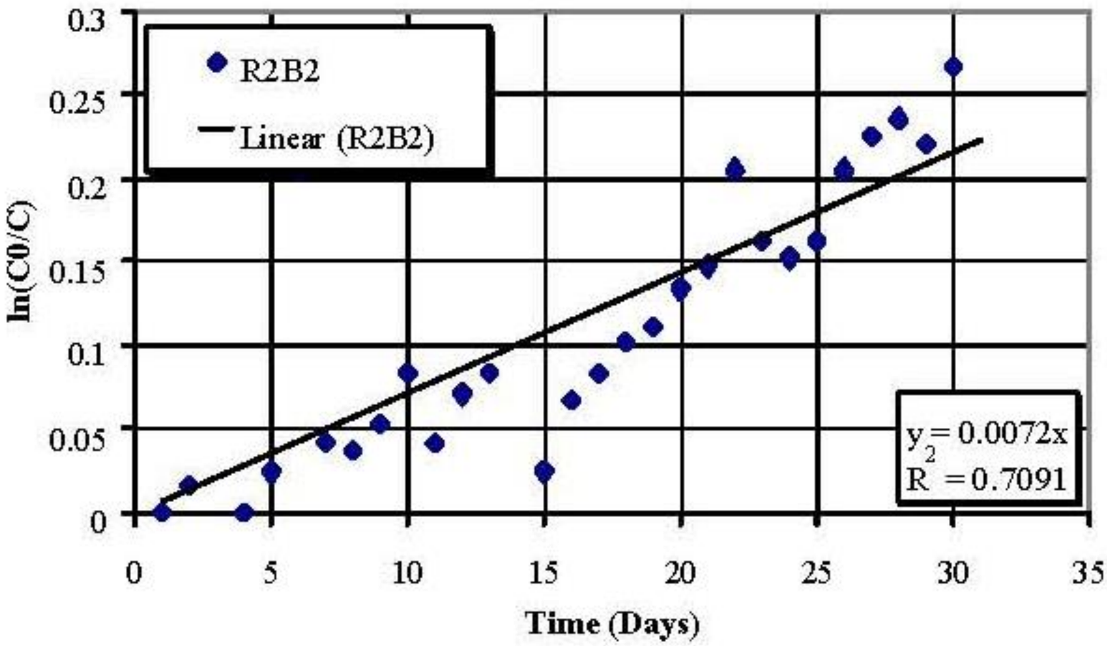

Fig. 3: Linearization of experimental data in R2B2

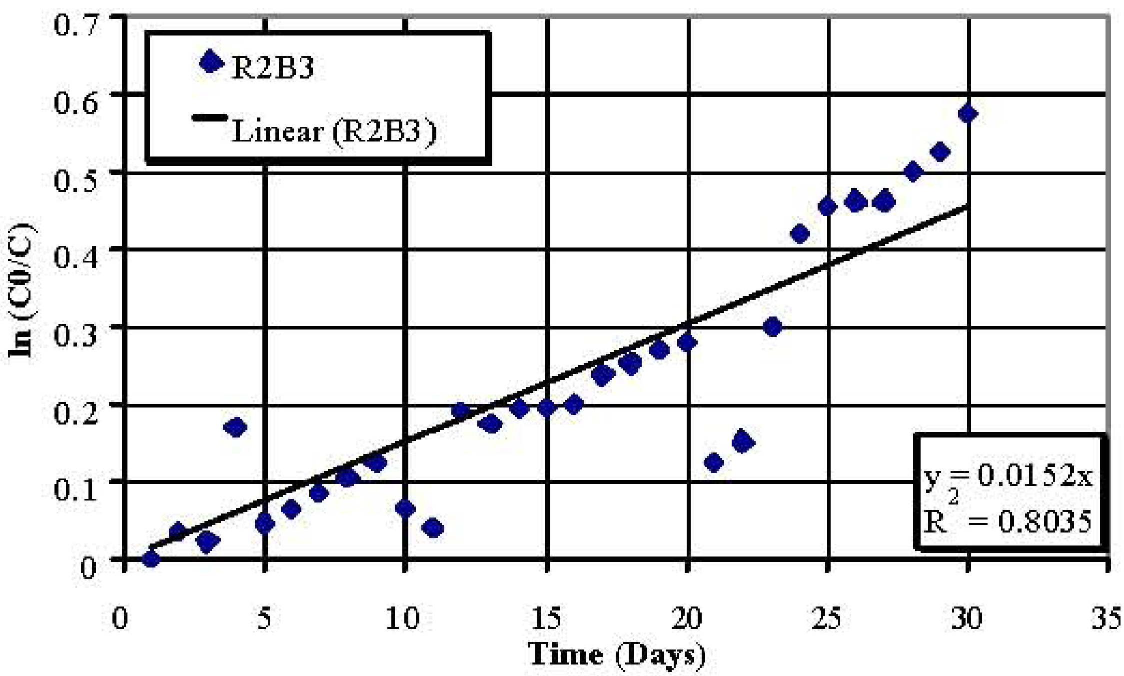

Fig. 4: Linearization of experimental data in R2B3

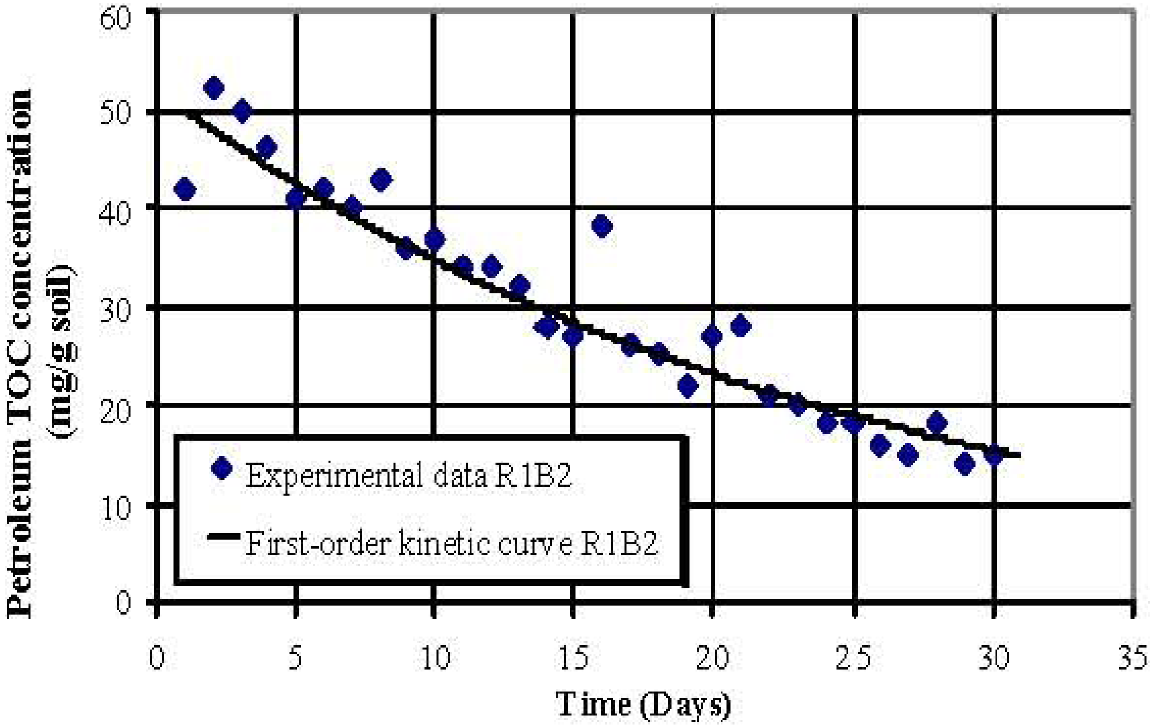

Fig. 5: First-order kinetic curve in R1B2

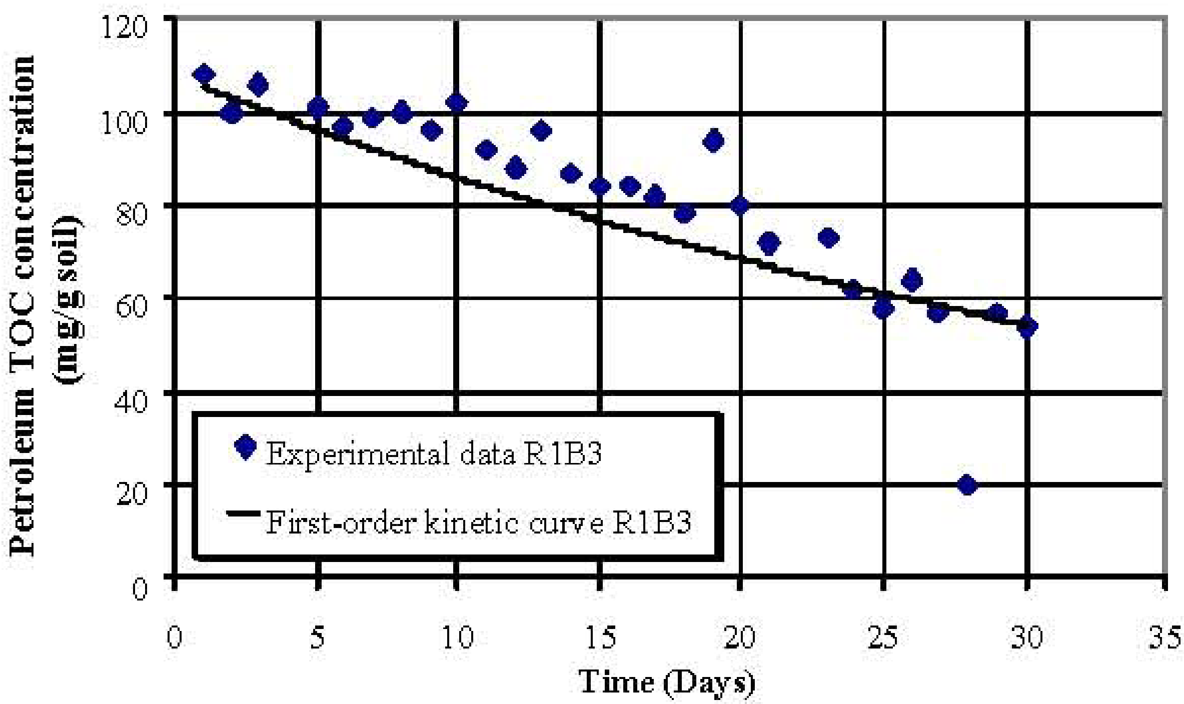

Fig. 6: First-Order kinetic curve in R1B3

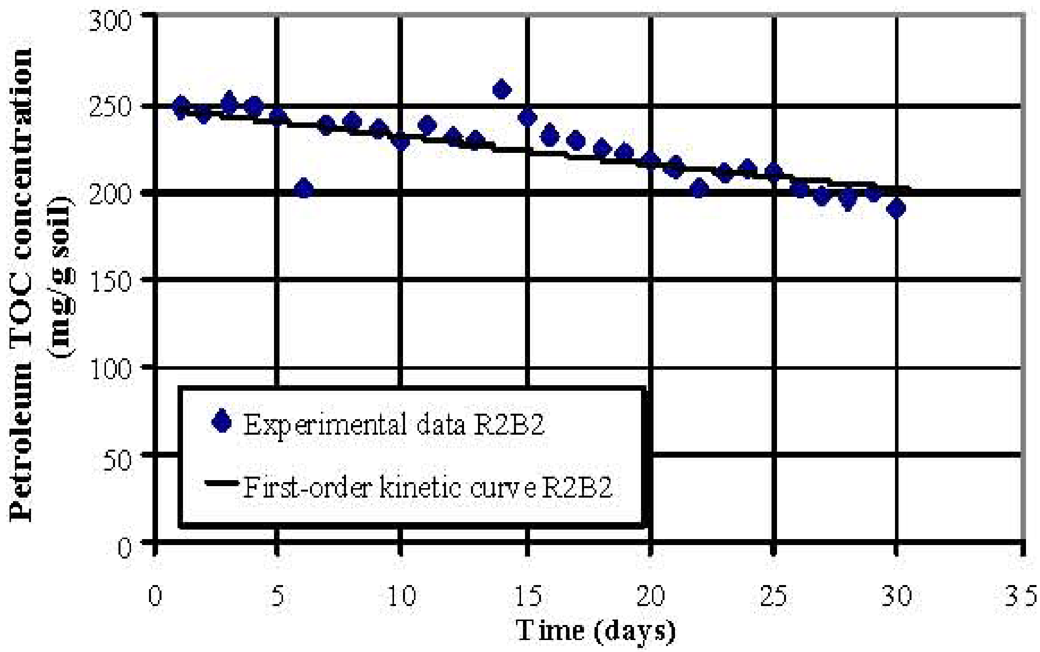

Fig. 7: First-Order kinetic curve in R2B2

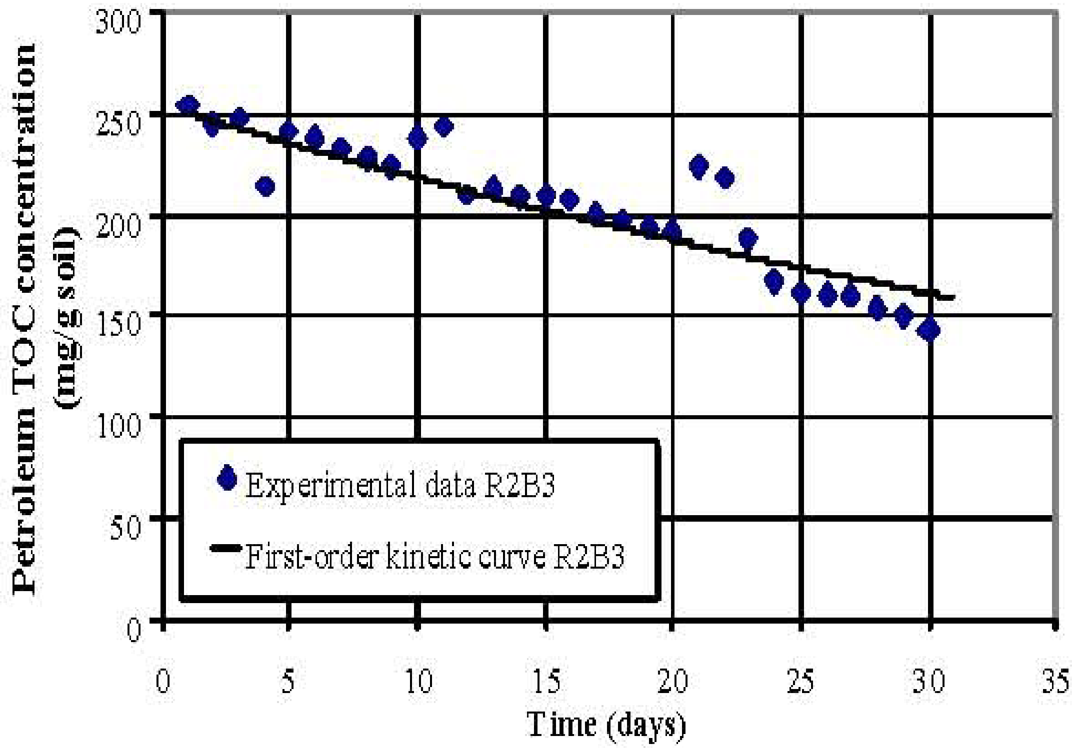

Fig. 8: First-Order kinetic curve in R2B3

3.4 Variation of TOC Concentration with Time

From Figures 1 - 4, the TOC reduction with time was estimated from the linearized graphs in accordance to Equation (3) above and the results are presented in Table 5. It was observed that the final concentrations of TOC in the studied laboratory reactors decreased linearly with time.

Analysis of the rate of hydrocarbon removal showed that most compounds obeyed first-order kinetics and the *observed* (deduced) values of the rates of hydrocarbons depletion seek only to give an insight of *rate of reaction* but processes necessary to confirm these values initiated the *statistical analytical model* approach to answer many question like:

(1) How does the proportion of the changing concentration differ from the corresponding days? Say concentration deviation within the runs vertically!

(2) How does the proportion of this changing concentration between the runs deviate from each other?

(3) Should we just conclude that bioremediation actually took place, without any analysis of result?

(4) What is our expectation supposed to be, should we describe the observed values to be false result by merely looking at the pattern of concentration kinetic of contaminant degradation *curves* and *lines*; or confirmed their authenticity.

Table 5: Variation of TOC with Time for Studied Reactors

Time *(days)*	**Remaining Total Organic Carbon Content (mg/g)**			
	R_1B_2	**R_1B_3**	**R_2B_2**	**R_2B_3**
1	35.80	112.1	251.8	258.9
2	43.74	103.5	248.2	251.1
3	42.02	109.9	246.4	253.6
4	37.20	103.9	251.8	216.2
5	35.67	101.9	245.6	246.2
6	34.28	101.4	241.1	243.8
7	32.90	101.4	241.8	238.9
8	35.81	102.5	244.2	231.9
9	30.35	98.43	239.2	228.0
10	29.12	59.10	234.3	243.8
11	27.98	93.63	241.9	248.7
12	27.96	90.86	235.2	214.5
13	27.88	90.86	234.7	215.6
14	24.00	89.96	227.6	211.9
15	23.77	84.17	245.6	211.9
16	32.40	87.30	235.7	211.9
17	21.93	84.72	234.7	203.6
18	21.06	80.35	227.8	198.6
19	19.57	96.48	223.5	195.7
20	22.60	76.50	220.2	193.7
21	23.76	75.14	216.7	229.6
22	17.90	73.65	205.1	222.8
23	17.19	75.89	213.3	191.8
24	15.46	64.67	216.7	170.9
25	15.77	60.90	213.3	165.0
26	13.57	66.65	205.1	163.4
27	12.65	59.10	200.8	162.9
28	15.77	65.66	198.2	157.0
29	11.92	59.10	201.0	153.9
30	12.93	55.67	194.2	128.5

This and other questions surrounding the need to *probe* into results and *manipulate* site parameter(s) in order to adjust parameter to the desired result called for this statistical approach adopted here. Test have been able to establish the indigenous microbes already adapted to the site parameter and determining the viability of the foreign strain to be inoculated for competition and subsequent faster and *surer* course of bioremediation to ascertain that concentration is definitely not yielding other compound as would be, if indigenous microbes are allowed to thrive alone.

The strains predominantly belong to the genera (*Pseudomonas*). The microbial activity, however, is strongly influenced by the soil temperature resulting in considerably higher decomposition rates at increasing temperature, i.e, increased metabolism due to relative increase in temperature. Initial decomposition may be accelerated by *seeding* the spill or sludge disposal with the appropriate microorganism species. This can be achieved by using soil from an old oil-spill location already remediated biologically.

Also, the chemical composition of the oil affects its degradation. It is well known that aromatic compounds usually can be much better attacked and more rapidly decomposed than other hydrocarbons. Of the long chain hydrocarbons the *paraffin* groups appears the most readily decomposable. They decompose readily and products formed vaporize readily as soon as bacterial act on them. An important practical finding in case of the authors' site was to allow oil spillage to spread itself as much as possible. The oil should not be confined. Infiltration of oil into deeper layers of the soil may greatly hamper proper treatment of the contaminated soil. This would be more likely so because the concentration of contaminant tend to kill bacteria and plant life on that spot.

The pairs of graphs, (Figures 1 and 5, 2 and 6, 3 and 7, and 4 and 8) represent equation of a straight line and the corresponding exponential curve equations respectively.
From Figure1, the general equation describing the relationship is given as in Equation 4**.** Which is an equivalent to Equation 5. From which, by comparison, K = Slope (m) = *0.0406***.**

$$y = 0.0406x \qquad (4)$$

$$ln(C_0/C) = Kt. \qquad (5)$$

If the linear graphs as given are defined by the equation of straight line as in Equation 5
Where all parameter definition remains as stated above.
Taking the logarithm of both sides we have:
$e^{\ln\left(\frac{c_0}{c}\right)} = e^{Kt}$ by law of exponent of natural Logarithm (it is $e^{lnK} = K$). Therefore we have $\frac{C_0}{C}$ = e^{Kt}. This is equivalent to $C_0 = Ce^{Kt}$. But taking the inverse of
$\frac{C_0}{C} = e^{Kt}$, gives us $\frac{C}{C_O} = e^{-Kt}$. Since our model would be to describe concentration changing level with respect to time (*i.e. C*) *other* than ultimate concentration (C_0).
The model formula is therefore as in equation 6.

$$C = C_0e^{-Kt} \qquad (6)$$

To find C_0 and C at specific time t (days), the corresponding curve (Figure 5) was read directly. Where, C at t = 1st day was found to be *42mg/g of soil/day*. By substituting into the equation of a straight line (Equation 5), we obtain Equation 7:

$$C_0 = 42e^{-0.0406x1} = 43.7mg/g\ of\ soil.day \qquad (7)$$

Then the model equation in numerical terms becomes as in Equation 8 by substituting directly into the form $C = C_0e^{-kt}$. It defines the duration of the First runs/test carried out.

$C = 43.7e^{-0.0406t}$, (8)

Similarly the pairs of graphs given in Figures 2 and 6, 3 and 7, then 4 and 8 were used to deduce the equations for all the studied reactors (R_1B_2, R_1B_3, R_2B_2, and R_2B3) respectively.

From the graphical readings, the four model equations derived are as presented in Equations 9-12 for R_1B_2, R_1B_3, R_2B_2 and R_2B_3 respectively.

$C_t = 43.74e^{-0.0406t}$ (9)

$C_t = 112.1e^{-0.0191t}$ (10)

$C_t = 251.8e^{-0.0072t}$ (11)

$C_t = 258.9e^{-0.0152t}$ (12)

Each equation (9, 10, 11, and 12) representing the models for the various experimental reactors was used to estimate the TOC concentration at selected times (5, 10, 15, 20, 25 and 30th days) and the results are as presented in Table 6. It was necessary to calculate C_t at 5days interval, in order to be able to detect the pattern of degradation as time elapsed. This was also recommended in the laboratory Instructions given during the study.

Table 6: Variation of C_t at five (5) day intervals for the studied bioreactors.

	RUN ONE				RUN TWO			
	BIOREACTOR 2		BIOREACTOR 3		BIOREACTOR 2		BIOREACTOR 3	
TIME (Day)	C_0 **mg/g of soil/day**	C_t **mg/g of soil/day**	C_0 **mg/g of soil/day**	C_t **mg/g of soil/day**	C_0 **mg/g of soil/day**	C_t **mg/g of soil/day**	C_0 **mg/g of soil/day**	C_t **mg/g of soil/day**
5	43.74	35.67	112.1	101.8	251.8	242.8	258.9	239.9
10	43.74	29.12	112.1	92.60	251.8	234.3	258.9	222.3
15	43.74	23.77	112.1	84.17	251.8	226.0	258.9	206.1
20	43.74	19.40	112.1	76.50	251.8	218.0	258.9	191.0
25	43.74	15.84	112.1	69.53	251.8	210.3	258.9	177.0
30	43.74	12.93	112.1	63.20	251.8	202.8	258.9	164.0

3.5 Results of Model Reliability Test

From tables reading the critical value of chi-square $\left(\chi^2_{crit.}\right)_4$ = 3.074 at 0.995 level of significance. Since the Null hypothesis is rejected if it fall outside the range of the critical value at a particular level of significance or accepted it if it fall within the range. Therefore, we accept the Null hypothesis and conclude that there is no significant difference between the observed and predicted values and that the deviations observed could be ascribed to mere fluctuation of samples submitted for test.

4. CONCLUSION

In conclusion, This study revealed that the factors affecting soil bioremediation for crude oil degradation by micro-organisms are soil temperature, and aeration condition, which influence the TOC decomposition rate and that the dominant micro-organism species dominant and tolerant to crude oil contamination in Afisols are bacteria and fungi. Furthermore, the study revealed that bioremediation inputs were able to reduce TOC levels in contaminated soils from 80,000 mg/kg of soil down to 500 mg/kg of soil within a month period with the methods employed in the current study.

The developed kinetic equations for bioremediation of crude oil-polluted Afisols in the tropics were found to be reliable for the prediction of TOC degradation with time as the experimental and predicted values were not significantly different at 0.01 level of significance. Furthermore, it is recommended that the models developed be tested for the remediation of crude-oil polluted Afisols at the pilot or full scale level in order to fully elucidate on the real life reliability of the models over a longer period of remediation.
It is recommended that areas of bioremediation that demand further research like (*Phytoremediation*) should be explored. This is a potential area of remediation yet to be fully explored in the study location.

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Evaluation of Bamboo as a Sole Construction Material for Poultry Housing in the Tropics

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ABSTRACT

In the current study, a prototype bamboo structure was developed under broiler production in comparison with a conventional burnt brick structure of the same size. The average indoor environmental conditions (temperature and relative humidity) in the two structures were monitored throughout the growing period of the birds using standard methods and instruments. The average weight (AW), average weight gain (AWG), and live bird analysis of broilers at maturity(shank Length(SL), Neck Length(NL),Thigh Length(TL),Body Length(BL), Drumstick(DS) and Wing Length(WL)) were monitored and compared in the two structures using standard methods and equipment. The indoor temperature and relative humidity under broiler production ranged from 30-35°C, 64-80% and 32-37°C, 57-91% for the bamboo and burnt brick structures respectively. The AW of broilers ranged from 1.42-2.64kg in the bamboo structure with the lowest value(1.42kg) and highest value(2.64kg) observed at weeks one and four respectively. On the other hand, the AW of broilers in the burnt brick structure ranged from 1.15 at week one to 1.94kg at week four. Similarly, the AWG of the broilers ranged from 0.34-0.61kg with the highest weight (0.61kg) and lowest weight (0.34kg) occurring at weeks one and four respectively in the bamboo structure, while the AWG in the burnt brick structure ranged from 0.81kg at week two to 0.32kg at week four. Live weight analysis on the broilers at maturity (week four) reveal that the average values of SL, NL, TL, BL, DS and WL were 7.8, 11.4, 13, 46.6, 10.4 and 18.6cm respectively for broilers trained in the bamboo structure while those for broilers raised in the burnt brick structure were 7.6, 9.6, 12, 44.4, 9.4 and 17.4cm respectively. It was generally observed that broilers trained in the bamboo structure out performed those raised in burnt brick structure in all parameters tested for. This could be attributed to the favourable environment created as a result of the use of bamboo as a sole construction material. It was therefore concluded that bamboo is a suitable material for use as walls, roof, floor and doors in poultry housing in tropical regions like Nigeria.

Key Words: Bamboo, Broiler, Housing, Burnt Bricks, Average Weight Gain.

1. INTRODUCTION

Providing adequate housing with favorable environmental parameters for optimum growth remains an important issue in poultry production (Kachilei, 2017). Many materials such as concrete, wood, nets etc. are used for poultry production in the past and they have attempted to provide favorable environmental condition for birds housed in them. Poultry contributes to improved human nutrition and food security by being a leading source of high quality protein in form of eggs and meat. It acts as a key supplement to revenue from crops and other livestock enterprises, thus avoiding over dependency on traditional commodities with inconsistent prices (Abu *et al.*, 2015). It has a high potential to generate foreign exchange earnings through export of poultry products to neighboring countries. Poultry is highly prized in many social-cultural functions such as dowry and festivities. The poultry industry in Nigeria is grossly inadequate and they are unable to support the meat requirement. Its major problem is therefore the need to maximize all the potential and investment opportunities in poultry care must in order to avoid pit falls that discourage the production. Poultry production needs optimum environmental conditions such as temperature, relative humidity etc (Abu *et al.*, 2015; Kalio and Okafor, 2012; Glatz and Pym, 2004). Other factors such as ventilation, lighting and heat management are also very important. Selection of suitable materials that provide favorable conditions for proper growth of the chickens becomes an issue. Concrete, wood, composite and burnt bricks all used in the past gave 6.0%, 3.0%, 5.0% and 4.0% mortality respectively with growth rate below 50% (Aland and Banhazi, 2013) in the tropics, hence there is need to continuously test indigenous materials for wholesome use as poultry house construction material. The aim of this work was develop a prototype poultry house using bamboo as the sole construction material. The specific objectives of the study were to design, construct and evaluate a prototype poultry house for broiler production using bamboo in comparison with a conventional burnt brick structure.

2. MATERIALS AND METHODS

2.1 Materials

Soft wood (Malina) was selected as the structural frame (including the pillars). Walls, roof and floor were made of bamboo because of its high strength and natural resistance to decay and insect attack (Latif and Jamaludin, 2007; Liese, 2014; Recht and Wetterwald, 2015).

2.1.1 Material selection and mobilization

To design an appropriate, less expensive poultry house, for smallholder farmers in a developing country like Nigeria, the following considerations were made in selecting the right material for construction; availability, affordability, workability, strength and suitability. Bamboo was found to possess all of the aforementioned criteria. The mechanical properties and availability of Bamboo (*Bamboo vulgaris*) in most communities made them appropriate choices for the design. The compressive and tensile strength of different portions of Bamboo stem are reported to range from 254 -359 Mpa and 2067 - 3658 Mpa, respectively with the top having the highest values as compared to the bottom and centre portions (Liese, 2014).

2.2 Methods

2.2.1 Design framework

Appropriate and standard design formulae and equations were employed to determine dead load, wind load, uniformly distributed load (UDL) and stress as described by Razak, (2007). Necessary design considerations and assumptions for sizing of beams and columns as well as for the design of the foundation and roof were employed.

2.2.2 Heat balance computation and analysis

Heat balance in the structure was determined in accordance with the methods described by (Roth, *et al.*, 1975; Aland and Banhazi, 2013).

2.2.3 Wind load and ventilation computation

The average recorded wind velocity in Makurdi is 5 $\mathrm{km/hr}$ i.e. about 1.39 $\mathrm{m/s}$ and the highest velocity recorded is 18.0 9m/s (Johnson, and Jennifer, 2017). In designing, the highest wind velocity of 18.09 m/s was used in calculating the wind pressure having the design height of 1.0m by employing Equation 1;

$$Q = 0.013V^2 \left(\frac{h}{6.1}\right)^{\frac{2}{7}} \quad (1)$$

Where,

Q = Wind Load (Pa),

h = Height of Structure (m), = 1.0m

V= Maximum Wind Velocity (ms^{-1})

2.2.3.1 Ventilation rate

Natural ventilation replaces indoor air with fresh outdoor air without using mechanical power. Hence, natural ventilation can save energy consumed by the heating, ventilating, and air conditioning systems in a building if it provides acceptable indoor air quality and thermal comfort levels. (Liddament. 1996) Ventilation rate or airflow rate is an important parameter for ventilation assessment. Ventilation Rate was calculated for using the equation 2.

$$Q_v = AV \quad (2)$$

Where,

Q_v = Ventilation rate, m^3/s

A = Area of opening, m^2

V = Average wind speed, m/s

2.2.3.2 Airflow due to wind

The rate of wind driven airflow across any opening in the structure can be calculated by using the empirical power law as stated in equation 3 (Liddament, 1996).

$$Q_A = EAV \quad (3)$$

$Q_A =$ Airflow due to Wind

$E =$ Effectiveness of opening, = 0.35 for diagonal wind.

The coefficient of discharge "E" depends upon the direction of the wind relative to the opening and the relative size of entry and exit openings. It ranges from about 0.35 for wind hitting an opening at a 45° angle of incidence to 0.6 for wind hitting directly at a 90° angle (Karava *et al.,* 2004).

2.2.4 Construction of the structure

Bamboo (*Bamboo vulgaris*) was selected for the structure frame (including beams and columns), walls, roof and floor because of its high strength and natural resistance to decay and insect attack. Bamboo sticks were used for cladding (structure walls) because they are readily available and relatively cheaper. They are also durable and light weight. The structural drawings of the bamboo structure was done with the aid of AutoCAD 2015 software, taking into consideration all design calculations and estimations.

2.2.5 Construction process

The poultry house was constructed in an open space within the Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi Benue State. Before construction, a suitable site was selected for the construction of the structure. The land selected has a good drainage and the door of the structure was oriented in a direction to provide good ventilation at all times. It was oriented that way to prevent direct sunlight from entering the structure. The bamboo used for structure was dried out before using them for construction. Local expertise was used for the entire construction process in other to facilitate adoption of the system.

The rectangular structural frame of the poultry house was entirely constructed using soft wood (Malina) and Bamboo (*Bamboo vulgaris*) with wire mesh held in position at the four corners by burying part of the wooden columns into the ground. The area dimension (2.5m × 1.2m) of the structure was marked out on the ground using line and pegs and holes for the pillars dug at 0.31m depth with the help of an earth chisel or digger. The main frame was raised after fixing the side beams and braced for accurate setting before consolidation of the pillar (column) foundation. The bracing allows for better structural stability so that the roof frame can be mounted as well. Each of the four corner columns were 1.45m tall; 0.25m as depth in the ground, 0.2m as platform height and 1m as height of the storage area. Again, slope angle for the roof was 30° in other to ensure that rain water did not stay long on the roof during and after any downpour.

The structure was 1.56 meters in length, 0.76 and 1.14m in width and height, respectively; giving a total storage volume of $1.35m^3$. An approximate gap of 0.01m was left between each cladding board to facilitate good ventilation within the structure. The gap was sizable enough to allow air to pass through and a net was also used to prevent harmful insects, pests or rodents/reptiles that could attack the broiler from entering the structure. The total vent area for both structures was kept the same (0.96 m^2). Table 1 outlines the cost of construction, while Table 2 gives summary of load carried by each component of the structure. Table 3 is the highlight of the cost of broilers management during the study period. Figures 1, 2 and 3 are the front elevation, floor and roof plan of the structure respectively. Figures 4 and 5 show the side elevation and isometric view of the structure, respectively.

Table 1: Cost of Construction

S/no.	**Item**	**Cost (#)**
1	Bamboo sticks	5,000
2	Nails	1000
3	Cement	500
4	Hinges	400
5	Wire guaze	4000
6	Transportation of materials	1,000
7	Labour	2,000
8	Padlock	500
9	Ceiling board	1000
10	4 inches leather	1000
	Sub- Total	18,400
	10% contingences	1840
Grand Total		20,240

Table 2: Summary of Design Loads for Each Component of the Structure

S/No	Components	Load Carried (N)
1	Roof	441.45
2	Beam	735.75
3	Column	760.23

Table 3: Cost of Broilers Management during the Study.

S/no.	Item	Quantity	Cost (#)
1	Day old Broiler	15	4,500
2	Feed(starter, grower)	3bags	12,900
3	Drinker	2	2000
4	Feeder	2	1,500
5	Vaccines		4000
6	wood shavings	-	1,200
		Sub- Total	26,100
		10% contingences	2610
		Grand Total	28,710.

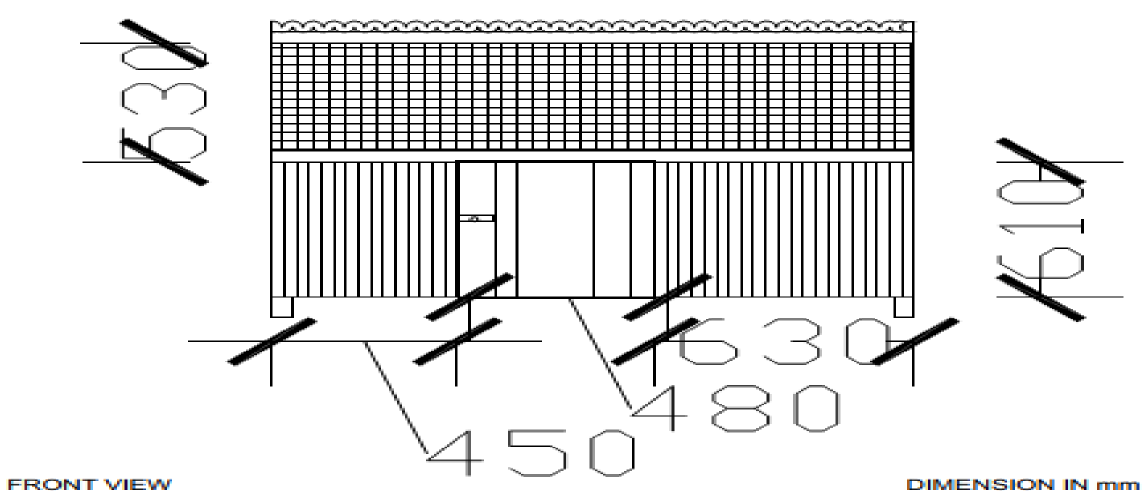

Figure 1: Front Elevation of Bamboo Poultry House

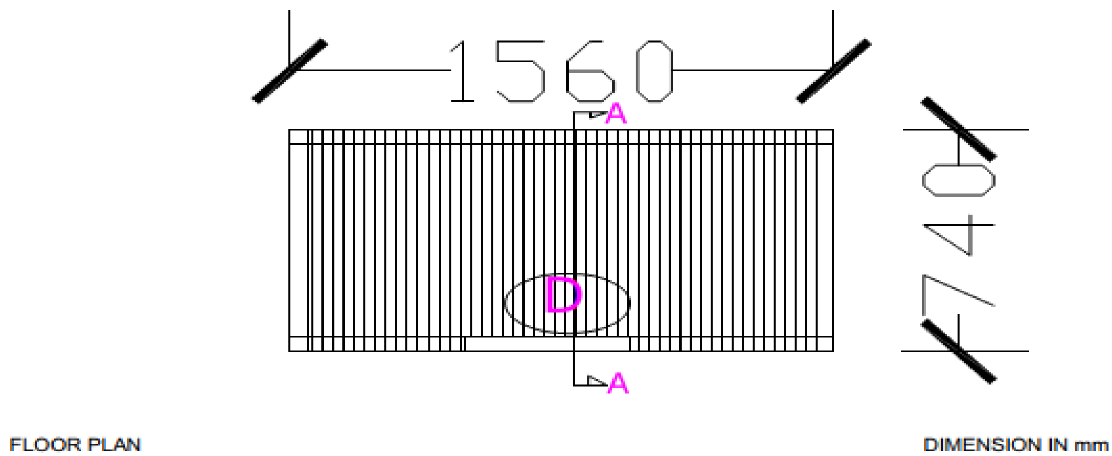

Figure 2: Floor Plan of the Structure

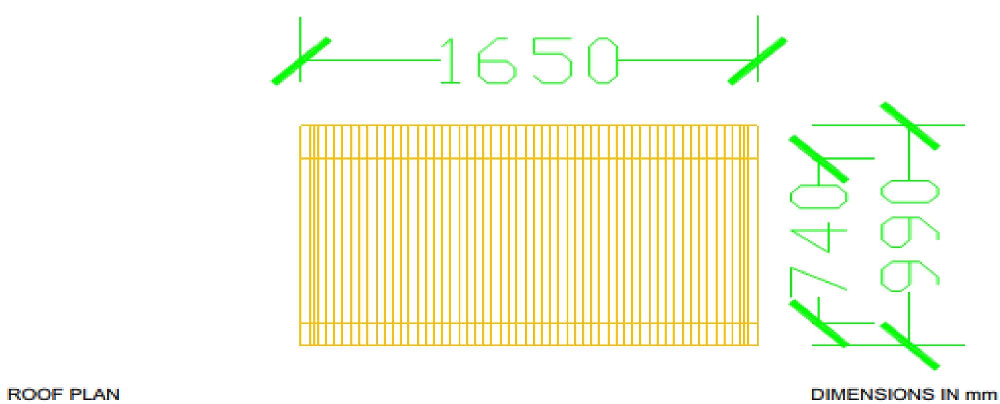

Figure 3: Roof Plan of the Structure

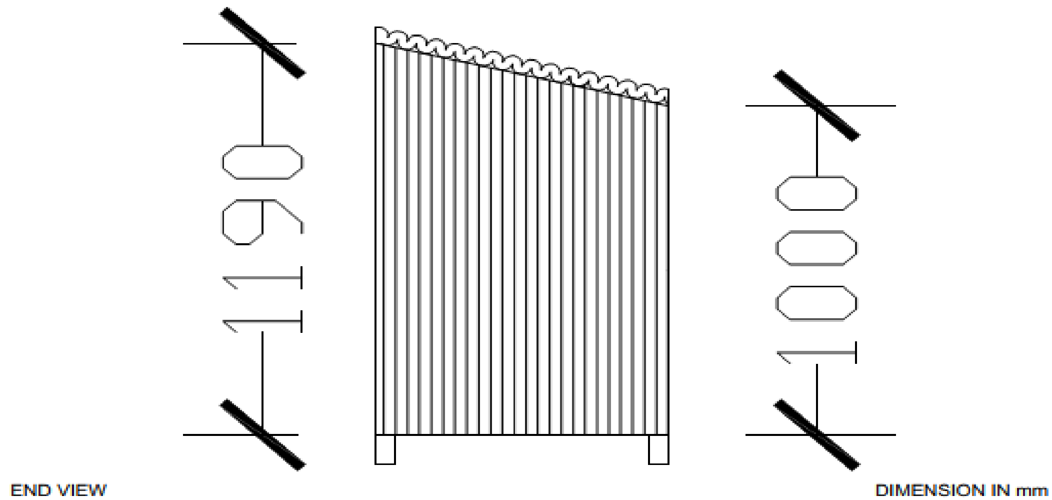

Figure 4: Side Elevation

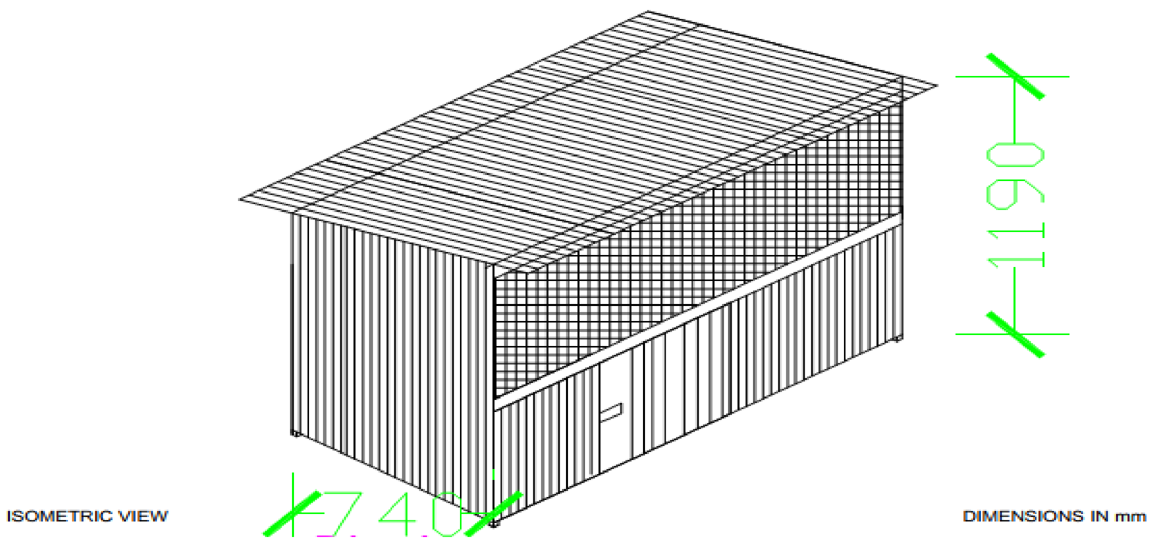

Figure 5: Isometric View of the Structure

2.2.6 Sizing of structure

In sizing of the developed bamboo structure, it was proposed that the structure should have enough space to accommodate broilers at full capacity. An average height of 1.0m was used for the height of the structure. A volume was used to ensure that there was no congestion during broiler growth in the structure. To achieve this convenient volume, dimensions of 1.56 m (length) × 0.740 m (width) × 1.14m (height) were selected.

Therefore, the volume of the structure was $1.35m^3$. This dimension was chosen with the aim of creating ease of access for cleaning, feeding and evaluation of birds during the course of the experiments. Adequate heat exchange and ventilation were also considered in choosing the structural dimensions. To create a basis for comparison of the two structures, it was ensured that the capacity of the burnt-brick structure was also approximately equal to $1.35m^2$ with dimensions of 1.50 m (length), 0.80 m (width) and 1.14 m (height). The same height was ensured for both buildings to take care of heat exchange by invasion.

2.2.7 Capacity of structure

It was important to calculate the number of broilers the structure could contain, such that only that number will be used in both structures. Since according to Ahlers *et al*., (2009), the average floor space requirement per fully matured bird (broiler) is $0.1m^2$ and the total area of the structure is estimated to be $1.3m^2$, then the capacity of the bamboo structure in terms of broiler content can be estimated using equation 4

$$\text{Capacity of structure} = \frac{Total\ area\ (m^2)}{Unit\ area\ (m^2)} \quad (4)$$

Where,

Unit Area of bird = $0.1m^2$

Total Area = length × width

Total Area = $1.3m^2$

$$\text{Capacity} = \frac{1.3m^2}{0.1m^2}$$

Capacity = 12

Therefore each structure was capable of housing approximately, 12 broilers as estimated.

2.2.7 Stocking of broiler and performance evaluation strategy.

A total of 22 day old broilers were purchased from a commercial supplier in the study area and brooded in a standard brooding structure in one of the commercial poultry farms in Makurdi for a period of four weeks, beginning from 2nd November, 2017 to 30th November, 2017. The brooded broilers were transferred to the bamboo and control structure in safe modes. 10 broilers each were stocked in each of the structure. Feeding and medication of the birds in both structures were done using standard procedures. The same treatments were given to the broilers in the both structure in order to remove bias from the evaluations. Evaluation of the structures under broiler production for the four weeks was based on measurement of temperature, humidity and weight of birds, with the aid of standard instruments over the growing period, in comparison with acceptable limits and standards.

2.2.8 Parameters and methods of evaluation

I. Temperature

Temperature readings within the structures and the environment were taken on a daily basis in the morning between 6:00am and 11:00am,afternoon between 12:00 noon and

1:00 pm, and evening between 5:00pm and 6:00pm using a thermometer for the period of the evaluation.

II. Relative humidity

Relative Humidity is the amount of moisture contained in the atmosphere of the structure and it was determined with the use of a hygrometer tables and psychometric chart for both structures.

III. Evaluation of broiler growth and performances

The birds in both structures were evaluated by weight and the measurement of some body parts like the shank, neck; thigh, drumstick, body and wings at the end of the housing period to compare growth coupled with weight to effectively determine performance of broilers in both structures. Figures 6-8 show the constructed bamboo poultry house, broilers feeding in the bamboo house and broilers feeding in the burnt brick poultry house respectively.

Figure 6: Constructed Bamboo Structure for Poultry Housing

Figure 7: Broilers Feeding in the Bamboo Structure

Figure 8: Broilers housed in the Burnt Brick Structure

3. RESULTS AND DISCUSSION

3.1 Structural Reliability of the Prototype Poultry House

The structural reliability was judged based on wind load and resistance of structural members to compressive and tensile stress. The wind load of the structure was calculated to be 2.5Pa which is negligible compared to the standard range of 70Pa to 130Pa suggested by NAHB (2000), the wind load is negligible also because the structure is not a high rising one. The compressive strength of bamboo which ranges from 254Mpa (254000000 N/m^2) to 359Mpa (359000000 N/m^2) (Liese, 2014) was higher than the overall load of 235.4N/m^2 on the floor thus making it impossible for failure to occur due to compression. The load on the roof was estimated to be 245.25Nm^2 and was below the compressive strength of bamboo. The total load on the beam was calculated to be 367.22N/m^2 with maximum bending moment of 238.56N/m^2 were all below the compressive strength of the bamboo also the overall column load of 480Nm^2 was also far below the compressive strength of bamboo. With a tensile strength range of 2067000000N/m^2 to 3658000000N/m^2, it was difficult for any load on the structural members to cause tensile failure in the structure (Liese, 2014). The bearing capacity of the soil was found to be 0.6 kN/m^2 (NAHB, 2000) while the depth of the foundation was calculated to be 0.313m which was again less than the bearing capacity of the soil. As such the developed bamboo structure was adjudged to be structurally reliable and could therefore serve its intended use.

3.2 Performance Evaluation of both Structures

3.2.1 Temperature and relative humidity.

Figure 9 represents the recorded average temperatures in the bamboo structure for the period of 28 days (4weeks). Similarly, the average temperatures observed from the burnt brick structure for the same duration is as shown in Figure 10. The morning temperatures observed in both structures were within 30-33°C, however, the temperature for the afternoon and evening periods in the structures, were slightly different. Temperatures ranging from 33-35°C were observed in the bamboo structure while those from the burnt brick structure ranged between 35-37°C. The high temperatures in the control structure were as a result of the high insulative properties of the construction materials and were responsible for the constant panting of the birds during those periods as observed. The birds in the burnt brick structure were found to feed mostly in the morning and night when temperatures were low and conducive as compared to the birds in the bamboo structure which fed at all times of the day. These observations were suspected to have negatively affected the growth rate of the birds housed in the control structure as could be seen in their weight (Table 4).

Figure 11, represents the average relative humidity in the bamboo structure during the study period, while Figure 12 represents the relative humidity in the burnt brick structure during the same period. It was generally observed that the relative humidity in the bamboo structure ranged between 64 - 80%. Jan (2005) observed that the optimum range of relative humidity for broilers after brooding was between 60% and 80% and that the higher the humidity within this range the better growth and feed conversion rate of the broilers. On the other hand, the relative humidity in the burnt brick structure was found to be between 58%-93% which fell below the minimum and above the maximum relative humidity for broiler production as posited by Jan (2005). These poor values of relative humidity were suspected to be responsible for the poor feed conversion rates and growth of the broilers housed in the control structure during the 4 weeks period of the study.

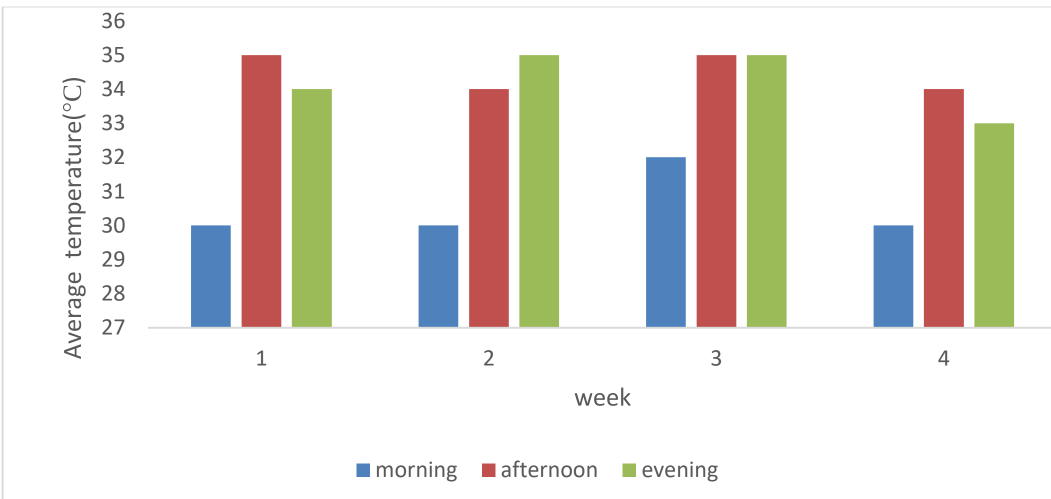

Figure 9: Average Temperatures in the Bamboo Structure under Broiler Production

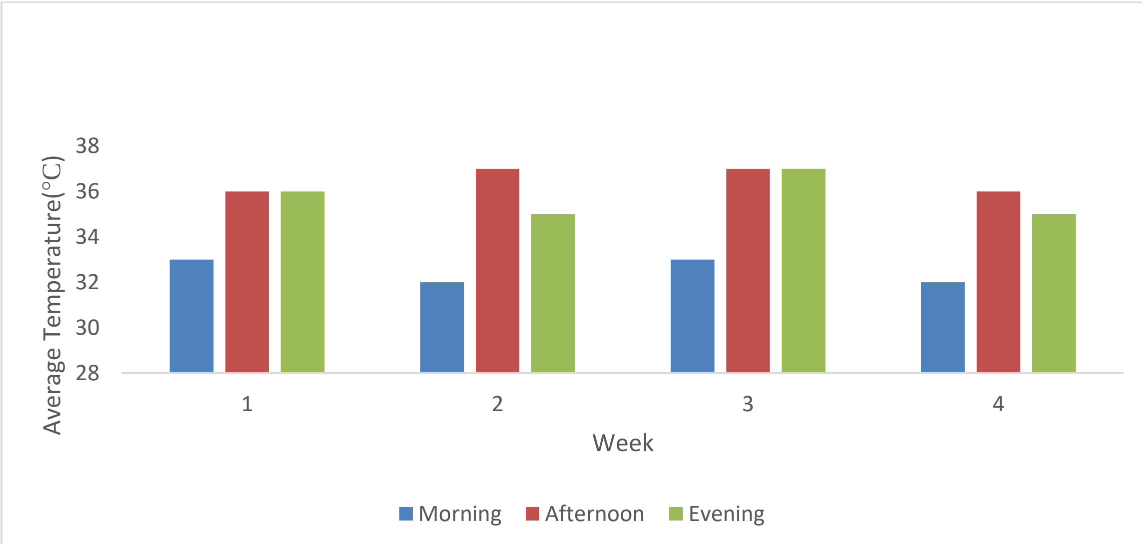

Figure 10: Average Temperatures in the Burnt Brick Structure under Broiler Production

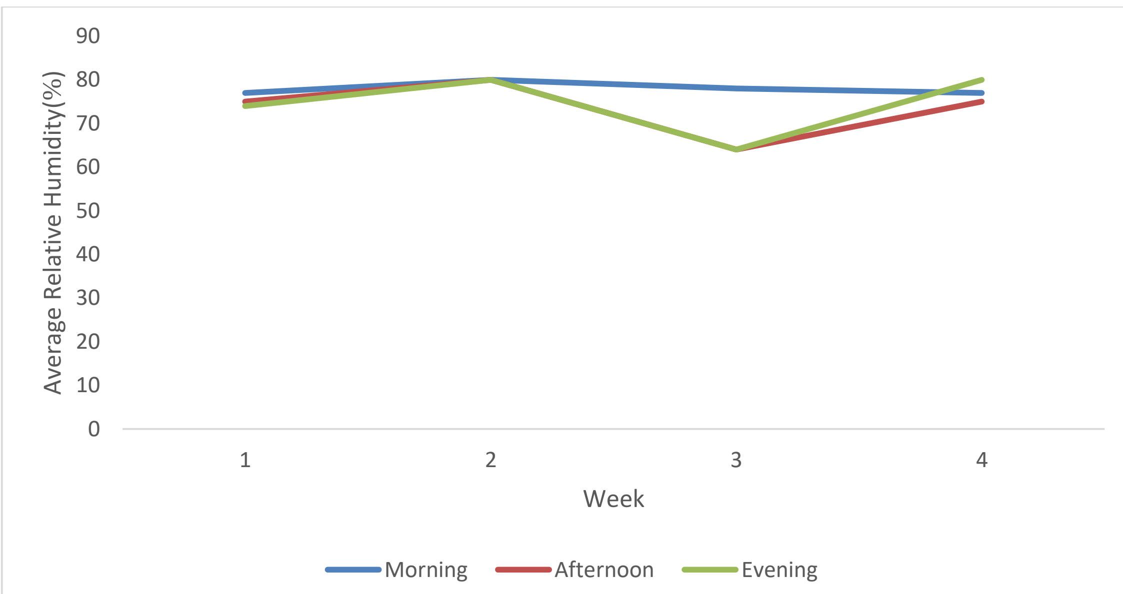

Figure 11: Relative Humidity in Bamboo Structure during the Period of Broiler Production

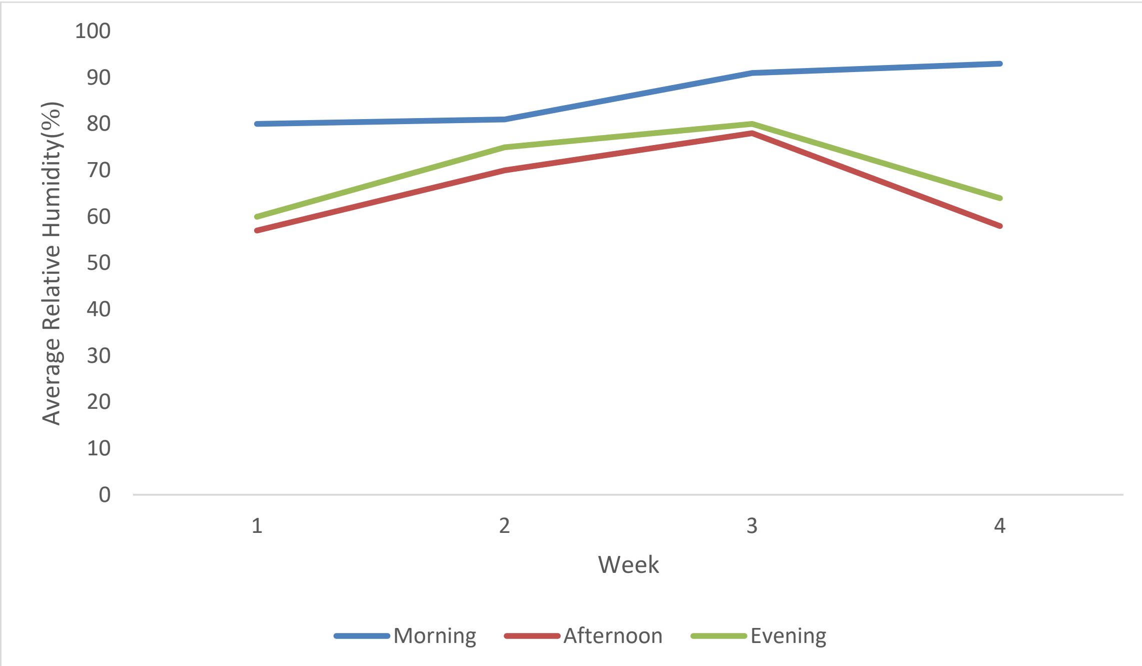

Figure 12: Mean Relative Humidity in Burnt Brick Structure under Broiler Production

3.2.2 Average weight of broilers.

Table 4 represents the average weight of the birds in the bamboo structure. The birds in the bamboo structure were observed to have an average weight of 1.4kg in the first week and 1.92kg, 2.26kg and 2.64 kg in the second, third and fourth weeks respectively. Contrary, the broilers housed in the control (burnt brick) structure were found to have an average weight of 1.15kg in the first week and 1.33kg, 1.62kg and 1.92kg in the second, third and fourth weeks respectively. The average weights at maturity (8 weeks) of the birds raised in both structures were higher than the minimal standard of 1.65kg (Farhadi *et al.*, 2016). For each week during the study period, it was observed that the broilers in the bamboo structure had better weight gain as compared to their counterparts housed in the burnt brick structure despite ensuring the same treatments in both structures. It should be noted that the average base weights (Weight after brooding) of the broilers housed in the bamboo and control structures were 0.81 and 0.88 kg respectively. Despite the higher average weight of the broilers in the control structure at the beginning of production, the broilers in the bamboo structure were found to steadily increase in weight above their counterparts in the control structure. This trend could be attributed to the environmental conditions (temperature and relative humidity) prevalent in the studied structures, since the same feed type, quantity, housing space and water was given to the birds in each structure. Therefore, the average weight gain of the birds could be seen as a function of the type of housing provided. These is in agreement with the findings of Farhadi *et al.*, (2016) who observed that housing type has significant effect on the average live weights of broilers raised in a conventional and

an environment-controlled structures. They observed that the birds raised in an environment-controlled structure performed better than their counterparts raised in the conventional poultry house.
Table 5 shows the average weight gain for the period of the entire work. The birds in the bamboo structure recorded high weight gains of 0.61kg and 0.50kg in the first and second weeks respectively, while in the third and fourth weeks they had the same weight gain of 0.34kg. It was generally observed that growth of broilers in the bamboo structure increased between the first and second week, and remained constant in the last two weeks. On the other hand, birds in the control structure were observed to have an inconsistent weight gain, which could also be attributed to their inconsistency in feeding as occasioned by environmental conditions in their housing (Beg *et al.*, 2011). The weight gain in the bamboo structure was recorded to be between 0.34kg-0.61kg, while that in the burnt brick structure was found to be between 0.32kg and 0.18kg bringing us to the conclusion that the weight gain was higher in the bamboo structure than what was recorded in the burnt brick structure.

3.2.3 Live bird analysis

Table 6 shows the average live birds analysis by the measurement of body parts such as the shank, thigh, drumstick, neck, wings and body in both the bamboo structure and the burnt brick structure. It was also observed that birds in the bamboo structure had longer necks, thighs, drumstick, wings and even big body size. The birds in the burnt brick structure had lower values in measurement than those in the bamboo structure as can be seen in Table 6. Generally the variations in the parameters considered for live bird analysis ranged from 0 -10.77% with the highest occurring for the neck length, while the shank length showed no variations between the broilers raised in the bamboo structure and those raised in the control. These observations are in tandem with those of Kalio and Okafor, 2012 who also observed that broilers raised in an intensive housing unit performed better in terms of their carcass analysis as compared to those raised in a semi-intensive unit. This is because poultry productivity is highly dependent on the environmental conditions (temperature, relative humidity, light intensity etc) of the poultry house which aids or averts efficient feed conversion as the case may be (Okujagu and Kalio, 2006).

Table 4: Average Weight of Broilers Housed in the two Structures for Four Weeks

Week	Bamboo structure(kg)	Burnt brick structure(kg)
1	1.42	1.15
2	1.92	1.33
3	2.26	1.62
4	2.64	1.94

*****Average base weight for broilers in bamboo structure is 0.81kg.
* Average base weight for broilers in burnt brick structure is 0.88kg

Table 5: Average Weight Gain of Broilers in both Structures

Week	Bamboo Structure(kg)	Burnt Brick Structure(kg)
1	0.61	0.27
2	0.50	0.18
3	0.34	0.29
4	0.34	0.32

Table 6: Average Live Broiler Analysis after Four Weeks of Housing in Both Structures

S/N	Parameters	Bamboo Structure	Burnt Brick Structure	Variation	% gain
1	Shank Length(cm)	7.8	7.8	0	0
2	Neck Length (cm)	11.4	9.6	1.8	10.77
3	Thigh Length (cm)	13	12	1.0	8.33
4	Body Length (cm)	46.6	44.4	2.2	4.95
5	Drumstick(cm)	10.4	9.4	1.0	10.63
6	Wing Length (cm)	18.6	17.4	1.2	6.89

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The bamboo structure was developed and compared with a burnt brick structure with average base weight of birds in the bamboo structure as 0.81kg and that of the burnt brick structure to be 0.88kg. At the end of the experimental period (4 weeks), broilers raised in the bamboo structure were observed to have the highest performance with an average weight of 2.64kg as against an average weight of 1.94kg gotten from the birds housed in the burnt brick structure.

It was observed that the bamboo structure had an average temperature ranging between 30-35°C as against ambient temperature of 32-38°C. The temperature in the surrounding was much higher than that in the bamboo structure. The temperature in the bamboo structure encouraged feeding at all times which in turn helped in the high growth rates of broilers recorded. In the case of the burnt brick structure, an average temperature of 32-38°C and same average ambient temperature with that of the bamboo structure. The slightly hot temperatures in the burnt brick structure affected feeding and growth adversely.

It was also observed that the average relative humidity in the bamboo structure (64%-80%) conformed to the acceptable standards for broiler production (60%-80%). This helped to increase their feed conversion ratio, as against the burnt brick structure which had an average relative humidity of 58%-93% falling clearly out of the range of standard relative humidity for broiler production.
It was concluded from data collected that broilers in the bamboo structure performed more in terms of weight gain as compared to the ones in the burnt brick structure. Environmental conditions such as temperature and relative humidity of the bamboo structure conformed more to standards thereby encouraging better performances than that of the data generated from the burnt brick structure during the course of work.

4.2 Recommendations

The effectiveness of bamboo structure as a novel poultry house in the tropics should also be tested during the rainy season. It is also recommended that further studies should be carried out on the environmental foot prints and cost effectiveness of using bamboo as a total poultry housing material in the tropics.

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Evaluation of *Piper guineense* and *Dennettia tripetala* with raw Diatomaceous earths against *Sitophilus zeamais* (Motschulsky) on stored Sorghum

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ABSTRACT

Sorghum is one of the most important staple food crops in Nigeria. In order to combat the menace posed by this insect, stakeholders employ series of control measures, mostly used are the synthetic chemicals but many hazards are associated with their use as a result of mis-use by unskilled handlers. Therefore, the objective of this study was to access the insecticidal efficacy of laboratory determined dose rates of raw Bularafa DE and raw Abakire DE, *P. guineense*, *D. tripetala* and *P. guineense*, *D. tripetala* in treatment combinations with Bularafa DE and Abakire DE against *Sitophilus zeamais* in stored sorghum. Bularafa and Abakire were applied at dose rate of 40 g/ 20 kg sorghum while *P. guineense* and *D. tripetala* were applied at 400 g/ 20 kg sorghum. Monthly parameters such as number of live insects, insect damage kernels and weight loss were monitored for a period of nine months. By the end of the study, no live insects were recorded from combination treatments; untreated control recorded the highest number of live insects (98). No insect damaged kernel and percent weight loss was recorded in combination treatments compared to Bularafa (0.20 ± 0.10), Abakire DE (1.44 ± 0.18), *P. guineense* (0.09 ± 0.01), *D. tripetala* (0.12 ± 0.04) and untreated control (2.23 ± 0.25). Hence, treatment combinations of *P. guineense* and *D. tripetala* with Bularafa DE and Abakire DE could be incorporated into postharvest management strategies for stored product insect pests by small and medium scale stakeholders.

Keywords: Sitophilus zeamais, piper guineense, dennettia tripetala, insect damaged kernels, live insects, weight loss, Nigeria.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is a tropical cereal plant, belonging to the grass family Poaceae (Adeyeye and Adesina, 2013). It is one of the most important staples in sub-Saharan Africa having more than 35% of the crop grown majorly for human consumption, animal feed, alcohol production and industrial products (Awika and Rooney, 2004a). MY 2017/18 Global Agricultural Information Network report by USDA Foreign Agricultural Services estimated sorghum production in Nigeria at 6.55 million tons and consumption is projected at 6.5 million tons (https://gain.fas.usda.gov>GainandFeed), hence the need for storage.

Storage is a postharvest activity by which agricultural products or produce are kept for future use. For small scale farmers in Africa, Nigeria inclusive, the main purpose of storage is to ensure food supplies for the home (reserves) and seed for planting (Adetunji, 2007). It is estimated that 60–70% of sorghum produced in Nigeria are stored at home level by about 95% of farmers (Mahai et al., 2015) in indigenous storage structures such as bamboo baskets, mud structures and modern bin (Karthikeyan et al., 2009) exposing them to insect infestation.

The maize weevil, *Sitophilus zeamais*, Motschulsky (Coleoptera: Curculionidae) is a primary pest of sorghum, maize, rice, wheat and millet (PaDil, 2009). The control of *S. zeamais* is a serious problem in the tropics due to inadequate storage measures and favorable climatic conditions which favours their rapid multiplication (Bekele and Hassanali, 1997).

In Nigeria, the use of chemical insecticides which hitherto was the control measure of choice in storage has recently been criticized. This is because of the difficulties associated with its procurement, hazard with its use, increased concern by consumers over insecticide residues in processed cereal products and the ecological consequences (Mahdian and Rahman, 2008). The concerns for food quality, health and environmental protection have caused the search for alternative organic sources considered to be readily available, reduced-risk, low-cost and environmentally friendly (Udo, 2005). Some of the alternatives that have been tested and published as having insecticidal properties are West African Brown Pepper (*P. guineense*) and Pepper fruit (*D. tripetala*) (Okonkwo and Ewete, 2000; Oparaeke and Bunmi, 2006; Otitodun et al., 2015); inert dust e.g Diatomaceous earth (Stathers et al., 2004; Nwaubani et al., 2014; Otitodun et al., 2015).
Therefore, the objective of this study was to access the insecticidal efficacy of laboratory determined dose rates of raw Bularafa DE and raw Abakire DE, *P. guineense*, *D. tripetala* and *P. guineense*, *D. tripetala* in treatment combinations with Bularafa DE and Abakire DE against *Sitophilus zeamais* in stored sorghum.

2. MATERIALS AND METHODS

2.1 Study location

The study was conducted in the rice processing building of the Nigerian Stored Products Research Institute (NSPRI) headquarters, Ilorin, Nigeria. Monthly samples were analyzed in the Entomology unit of NSPRI. Ambient temperature and relative humidity was monitored during the study using LASCAR data loggers and Onset®U23–001 HOBO Pro V2 Temp/RH.

2.2 Preparation of sorghum grain samples

Freshly harvested, dried and untreated sorghum (Variety: Kaura) was procured from an identified farmer in Kano, Kano State, Nigeria through an agricultural extension agent. The grains were cleaned on-farm before bagging and then transported to NSPRI, Ilorin. The initial grain moisture content (9.03%) was determined on-farm using John Deere Moisture Chek Plus™ (SW08120) meter. At NSPRI, the grains were turned into seven 100 L capacity and one 120 L capacity plastic drums and subjected to phosphine gas fumigation under sealed fitted lids inside the warehouse. Before use, sorghum grains were properly cleaned of dockage (stones, shaft etc) dust and other dirt. Initial insect count, number and percentage of insect damaged kernels and grain weight loss was determined.

2.3 Phosphine gas fumigation of sorghum grains

Seven 100 L capacity and one 120 L capacity plastic drums were filled up with sorghum grains. The fumigation exercise was conducted inside the NSPRI's warehouse located 304.8 m from office complex. The sorghum was subjected to gas fumigation using aluminium phosphide tablets (Celphos®) manufactured and exported by Excel Crop Care Limited, Kutch, Gujarat, China. One tablet was enclosed in soft toilet tissues and inserted into each plastic drum following the manufacturers recommended dose of 3–4 tablets/m^3. The edges around the lids were sealed up properly with duct tape to prevent escape of gas from the fumigation chamber. Warning signs were placed around the building where the exercise was conducted to alert people of the impending danger of loitering around the area. Fumigation was conducted under safety and lasted for 7 days and thereafter the plastic drums were left open for 2 days to dissipate phosphine gas before use. The fumigated sorghum grains were then winnowed to remove dirt.

2.4 Monthly acquisition of sorghum grain samples from bags

Bags of sorghum grains were sampled once every month (7th day of each month) throughout the 9 months storage period. The samples were obtained using the open handled brass made Trier (grain probe) having six openings. The Trier was inserted into the bag in the closed position, opened up after it was properly inserted into the bag and closed up when full before being pulled out. Small opening of about 3 cm wide was made at the seam area of every bag to accommodate the insertion of the Trier during sampling. Samples were drawn with the Trier from each bag, poured into labeled Ziploc bags and taken into the laboratory for further analyses. The sorghum grains were emptied into the Ziploc bag by placing an open bag over the open end of Trier filled with sorghum sample, when the tip of the Trier was facing down (upright position). While holding the bag in place, the Trier was then turned such that the tip faced upwards (the Trier is inverted) to empty grains into the bag. Caution was exercised to prevent the inner piece of the Trier from coming loose and hurting the person emptying the Trier. The opening on the bag was properly sealed up using flash bands (Duct tape) to remove the stress of unstitching and sewing at every sampling time.

2.5 Collection and preparation of plant powders

Ripe and freshly harvested *P. guineense* and *D. tripetala* fruits were sourced from an identified farmer in Oro Kingdom, Ondo State. The fruits of *P. guineense* were plucked using a sickle-shaped harvesting knife attached to a long stick while fruits of *D. tripetala* were plucked using a short stick. Fruits of *D. tripetala* were poured into a 25 kg capacity polythene bag, tied at the open end and kept inside a room for 3 days to generate heat which softened the fruits. Thereafter, the seeds were removed with a scalpel from the soft pericarp and washed under running water. *Piper guineense* fruits and *D. tripetala* seeds were processed using the method described by Okonkwo and Okoye (2001). After shade -drying for 30 days, they were further dried inside a laboratory drying oven (DHG-9240A) at 30°C for 72 hours (Donald *et al*., 2008). The dried fruits and seeds were separately ground into powders using the local milling machine, sieved with Rupson standard test sieve to provide particles of not more than 250 microns and then sealed in air-tight containers until they were used.

2.6 Collection and preparation of Diatomaceous Earth (DE)

Crude diatomaceous earth ore of fresh water origin was obtained from two communities in Yobe State, Nigeria. One type was obtained from Bularafa community (hereafter referred to as DE 1) and the second type from Abakire community (hereafter referred to as DE 2). They were oven dried at 40°C to 4.5% moisture content (Arnaud *et al*., 2005). The sample was manually ground into powder in a mortar and pestle, sieved using an Endecotts laboratory test sieve (SN. 5836058) to provide particles of not more than 90 microns. The fine powder was stored in an air-tight container until used. A registered commercial DE (Insecto®) obtained from the manufacturer—Natural Insecto Products Inc. in the United States of America was used as the standard check.

2.7 Experimental Protocol

This study was conducted on sorghum grains stored for 9 months (September, 2016 – May, 2017). The experimental set up was Complete Randomized Design (CRD).

2.7.1 Protective potentials of single treatments of *P. guineense*, *D. tripetala*, Bularafa DE (DE 1), Abakire DE (DE 2) and treatment combinations of *P. guineense* and *D. tripetala* with Bularafa DE (DE 1) and Abakire DE (DE 2) against *S. zeamais* infestation in sorghum grains stored in bags.

The study was to investigate the insecticidal potency of these treatments against stored product insect, *S. zeamais* infestation. Observations were based on the presence or absence of live *S. zeamais*. The experimental set up was a complete randomized design (CRD) with each treatment and dose rates having three replicates. Application rates of each treatment used were based on results from the laboratory studies.

Twenty kilogrammes (20 kg) of clean, dried and insect-free sorghum grains were admixed separately with DE 1 and DE 2 at the rate of 40 g in three wide plastic bowls, respectively. Manual shaking to ensure proper coating of the grains was done for about 5 minutes. The mixture was poured into 25 kg capacity polypropylene bags and the bags sealed up using the Guru Bag closure machine. Grains were arranged per treatment on white painted wooden pallets for monthly sampling and analysis. Three replicates each of Rambo® powder—a pyrethroid (Permethrin 0.6% a.i) and Insecto®—a food grade DE served as positive controls at dosage rates of 33.4 and 20 g respectively. Another three lots of untreated 20 kg sorghum grains in 25 kg capacity polypropylene served as the untreated control. Similarly, 400 g of both *P. guineense* and *D. tripetala* were separately admixed manually with three 20 kg grains each, poured into 25 kg capacity polypropylene bags and then sealed up. There was another set up which included three each of 20 kg sorghum grains manually mixed with combinations of all the treatments in the aforementioned dose ratio (*P. guineense* + DE 1, *P. guineense* + DE 2, *D. tripetala* + DE 1 and *D. tripetala* + DE 2); thereafter poured into 25 kg capacity polypropylene bags. The experiment was conducted under ambient conditions of 28 ± 2°C; 69 ± 5% r.h. Temperature and relative humidity inside the experimental building was monitored using Onset HOBO® Data Loggers. All the set up were without initial insect infestation and each treatment and dose rates were replicated three times.

Grain samples were drawn every month following the grain acquisition method described above and the samples taken into the laboratory for further analysis.

2.7.2 Determination of insect damaged kernels (IDK)

Insect damaged kernel was determined monthly after live insects count. Two hundred and fifty gram was taken from each sampled lot and sorted out for number of damaged (Nd) — grains with insect exit holes — and number of undamaged (Nu). Their numbers were recorded and the percent insect damaged kernels-number basis (%IDK) was calculated according to Quitco and Quindoza (1986) using the formula below;

$$\%IDK = \frac{Nd}{250} \times 100$$

Where: Nd = Number of damaged out of 250 g
IDK = Insect damaged kernels

Similarly, out of the 250 g grain taken from each sampled lot, weight of damaged (Wd) — grains with insect exit holes — and weight of undamaged (Wu) were recorded and percentage insect damaged kernels-weight basis was calculated according to Quitco and Quindoza (1986) using the formula below;

$$\%IDK = \frac{Wd}{250} \times 100$$

Where: Wd= weight of damaged out of 250 g
IDK = Insect damaged kernels

2.7.3 Determination of grain weight loss

Grain weight loss was determined every month. Two hundred and fifty gram was taken out from each sampled lot and the lot was sorted out for damaged and undamaged grains. Their numbers and weights were recorded and percentage weight loss calculated according to Gwinner *et al*., (1996) thus:

$$\%\,Wt\ loss = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu \times (Nd + Nu)} \times 100$$

Where: Wu = weight of undamaged grains
Nu = number of undamaged grains
Wd = weight of damaged grains
Nd = number of damaged grains

2. RESULTS AND DISCUSSION

3.1 Protective potentials of single treatments of *P. guineense*, *D. tripetala*, Bularafa DE (DE 1), Abakire DE (DE 2) and treatment combinations of *P. guineense* and *D. tripetala* with Bularafa DE (DE 1) and Abakire DE (DE 2) against *S. zeamais* infestation in sorghum grains stored in bags.

During the 9 months storage period, live insect species were first observed by December and their abundance increased as months of storage progressed. The following insect species were identified, *S. zeamais*, *Oryzaephilus surinamensis* and Psocid. By the end of the study, abundance of live *S. zeamais* was more in untreated control (96), followed by Abakire DE (34), Rambo (9), Bularafa (8), *P. guineense* (3) and *D. tripetala* (2) compared to no insect in Insecto and treatment combinations (Fig. 1); *O. surinamensis* was more in untreated control (8), followed by Abakire DE (6), Bularafa DE (2), Rambo (2) and *D. tripetala* (1) while no live insect was recorded from *P. guineense*, Insecto and treatment combinations (Fig. 2); Psocid was more in untreated control (9), followed by Abakire DE (4), Bularafa DE (3) and Rambo (2) compared to no live insects in *P. guineense*, *D. tripetala*, Insecto and treatment combinations (Fig. 3).

With respect to the total number of live insects per treatments, there was significant difference in the total number of live insects found in various treatments compared to the untreated control (Fig. 4). Between December and February, live insects were only found in Abakire DE and untreated control; By March, live insects were recorded in Abakire DE, Bularafa DE, Rambo and untreated control, although Rambo had the least number of 2 insects. In April and May, some live insects were recorded from *D. tripetala* and *P. guineense* treatments, but there was significant difference in the numbers found in *D. tripetala* and *P. guineense* treatments compared with those in Abakire DE, Bularafa DE, untreated control and Rambo; the highest total number of live insects was in the untreated control.

Throughout the period of storage (September–May), no insect, either live or dead was recorded from treatment combinations of *P. guineense* and *D. tripetala* with Abakire DE, Bularafa DE and no live insect was also recorded in Insecto.

Insect infestation increased progressively after 3 months of storage and resulted in higher numbers of live *S. zeamais, O. surinamensis and* Psocid as the study period progressed and breeding conditions becomes favourable. The numbers of live insects were higher in untreated control except in Abakire DE, where there was no significant difference compared to untreated control based on the abundance of *S. zeamais* in May. This agree with the work of Benhalima et al. (2004) and Upadhyay and Ahmad (2011) who reported that coleopterans are among the insect species that cause major infestations and serious damage to stored commodities. Grains are hygroscopic; therefore, there is the possibility of moisture movement from the atmosphere to the grains whenever atmospheric humidity increased. This probably explains why numbers of live Psocid increased gradually as the rain sets in (March–May), although increase in grain moisture content was not assessed in this study. This observation supported the report by Mills et al., (1992) that Psocid infestations are favoured when moisture content of commodities is high.

Treatment combinations completely prevented the emergence of progeny; hence, no live insect was recorded throughout the 9 months of sorghum storage in bags. This was also the case with the types of insect species; no kind of insect was recovered from sorghum samples obtained from the bags preserved with treatment combinations. This finding was similar to earlier reports by Otitodun et al., (2015) where no live insect was recorded throughout the study period, although their study was done for only 3 months. There was also a synergistic interaction between the treatment combinations because some live insects were recorded from the single treatments. Grains treated with Bularafa DE and Abakire DE had live insects, although the number was few in Bularafa DE compared to Abakire DE. This finding was similar to reports by Nwaubani et al., (2014). By the end of the study, the lowest numbers of insects were found in *P. guineense* and *D. tripetala* treated grains. This finding corroborates reports by Otitodun et al., (2015) where no live insect was found in these treatments, although they used higher dose than was used in this present study.

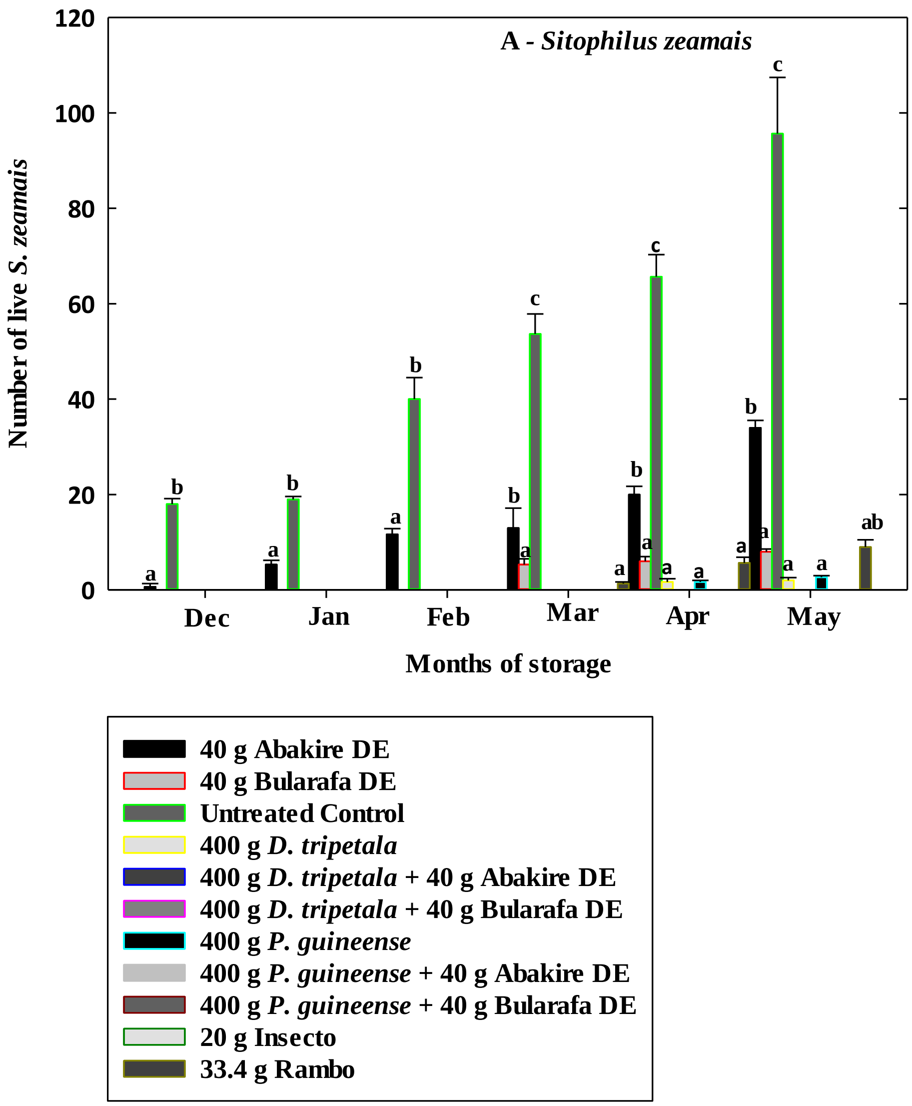

Figure 1: Number of live *Sitophilus zeamais* in stored sorghum preserved with *P. guineense*, *D. tripetala*, bularafa (DE 1), abakire (DE 2) and their treatment combinations.

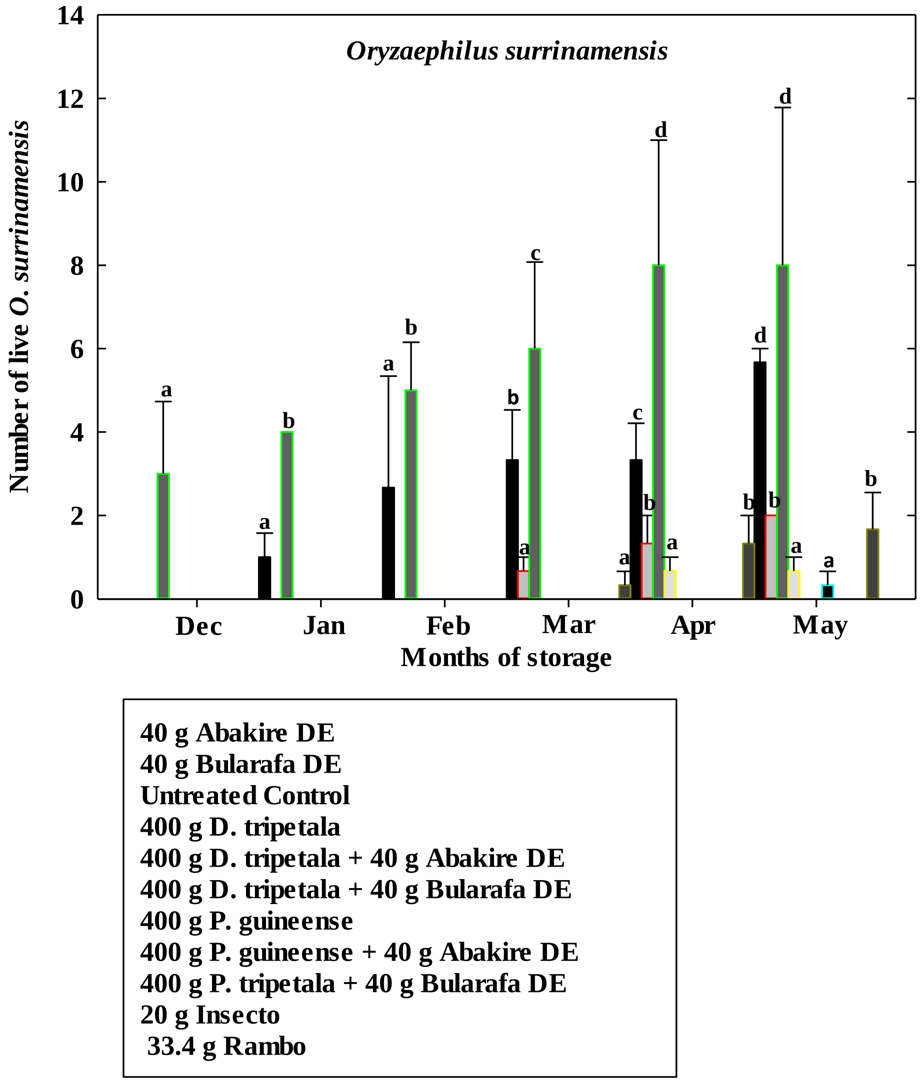

Figure 2: Number of live *Oryzaephilus surinamensis* in stored sorghum preserved with *P. guineense*, *D. tripetala*, bularafa (DE 1), abakire (DE 2) and their treatment combinations.

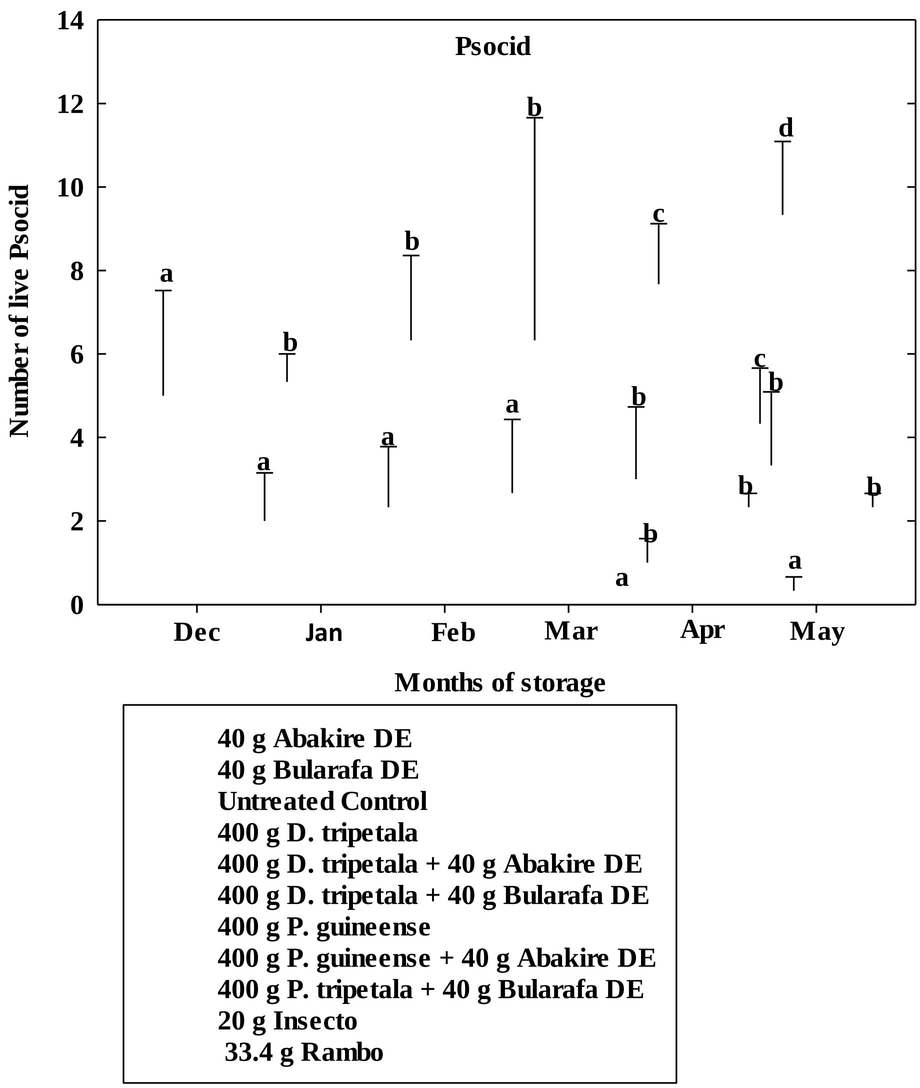

Figure 3: Number of live Psocid in stored sorghum preserved with *P. guineense*, *D. tripetala*, bularafa (DE 1), abakire (DE 2) and their treatment combinations.

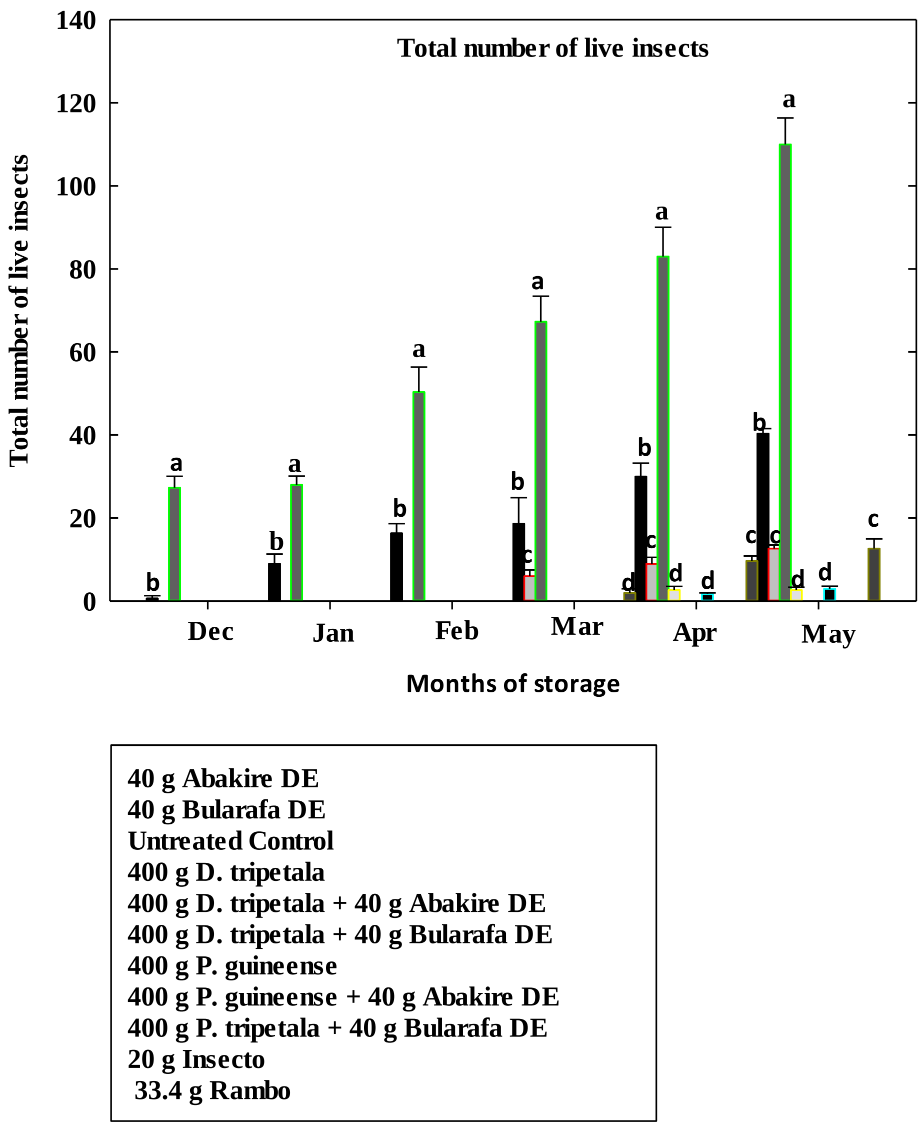

Figure 4: Total number of live insects in stored sorghum preserved with *P. guineense*, *D. tripetala*, bularafa (DE 1), abakire (DE 2) and their treatment combinations.

3.2 Effect of single treatments of *P. guineense, D. tripetala,* Bularafa DE (DE 1), Abakire DE (DE 2) and treatment combinations of *P. guineense* and *D. tripetala* with Bularafa DE (DE 1) and Abakire DE (DE 2) on percentage insect damaged kernels in sorghum stored in bags

The result from the study revealed that insect damaged kernel was first observed by December in Abakire DE and untreated control (Fig. 5). There was significant difference in percentage insect damaged kernels found in each treatment compared to the untreated control. In December and February, high mean values of insect damaged kernels were observed only in Abakire DE (0.07 ± 0.04) and untreated control (0.13 ± 0.05); in March, insect damaged kernels were only recorded in Abakire DE (0.17 ± 0.05), Bularafa DE (0.07 ± 0.04), untreated control (1.52 ± 0.12) and Rambo but the value was lower in Rambo (0.03 ± 0.03).

Between April and May, lower mean values of insect damaged kernels were recorded in *P. guineense* (0.09 ± 0.01) and *D. tripetala* (0.12 ± 0.04) treatments compared to values from Abakire DE (1.44 ± 0.18), Bularafa DE (0.20 ± 0.10), untreated control (2.23 ± 0.25) and Rambo (0.31 ± 0.10); the highest number was in the control.

Throughout the 9 months storage period (September–May), no insect damaged kernel was recorded from treatment combinations of *P. guineense* and *D. tripetala* with Abakire DE and Bularafa DE, no insect was also recorded in Insecto.

Observations from results on insect damaged kernels corroborate the report by Reed et al., (2007) that insect infestation can result in not only grain damage as understood by shorter storage times, but can also affect the actual weight of the grain, leading to lower prices in the market and reduction in nutritional value of the grain. Untreated control recorded the highest percentage of insect damaged kernels followed by Abakire DE. This was evident because number of live insects, especially *S. zeamais* was highest in untreated control followed by Abakire DE. The observation corroborated report of Paudyal *et al.* (2017) that there was severe and significant postharvest losses in Sub-Saharan Africa due to insects activities in grains stored in traditional polypropylene bags that are without any form of protection. The insect developed and feed inside the kernel and adult emerged by creating an exit hole on the kernel. The synergistic interactions between treatment combinations completely suppressed progeny which led to reduced insect activities cum reduced insect damaged kernels. This also translates to what was observed in the single applications.

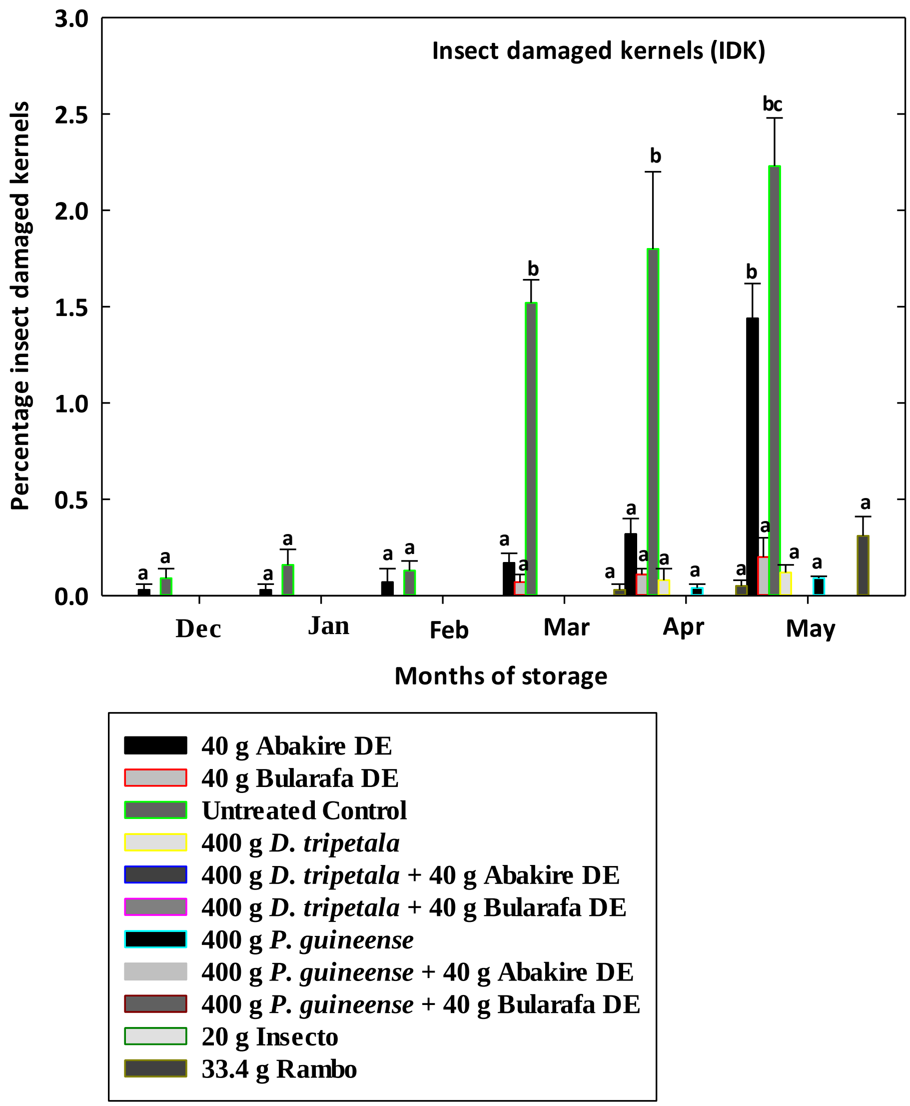

Figure 5: Percentage insect damaged kernel in stored sorghum preserved with *P. guineense*, *D. tripetala*, bularafa (DE 1), abakire (DE 2) and their treatment combinations.

3.3 Effect of single treatments of *P. guineense, D. tripetala*, Bularafa DE (DE 1), Abakire DE (DE 2) and treatment combinations of *P. guineense* and *D. tripetala* with Bularafa DE (DE 1) and Abakire DE (DE 2) on percentage weight loss in sorghum grains stored in bags

In the storage period of September–December, no noticeable weight loss was recorded until January when different mean values were recorded from various treatments and these values increased as storage period progressed (Fig. 6). Only Abakire DE and untreated control recorded mean weight loss of 0.03 ± 0.01 and 0.22 ± 0.07 in January while the values were 0.07 ± 0.05 and 0.26 ± 0.10, respectively in February. In March, Rambo had lower mean percentage weight loss (0.01 ± 0.01) followed by Abakire DE (0.07 ± 0.03) while the highest value was recorded in untreated control (0.46 ± 0.09).
By April, weight loss was recorded in grains treated with *P. guineense* (0.01± 0.01) and *D. tripetala* (0.02 ± 0.00), Rambo (0.01 ± 0.01), Bularafa DE (0.02 ± 0.00), Abakire DE (0.08 ± 0.01), respectively. There was significant difference ($P < 0.05$) between the values from all these treatments and untreated control (0.70 ± 0.21). In May, there was significant difference in weight loss recorded *P. guineense*, *D. tripetala*, Bularafa DE and Rambo compared to Abakire DE (0.77 ± 0.25) and untreated control (0.81 ± 0.10).
Throughout the period of storage (September–May), no weight loss (0.00 ± 0.00) was recorded from Insecto, treatment combinations of *P. guineense* and *D. tripetala* with Abakire DE and Bularafa DE.
Grain weight loss due to infestation reduces the quality of grains thereby making the grains unacceptable by consumers, resulting in less profit for farmers since they cannot be bought at premium price. This corroborates the report by Patrick (2013) that postharvest losses make farmers poorer. Results from this study on grain weight loss in sorghum grains preserved with *P. guineense* and *D. tripetala* corroborate the report by Asawalam et al., (2012) that rice seeds treated with *P. guineense* seed powder performed best in terms of percentage weight loss compared to the untreated control. Also since feeding activities of the insects were reduced as a result of the treatment preventing or suppressing progeny production especially of *S. zeamais*, ultimately, grain weight loss would be reduced since damage to grains are low. The synergistic interactions between treatment combinations completely suppressed progeny which led to reduced insect activities cum reduced insect damaged kernels and weight loss. Ultimately, the highest percentage grain weight loss was recorded from the untreated control followed by Abakire DE.

4. CONCLUSION

The study shows that raw Nigerian-derived diatomaceous earths contain some level of insecticidal potency and their rates of application can be controlled to prevent unnecessary tainting of the stored sorghum. The level of insecticidal potency of the raw DEs can be

enhanced when combined with some botanicals that have been proven to have insecticidal properties. The treatment combinations of both the raw DEs and botanicals have been shown to confer protection on sorghum against attack from insect pests.
Based on the results obtained from the study, *P. guineense* and *D. tripetala* in combinations with raw Bularafa DE and Abakire DE have a broad spectrum of activity against *S. zeamais* and could have potentials as bio insecticides in stored-product protection. Hence treatment application and re-application may not be necessary during storage provided good agricultural practices are maintained.
As part of contributions to food safety and food security in Nigeria and globally, a Nigerian-derived DE based product have been developed and registered as NSPRIDUST® by the Nigerian Stored Products Research Institute (NSPRI) for postharvest management of stored product insect pests and it is at the verge of commercialization.
In conclusion, since the materials tested are locally sourced and have been reported safe to handle and use, they are therefore an attractive storage tool which can be formulated into new products for postharvest management of *S. zeamais* by small and medium scale farmers.

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Design and Construction of A Tunnel Dryer for Plantain Chips Drying

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ABSTRACT

Conventional sun drying of tropical crop often results in low quality product due to unpredictable nature of weather. Utilizing mechanical dryer such as tunnel dryer can improve the quality of the products as well as increasing the acceptability of such crop in global market. In this study, a tunnel dryer in two modes of operation (co-current and counter-current) with a capacity of 35kg of chips per batch was designed, fabricated and tested. The dryer had a chamber volume of 0.408m^3; the number of trucks in the tunnel was 6, each truck contained 6 trays. The operating temperature of the pilot dryer ranged from 50 to 150 ^oC and air velocity ranged from 2 to 8 m/s, respectively. Plantain chips was used to test the dryer and the results showed that the dryer reduced the moisture content from 9.404 kg water/ kg solid to 0.013 kg water/ kg solid in 7 hours with drying rate average of 1.34 kg H_2O/h.

Keywords: Tunnel dryer, design, construction, plantain chips, Nigeria

1. INTRODUCTION

Nigeria is one of the largest producers of plantain in Africa of more than 1.5 million ton annually [Ajala and Ajala, 2015]. Large proportion of this plantain are processed into flour after drying. Drying of plantain produce is not simply the removal of excess moisture but a technological process which results in a change of moisture content of the material and of the property of the material itself [Ajala et al 2018]. In Nigeria, common methods of drying plantain include sun drying or artificial drying using mechanical dryers. Often, sun drying is used for this drying process because most farmers cannot afford the use of mechanical dryer due to cost. Up till mow, there have been little or no dryers designed specifically to handle plantain drying in the country.

Attempt were made by some researchers to develop dryers for agricultural products; for instance, Gual *et al.*, (2012) constructed a cabinet dryer to dry apricot; also, Mourad *et al.* (2014) studied drying of Tunisian spearmint in a dryer which was specifically designed for fish. Furthermore there are dryers manufactured from Western world which can be imported into the country for drying purposes. However, not only the problem of capital to import these high technology dryers faces the farmers and processors in developing countries like Nigeria but the problem of maintaining such dryers is a critical issue. Not only this, farmers need dryers (such as tunnel dryers) that can handle high volume of farm produce better than cabinet dryer but the problem of cost of importation is higher than the reach of small and medium scale farmers. Therefore, construction of dryers with locally available material (such as wood, bricks and steel) will help the farmers' affordability of such equipment. Therefore the objective of this work is to develop a tunnel dryer for dehydration of plantain chips from local raw materials.

2. MATERIALS AND METHODS

2.1 Design Features of the Constructed Tunnel Dryer

The diagrammatic feature of this dryer is as shown in Figure 1

- It has both counter-current and co-current mode of drying
- Expected Production rate: 32.5kg/batch
- Expected number of trucks: 6
- Expected number of trays per truck: 6
- Initial moisture content of plantain: 60% wet basis [Adam *et al.*, 2017]
- Desired final moisture content: 14% wet basis
- Air temperature before entering dryer: 32^{o}C
- Bulk density of plantain: 730 kg/m^3 [Ogundare-Akanmu, *et al.*, 2015]

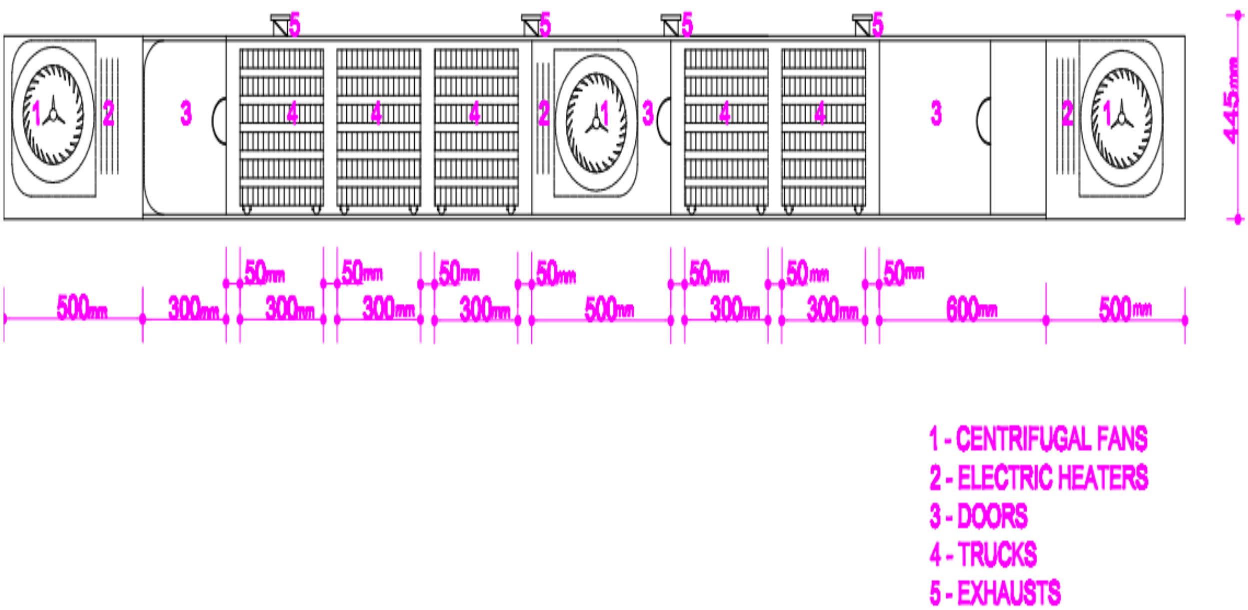

Figure 1: Front view of the tunnel dryer with six trucks

2.2 Description of Major Components and Materials of Construction

The dryer consists of the following components

2.2.1 Drying Chamber (Tunnel)*:* This is the action chamber for drying. It contains six trucks which are loaded periodically. The trucks could be loaded in counter-current and co-current modes. The inside was constructed with aluminum frame which served as the skeletal frame of the dryer which was then covered with a aluminum sheet because of its corrosion resistance property, availability and cost. The outer covering was made from aluminum sheet because of its malleability, ductility, lightness and relative low cost. The length of the tunnel was 3.25m with a breadth of 0.35m and a height of 0.30m.

2.2.2 ***Electric Heater****:* The electric heater supplied heat to the drying chamber for drying the product (plantain). Selection of heater was based on several factors like loading mass of the product to be dried, the optimum moisture content of the product and temperature difference in the chamber. Three heaters of 3kW were used in the dryer to supply the heat needed for the drying operation. A heater was placed at both end and the third was put in the middle as supplementary.

2.2.3 ***Blower (fan):*** The fans were used to circulate heated air in the drying chamber. For effective drying system, three centrifugal fans that could deliver 5 m/s at 0.75kW each was employed at both ends and 0.375 kW at the middle.

2.2.4. Trucks: The tunnel consisted of six trucks with each truck containing six (6) trays. The trucks were made from aluminum angles and contained roller-wheels for easy movement in and out of the chamber. It has a length and breadth of 0.30m and a height of 0.30m.

2.2.5 Trays: These were flat, square–shaped containers which contain the product to be dried. They were made from aluminum plate, so that the water from the product will not corrode the surface. The dryer had thirty-six (36) trays in total. The tray had a length and breadth of 0.25mx 0.20m and a height of 0.015m.

2.2.6 Fastener (Bolts and Nuts)*:* Bolts and nuts were used for coupling different components or parts together especially for rails in the chamber which allowed easy movement of trucks.

2.2.7 Lagging Material*:* Fibre glass material was used for lagging tunnel dryer because of its ability to reduce heat losses in the dryer to a greater extent.

2.2.8 Electrical and Electronic Components*:* Wires were used to connect the heater and the blower to an electrical power source. The thermocouples were used for sensing the temperature rise in the dryer and also to regulate temperature at the desired temperature of drying.

2.2.9 Centre Exhaust*:* These were small round-shaped perforated openings for allowing the passage of wet hot air out of the drying chamber. They were situated on the top of the tunnel in four places.

2.3 Design Calculations

2.3.1 Calculation for the Volume of Plantain Chips on the Trays

From the relationship

Volume = Mass/ Density

= 0.73/730

$=0.001m^3$

Each tray will carry $0.001m^3$ of raw plantain chips

2.3.2 Design of Trays

Length of tray=0.25m

Breadth of the tray= 0.20m

Height of the tray= 0.015m

Area of the tray = LxB

= 0.25x0.0.3

$= 0.075m^2$

Volume of the tray =LxBxH

=0.075x0.015

$=0.001125m^3$

Height of the truck = Height of the tray trays + height of roller Wheel

= (0.025)6 + 5(0.015) +0.025

= 0.25m

Length of the truck = length of the tray + allowance for easy movement

= (0.25+ 0.05)

= 0.30m

Breadth of the truck =0.2m

Area of each truck = L x B

$= (0.3 \text{ x } 0.2) m^2$

$= 0.06m^2$

Volume of each truck = Lx B x H

=0.30 x 0.20 x 0.25

$=0.017m^3$

2.3.3 Design for Drying Chamber of the Tunnel

Length of the drying chamber = length of each truck x number of trucks + spaces between the truck

=3.25m

Breadth of the drying chamber =0.35m

Area of the drying chamber = LxB

= 3.25 x 0.35

$=1.1375m^2$

Volume of the drying chamber = LxBxH

$= (1.05 \text{ x } 0.35 \text{ x } 0.49) m^3$

$=0.18m^3$

2.3.4 Design Space for Components of the Tunnel

Length of the whole tunnel = length of each truck x number of trucks + interspaces +spaces for heating chamber

= 4.25 m

Breadth of the whole tunnel = Breadth of the truck + allowance for clearance

= {0.30 + 0.05} m

= 0.305m

Height of the whole tunnel = Height of the truck + height of the roller wheel + clearance between trucks' height and tunnel's roof

= (0.275 +0.04) m

= 0.315 m

Area of the whole tunnel = L x B

= (4.25 x 0.305) m^2

= 1.296 m^2

Volume of the whole tunnel = L x B x H

= (1.296 x 0.315) m^3

= 0.408 m^3

2.3.5 Selection of the Heater

Feed rate (m_w) = 32.5 kg/hr

Intended drying time = 6 hours

Initial moisture content of the plantain chips = 60%

Desired final moisture content = 14%

Therefore, weight loss from wet to dried chips is calculated thus

$$m_d = m_w\left(\frac{100-m_0}{100-m_f}\right)$$

where m_w is the mass of wet plantain chips, m_0 =initial moisture content (%)

m_d is the mass of dried plantain chips, m_f =final moisture content (%)

$$M_d = 32.5\frac{100-60}{100-14}$$

m_d = 15.11 kg

Mass of water to be removed during drying = mass of wet plantain chips – mass of dried plantain chips

= (32.5- 15.11) kg

=17.39kg

Quantity of heat required to remove the water = quantity of heat on the plantain chips + latent heat of evaporation of water inside the chips

Specific heat of Plantain chips = 3.26kJ/kg°C [Njie *et al.*, 1998]

Latent heat of water= 4.186 x10^3 {(597- 0.56(T_{pr})} [Youcef-Ali *et al.*, 2001]

where T_{pr} is the product temperature

Q = mass of plantain chips x specific heat of the chips x temperature difference + Mass of water x 4.186 x10^3 {(597- 0.56(T_{pr})}
= 32.5 x 3.26 x (80-30) + 17.39 x 4.186 {(597- 0.56 (60)}
= (5297.50 +57485.81) kJ
= 62783.31kJ

Power of heater to be used = Quantity of heat /Time
= 62783.31/ (6 x 3600)
= 2.906 kW

From the above calculation, a heater of about 3kW was used.

2.3.6 Selection of Fan

Length of the drying chamber (previously calculated) = 3.25 m
Breadth of the drying chamber (previously calculated) = 0.35m
Height at which chips fill each tray = 0.05m
Total depth of chips for 36 trays = 36 x 0.05
=1.8m

Volume of the material in the tunnel (m^3) = 3.25 x 0.35 x 1.8
= 1.134m^3

Minimum required range of air velocity necessary for drying food products as recommended is 0.5 m/s [Bulent *et al*., 2007], [Ndukwu 2009].
In this design, a minimum velocity of 0.5 m/s was used
Air flow rate = air velocity x area of drying
=0.5x3.25x0.35=0.56875m^3/s
It is necessary to convert the value of the volumetric flow rate to cubic per minute (cfm) for standard fan selection
1 cfm = 4.91747 x 10^{-4} m^3/sec [Adzimah and Seckley, 2009].
Therefore, 1.365m^3/s = 1156.607cfm
Static pressure of plantain has moisture content close to that of potato, so a static pressure of 1.2 inches per foot depth is taken [Adzimah and Seckley, 2009].
From previous calculation,
Total depth of chips = 1.8m = 5.91ft
Static pressure loss equation = total depth of chip x static pressure per foot
= 5.91 x 1.2
= 7.092 inch of water

If there are foreign materials in the chips, the static pressure is multiplied by 1.5 as reported by [Adzimah and Seckley, 2009].
Therefore, the static pressure due to resistance of air flow by chips = 1.5 x 7.092
=10.638 inches of water

$$\text{Fan horse power (P)} = \frac{\text{volume air flow rates x total static pressure}}{\text{6320 x fan efficiency}}$$

Most industrial fan have efficiency between 70- 85% as reported by [Adzimah and Seckley, 2009].
Hence,

$$P = \frac{1156.607x10.638}{6320x0.85}$$

$= 2.29$ Hp

A centrifugal fan with 2.5 Hp and 3.64 inches water pressure was used. A centrifugal flow fan is used to ensure proper distribution of air to the drying chamber and for effective heat distribution as reported by [Holman, 1998]

2.3.7 Design for Insulation

Assuming a loss of 1% of the quantity of heat produced through the wall as reported by [Adzimah and Seckley, 2009].
Quantity of heat per second= 3kW (from previous calculation)
1% of 3kW =31.65w

$$\Delta T = \frac{q}{A}[\frac{\Delta x_g}{k_g} + \frac{\Delta x_s}{k_s} + \frac{\Delta x_a}{k_a}]$$

$\Delta T = T_1 - T_2$ is the change in temperature (^oC)
T_1 = Outside temperature = 32^oC
T_2 = Temperature in the drying chamber =100^oC (inlet)
q = Quantity of heat loss from the chamber = 31.65W
A = Area of the drying chamber = $0.28m^2$
Δx_g = Thickness of the aluminium plate = 0.26mn = 2.6×10^{-4}m
Δx_s = Thickness of the fibre glass = ?
K_f = Thermal conductivity of the fibre glass = $0.048W/m^oC$
K_a = Thermal conductivity of the aluminium sheet = $204w/m^oC$

$$80 - 30 = \frac{31.65}{0.28}[\frac{2.4x10^{-3}}{56} + \frac{\Delta x_s}{0.048} + \frac{2.4x10^{-3}}{204}]$$

$$48 = 113.03\{4.29x10^{-6} + \frac{\Delta x_s}{0.048} + 1.27\ x10^{-6}]$$

Δx_s = 0.016m =16mm
Hence fibre glass of 0.02m thick was used for safety reason.

3. RESULTS AND DISCUSSION

3.1 Drying Rate Profile of the Plantain Chips in the Dryer

Plantain chips were used to test the dryer, co-current form of drying was used throughout the drying operation. The drying rate exhibited only a first falling rate profile as shown in Figure 2. It is obvious from the graph that there was a sharp decline of moisture in the first 1 hour, then the slope gradually declined before it stops at the 7th hour. Some agricultural products exhibit a second falling rate period occasionally; such products include cassava chips and okra. This second rate phenomenon could be as a result of the plane of evaporation that slowly receded from the surface and all evaporation occurred at the interior of the foods. [Ajala *et al.*, 2011; Ajala *et al.*, 2012].

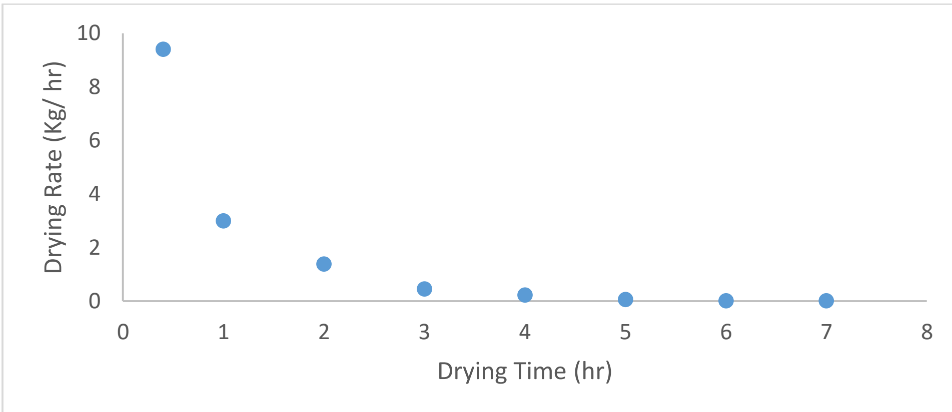

Figure 2: Drying rate against temperature

According to [Ajala and Ojewande, 2014], drying rate is the amount of water removed in a specific time interval from a food product and is affected by size, shape and thermo-physical properties of the product. In this study, the average drying rate was found to be 1.34 kg H_2O/h. Slicing and dicing into smaller pieces could expose more surface area for heating and evaporation and may address the problem of case hardening and spoilage. Drying a large quantity of material means more evaporative cooling, higher humidity and lower air temperature in the dryer. Unless drying time is increased, the product being dried will have higher moisture content at the end of the process. High moisture content can lead to mould spoilage.

3.2 Truck Velocity Pattern in the Dryer

The distance of the truck in the tunnel varied from one point to another at time t in the tunnel. When a truck enters at the inlet end with fresh plantain, it advanced through the length of the tunnel until it exited out at the other end with dried chips. Figure 3 shows the traveling pattern of these trucks. It took the first truck 7 hours before it exited from the outlet. Factors affecting residence time of the truck in the tunnel depends on the air speed, loading area; shapes of the food material, initial moisture content and temperature profile as reported by other authors such as [Ajala *et al.*, 2013], [Kashaninejad *et al.*, 2007].

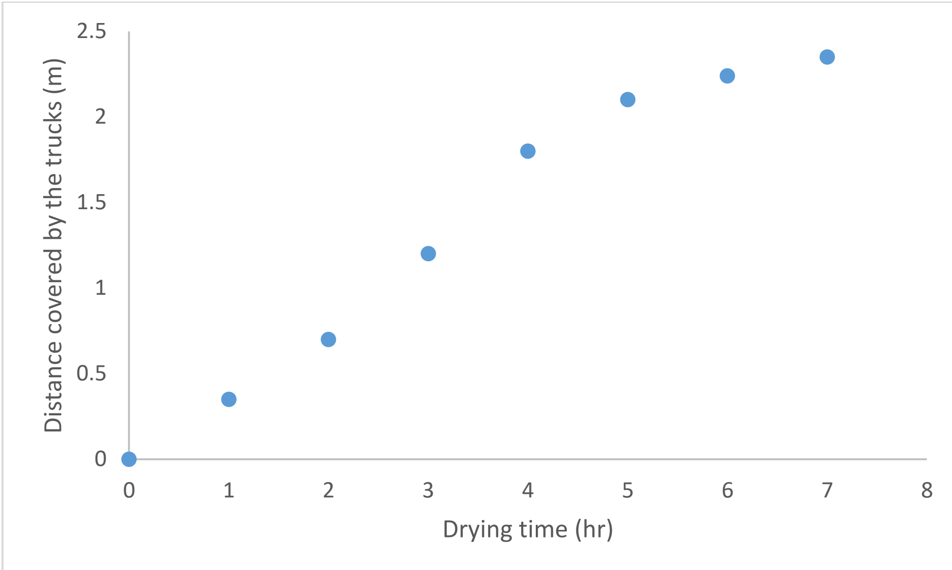

Figure 3: Truck movement against residence time

3.3 Temperature Profile in the Dryer

Temperature is the major factor in drying operation. At higher temperatures, water molecules get excited and break away from their active site which results in drying process [Ajala et al, 2018]. In this dryer, temperature regime lied between 70 (the heating side) and 55°C (the exits side) as shown in Figure 4. This means that temperature differential of 15 °C occurred between heating and exiting section. For any effective dryer, temperature gradient regime must not be too steep (large) otherwise drying would be difficult to achieve. The natural problem of convective dryer is temperature

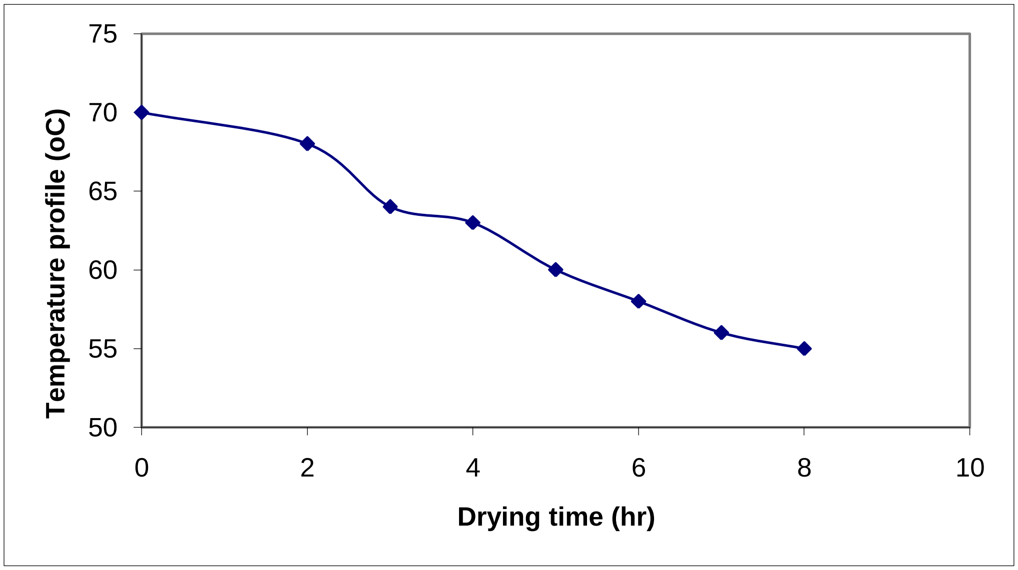

Figure 4: Temperature profile against drying time

fluctuations within the drying chamber, hence there is the need to maintain consistent temperature in the tunnel otherwise there is a tendency for samples to pick up moisture especially at the low temperature end. Leakages and poor insulations increased heat loss in any dryer [Rayner, 2005], therefore proper check for these factors are necessary.

3.4 Pattern of Air Velocity in the Dryer

Air velocity is the medium of drying in convective dryer such as tunnel. The drying characteristics of a tunnel are strongly influenced by its general design and arrangement, especially the direction of progression of the trucks relative to the direction of the airflow as reported by [Ajala *et al.*, 2018]. Evaporation rate increased linearly as air velocity increased in the dryer. Maximum useful air speed was estimated at 3.0m/s flowing parallel to the tray surface. This is based on the recommended speed for a wet bulb thermometer on a sling psychrometer; regardless of the humidity in the air [ASTM]. Figure 5 shows the air velocity pattern in the dryer. The highest values of the 5 m/s was observed at the inlet end but reduced to 2.45 m/s at the exits end.

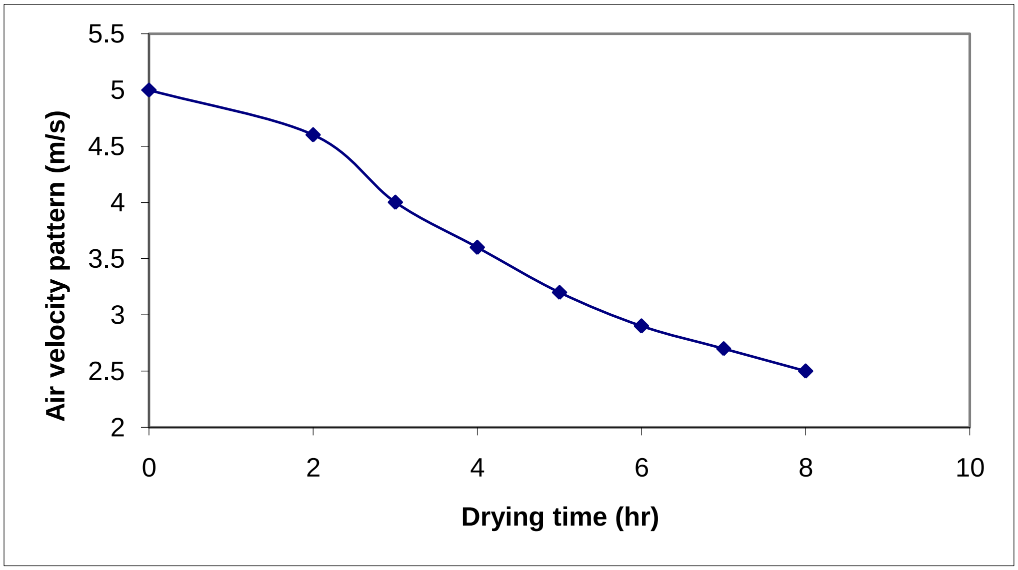

Figure 5: Air velocity against drying time

This is as a result of obstacles/resistance caused by the trucks to the air movement. For any effective drying in the tunnel, powerful fan that can deliver enough velocity pressure to drive the heat across the trucks should be employed, otherwise it would result into a localized heating. There are fans and blowers (axial and centrifugal design) for dryers but the best for tunnel dryer is centrifugal fan/blower which can generate enough velocity pressure to deliver the air across the bed length of the dryer.

3.5 Advantages of Using this Tunnel Dryer

(i) It can process relatively large volume of product at a time for medium scale food processors.
(ii) Better control leading to uniformity distribution of air in regard to heat transfer as a function of temperature and air velocity even distribution.
(iii) Cost effective drying and maximum product quality.
(iv) Adaptable to drying tubers, fruits and vegetables
(v) Simplicity in construction

4. CONCLUSION

Drying of plantain chips in this tunnel was better in terms of quality. The design and fabrication of this dryer has catered for most deficiencies experiences with sun drying. This machine can dry 35 kg product per batch operation. The maintenance cost was minimal because air (instead of gas) was used as drying agent; the fans and heaters were capable enough to deliver the required heat needed for the drying operation. Further study on automation of the machine will be a great advantage for drying of food products

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Effects of Geometrical Shapes and Sizes on the Drying Characteristics of Carrot (*Daucus carota* subsp. *sativus*) Tubers

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ABSTRACT

This study was carried out to observe the effects of geometrical shapes and sizes on the drying characteristics of carrot tubers during hot air thin layer drying. Carrot tubers were procured and sliced into 30 mm diameter circular shapes of 3, 5, 8 and 10 mm thickness, and cubic shapes of 3, 5, 8 and 10 mm^3 using stainless steel knives. Drying was done using a mechanical dryer at a constant temperature of 60 ^oC and air velocity of 1.2 m/s. The dependence of drying rate constant on the shapes and sizes of carrot was investigated, and ten (10) existing mathematical models were tested to fit the drying data of the carrot samples. The drying process for all carrot samples took place in the falling rate period, with a short accelerating period at the start of drying. It was observed that as the sizes of the samples increased, the average drying rate decreased while the drying time and effective moisture diffusivity increased. It was also observed that the cubic shaped samples dried faster than the circular shaped samples. The average drying rates for both circular and cubic shaped samples ranged from 0.0041–0.0028 kg/hr. The Hii et al. (2009) model was selected as the best mathematical model for describing 3, 5 and 8 mm circular shaped samples, as well as the 3, 5, 8 and 10 mm^3 cubic shaped samples. The Page model was selected for the prediction of 10 mm circular shaped samples.

Keywords: Carrot, Geometrical shapes, Sizes, Hot air drying, Mathematical modelling, Drying, Nigeria.

1. INTRODUCTION

Carrot (*Daucus carota* L.) is an economically important root crop, often classified for culinary purposes as a vegetable. Among 39 fruits and vegetables, carrots have been ranked 10th in nutritional value (Acharya et al., 2008). The usually orange-coloured root is the most commonly consumed part of the plant. Carrots do not supply a significant amount of calories to the human diet, but is a rich source of β-carotene and contains thiamine, riboflavin, vitamin B-complex, and minerals (Walde et al., 1992). Carrot is also an excellent source of calcium pectate, a pectin fiber that has cholesterol-lowering properties, and has shown potential in reducing the risk of high blood pressure, stroke, heart disease and some types of cancer (Bakhru, 1993). Carrot roots are eaten directly after washing, consumed uncooked in salads, or may be used with other vegetables in the preparation of soups and stews (Anjum and Amjad, 2002). Besides being food, carrot has therapeutic importance as it enhances resistance against blood and eye diseases (Pant and Manandhar, 2007).

Carrots stored for long periods of time are subject to storage rot. They may also sprout, and may lose moisture, sweetness and carotenoids (Chen et al., 1996). To overcome these problems, carrot is preserved by processing into frozen, dried, canned and fermented products. Dehydrated carrots are used as an ingredient in many prepared foods such as instant soups, and are an excellent ingredient for developing healthy snack foods if the nutritional value can be well preserved (Koca et al., 2007).

The drying process plays an important role in the preservation of agricultural products (Waewsak et al., 2006). It enhances the resistance of high humid products against degradation by decreasing their water activity (Simal et al., 2005; Hadrich et al., 2008), as the losses of fruits and vegetables in developing countries are estimated to be 30-40 % of the production (Karim and Hawlader, 2006). Given the high amounts of energy required for drying in the food industry, it is important to design and study new drying techniques and dryers in order to minimize the energy cost of the drying process (Kocabiyik and Tezer, 2009). A critically important aspect of the drying technology is mathematical modelling of the drying processes (Demir et al., 2007). Thus, the definition of accurate mathematical models is necessary to simulate the drying kinetics of biological materials. Simulation models of the drying process are used for designing new drying systems, improving the existing systems, predicting the air flow over the product, and even for controlling the process (Xia and Sun, 2002; Babalis et al., 2006). Drying of materials having high moisture content is a complicated process, which involves simultaneous heat and mass transfer. The materials are dried using several techniques, but thin layer drying is most popular due to its faster rate and minimum nutrient loss in comparison to others. Thin-layer drying describes the process of drying in a single layer of sample particles.

This study was carried out to investigate the effect of geometrical shapes and sizes on the drying characteristics of carrot tubers in a hot air cabinet dryer at a constant temperature, and to propose the best drying model for carrot of different geometrical shapes and sizes.

2. MATERIALS AND METHODS

2.1 Experimental Material

Fresh carrot (*Daucus carota*) tubers were procured from a local vegetable market in Akure, Nigeria. Carrot tubers were sorted for uniform size and washed with potable water to remove impurities, after which they were trimmed with a stainless steel knife and washed again. The carrot tubers were divided into two (2) batches: Batch A was sliced into circular shapes of 30 mm diameter, with four (4) different thickness of 3, 5, 8 and 10 mm; Batch B was cut into cubes of four (4) different sizes 3, 5, 8 and 10 mm^3.

2.2 Experimental Procedure and Determination of Drying Characteristics

The initial moisture content of each sample was determined using the oven drying method at 105 ^{o}C until no further weight loss was recorded (Ahn et al., 2014). The initial weight of each sample was determined and final weight was taken after oven drying using an electronic weighing balance. The moisture content was calculated as a percentage (Owoso and Ogunmoyela, 2001):

$$MC = \frac{M_1 - M_2}{M_1} \times 100 \qquad [1]$$

where:
MC = Moisture content of the sample, % wet basis
M_1 = Initial weight of the sample, g
M_2 = Final weight of the sample, g.

For each shape and size, 40 grams was weighed out on a sensitive (analytical) weighing balance and spread in a thin layer on paper carton wrapped with aluminium foil. Samples were then placed on the trays of the hot air cabinet dryer. Prior to wrapping in aluminium foil, all paper used was allowed to dry for 4 hours to ensure that no residual moisture in them would affect the results. The samples were subjected to a constant drying temperature of 60 ^{o}C (Cui et al., 2004) and air velocity of 1.2 m/s, and dried continuously to equilibrium moisture content (EMC). The initial weight of each sample and drying surface was noted, and subsequent weights of each sample were taken at intervals of 30 minutes until no further weight change was recorded. All measurements were carried out in triplicate. Withdrawal and weighing of sample, taken as a single activity, was not allowed to exceed 30 seconds. All drying activities were carried out at the Central Research Laboratory, Federal University of Technology, Akure, Nigeria.

Using the weights of samples taken at intervals, the moisture contents at these intervals were calculated. The moisture content of a given sample at any point during drying is related to the initial moisture content by the following formula (FAO, 1994):

$$M_2 = \frac{100(W_2 - W_1) + W_1 M_1}{W_2} \qquad [2]$$

where:
M_2 = moisture content of material of weight W_2 during drying, % wet basis
M_1 = initial moisture content of material (i.e. moisture content of material before commencement of drying), % wet basis

W_1 = weight of material before commencement of drying, g
W_2 = weight of material at time t during drying, g.
The drying rate is expressed as the amount of moisture lost over time. It can be calculated using the following equation (Evin, 2012):

$$\frac{dW}{dt} = \frac{W_t - W_{t+\Delta t}}{\Delta t} \quad [3]$$

where:
$\frac{dW}{dt}$ = Drying rate, g/min
W_t = Weight of material at time t_1, g
$W_{t+\Delta t}$ = Weight of material at time t_2, g
Δt = Change in time, i.e. $t_2 - t_1$, min.
Moisture ratio is the ratio of the moisture content at any given time to the initial moisture content (both relative to the equilibrium moisture content). It was determined as follows (Ozbek and Dadali, 2007):

$$MR = \frac{M - M_e}{M_0 - M_e} \quad [4]$$

where:
MR = Moisture Ratio (dimensionless)
M = Moisture content at drying time t, % wet basis
M_0 = Initial moisture content, % wet basis
M_e = Dynamic equilibrium moisture content, % wet basis.

2.3 Modelling of the Thin Layer Drying Curves

Thin layer drying equations are used to estimate drying time of several products and also to generalize drying curves. Thin layer dehydration studies have become essential as a step for developing updated methods for equipment design (Marquez et al., 2006). The experimental drying data of the carrot samples were fitted into ten (10) commonly used thin layer drying model equations (Table 1) to select the best model for describing the drying curves of carrot slices of different shapes and sizes. In these models, *MR* represents the dimensionless moisture ratio.

Table 1. Thin-layer drying models most frequently used by various authors

Model Name	Model Equation	Reference
Lewis	$MR = exp(-kt)$	Upadhyay et al. (2008)
Page	$MR = exp(-kt^n)$	Kulanthaisami et al. (2010)
Henderson & Pabis	$MR = a.exp(-kt)$	Ozdemir and Devres (1999)
Logarithmic	$MR = a.exp(-kt) + c$	Yaldiz and Ertekin (2001)

Two-term	$MR = a.exp(-k_o t) + b.exp(k_1 t)$	Togrul and Pehlivan (2004)
Verma et al.	$MR = a.exp(-kt) + (1-a)\exp(-gt)$	Yaldiz and Ertekin (2001)
Midilli & Kucuk	$MR = a.exp(-kt^n) + bt$	Midilli et al. (2002)
Wang & Singh	$MR = 1 + at + bt^2$	Ozdemir and Devres (1999)
Hii et al.	$MR = a.exp(-kt^n) + c.exp(-gt^n)$	Hii et al. (2009)
Two-term Exponential	$MR = a.exp(-kt) + (1-a)\exp(-kat)$	Sacilik et al. (2006)

2.3.1 Statistical Analysis

The goodness of fit of the selected thin layer mathematical models to the experimental data was evaluated with the coefficient of determination (R^2), the reduced chi-square (χ^2), the root mean square error (*RMSE*) and the modelling efficiency (*EF*). The goodness of fit is better if R^2 and *EF* values are higher, and if χ^2 and *RMSE* values are lower (Wang et al., 2007). The coefficient of determination (R^2), reduced chi-square (χ^2), the root mean square error (*RMSE*) and modelling efficiency (*EF*) were calculated using following expressions (Hii et al., 2009):

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \qquad [5]$$

where:
SSR = Sum of Squares Regression
SSE = Sum of Squares Error
SST = Sum of Squares Total.

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N-n} \qquad [6]$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)\right]^{1/2} \qquad [7]$$

$$EF = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{mean}\right)^2 - \sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{mean}\right)^2} \qquad [8]$$

where:
$MR_{exp,i}$ = i^{th} experimental moisture ratio
$MR_{pre,i}$ = i^{th} predicted moisture ratio
N = number of observations
n = number of constants in drying model
$MR_{exp,mean}$ is the mean value of experimental moisture ratio (Sacilik and Elicin, 2005).

2.4 Calculation of Effective Moisture Diffusivities

The falling rate period can be described by using Fick's diffusion equation for the characteristics of biological products (Wang et al., 2007). In most situations, Fick's second law of diffusion is used to describe a moisture diffusion processes (Simal et al., 2005). The solution to this equation is used for various regularly shaped bodies such as rectangular, cylindrical and spherical products, and the form of equation 4 given in equation 9 can be applied to particles with slab geometry by assuming uniform initial moisture distribution:

$$MR_i = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L_0^2}\right) \quad [9]$$

where:

D_{eff} is the effective diffusivity, m^2/s

L_0 is the half thickness of slab, m.

For longer drying periods, equation 9 can be further simplified to only the first term of series (Tutuncu and Labuza, 1996), and can be written in a logarithmic form as follows:

$$\ln MR = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}t}{4L_0^2} \quad [10]$$

Diffusivities were determined by plotting experimental drying data in terms of lnMR versus drying time t in equation 10. The slope and effective diffusivity as used in the above equation were calculated as:

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L_0^2} \quad [11]$$

$$D_{eff} = \left(\frac{4L_0^2}{\pi^2}\right)\text{slope} \quad [12]$$

where slope = $\frac{lnMR_2 - lnMR_1}{t_2 - t_1}$.

3. RESULTS

3.1 Drying Characteristics

The carrot samples in circular shapes were dried at an initial moisture content of 89.09 % wet basis. The circular shaped samples of 3, 5, 8 and 10 mm diameter were dried to equilibrium moisture content of: 4.46 % wet basis for 8 hours; 4.69 % wet basis for 9 hours 30 minutes; 5.76 % wet basis for 11 hours and 20.80 % wet basis for 12 hours, respectively. The maximum drying rates for drying circular shape samples of 3, 5, 8, and 10 mm were 0.0108, 0.0093, 0.0086 and 0.0062 kg/hr respectively and the minimum drying rate was observed as low as 0.0001 kg/hr. The average drying rates were 0.0041, 0.0035, 0.0031 and 0.0028 kg/hr for 3, 5, 8 and 10 mm respectively, indicating that the maximum drying rate is about 3 times more than the average drying time rate, except for the 10 mm sample which was about 2 times more that the average drying rate. It was observed that the moisture ratio decreased continuously with the increased drying time.

The carrot cubic samples were dried at an initial moisture content of 88.25 % wet basis. The samples of 3, 5, 8 and 10 mm^3 were dried to equilibrium moisture content of: 4.35 % wet basis for 8 hours; 4.77 % wet basis for 9 hours; 5.16 % wet basis for 10 hours 30 minutes and 5.48 % wet basis for 12 hours, respectively. The maximum drying rates for drying carrot cubes of 3, 5, 8 and 10 mm^3 were 0.0146, 0.0110, 0.0114 and 0.0114 kg/hr respectively, and the minimum drying rate was observed as low as 0.0002 kg/hr. The average drying rates were 0.0041, 0.0036, 0.0032 and 0.0028 kg/hr for 3, 5, 8 and 10 mm^3 respectively, indicating that the maximum drying rate is about 4 times more than the average drying rate. It was observed that the moisture ratio decreases continuously with the increased drying time.

It was further observed that constant rate period was not present during drying of carrot samples and moisture loss was faster at the start of drying than at the end. The reduction in the drying rate is mainly due to reduction in moisture content as drying advances. The rate of migration of moisture from inner surface to outer surface decreases at the final stage of drying and hence lower drying rates (Rajkumar et al., 2007).

3.2 Effect of Geometrical Shapes and Sizes

From the drying data, it was observed that the cubic shaped samples dried faster than the circular shape samples. This may be as a result of the surface area of cubic shapes, being larger than the circular shapes. This result contrasted with results obtained by Bettega et al. (2014), where the carrot cubes showed considerably slower drying characteristics as compared with the disc shape and stick shape, although the drying was done using the combination of vacuum with microwave drying. It was also observed that drying time increases and thus also drying rate constant decreases with increasing sample thickness at a constant drying temperature. This is in agreement with results obtained by Kabiru et al. (2013) during the thin layer drying of *Mangifera indica*, that drying time increased as the slice thickness increased. This may be because at lower thickness, the free moisture was rapidly removed or evaporated at a higher rate at the initial stage of drying; the reduction in the drying rate subsequently witnessed was as a result of the movement of moisture from the core of the slices to the surface before evaporation. This led to decreased drying rate toward the equilibrium moisture content.

3.3 Mathematical Modelling

The experimental moisture data were expressed as the dimensionless moisture ratio (MR) and fitted into the ten (10) thin-layer drying models given in Table 1. The Hii et al. (2009) model provided the best fit for all samples except the 10 mm circular shaped samples, which were best predicted by the Page model. The statistical results of the best fit model for various samples are summarized in Table 2, including the model constants used to achieve these results.

Table 2. Thin-layer model that best describe drying characteristics of each carrot sample.

S/N	**Sample**		**Model**	**R^2**	**RMSE**	**EF**	**a**	**c**	**g**	**k**	**n**
1	Circular	3 mm	Hii et al.	0.996	0.02206	0.99692	7.32152	-6.35009	0.00187	0.00187	3.76651

2		5 mm	Hii et al.	0.995	0.02615	0.99563	6.61897	-5.65557	0.00249	0.00235	3.76994
3		8 mm	Hii et al.	0.996	0.02437	0.99618	6.37752	-5.41949	0.00061	0.00064	3.83848
4		10 mm	Page	0.995	0.02686	0.99423	-	-	-	0.00259	2.89286
5	Cube	3 mm^3	Hii et al.	0.998	0.01309	0.99875	8.24772	-7.27672	0.00745	0.00788	2.80472
6		5 mm^3	Hii et al.	0.997	0.01976	0.99747	6.58006	-5.61947	0.00189	0.00199	3.59838
7		8 mm^3	Hii et al.	0.995	0.02759	0.99498	8.14740	-7.15237	0.00846	0.00966	2.23217
8		10 mm^3	Hii et al.	0.997	0.02202	0.99691	6.36946	-5.41234	0.00225	0.00236	3.40818

3.4 Determination of Effective Moisture Diffusivity

Effective moisture diffusivity during convective dehydration at constant temperature increased with increase in sizes of the samples. As shown in Table 3, 10 mm-thick circular shape sample had the highest value of effective moisture diffusivity of 17.7865×10^{-6} m^2/s, and the 3 mm-thick sample had the lowest value of 1.0553×10^{-6} m^2/s, for circular samples. Also the 10 mm^3 cubic shape sample had the highest value of effective moisture diffusivity of 68.5892×10^{-6} m^2/s, and the 3 mm-thick sample has the lowest value of 0.8017×10^{-6} m^2/s, for cubic samples.

Table 3. Effective moisture diffusivity values of each carrot sample

Sample			Effective Moisture Diffusivity (m^2/s)
1	Circular	3 mm	1.0553×10^{-6}
2		5 mm	2.8938×10^{-6}
3		8 mm	7.3782×10^{-6}
4		10 mm	17.7865×10^{-6}
5	Cube	3 mm^3	0.8017×10^{-6}
6		5 mm^3	3.2894×10^{-6}
7		8 mm^3	8.3403×10^{-6}
8		10 mm^3	68.5892×10^{-6}

4. CONCLUSION

The whole drying process of the carrot samples took place in the falling rate period, with the exception of a short accelerating period at the beginning. The drying time increased and the drying rate constant decreased with increasing sample thickness at a constant drying temperature of 60 ºC and air speed of 1.2 m/s. It was also observed that the cubic shaped samples dried faster than the circular shaped ones. The effective moisture diffusivity increased with increase in the sizes of the samples. The Hii et al. model was recommended for predicting the 3, 5 and 8 mm circular shapes, and the 3, 5, 8 and 10 mm^3 cubic shapes. The Page model was recommended for predicting 10 mm circular shaped samples.

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Nutritional and Sensory Analyses of Wheat-Unripe Plantain Composite Flour on Bread Making

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ABSTRACT

This study analyzes the nutritional and sensory properties of wheat-unripe plantain composite flour having a mix ratio of 70:30, 80:20, 90:10 and 100:0 respectively, with 100:0 ratio mix serving as the control. Unripe plantain flour was selected due to its high iron content which can solve dietary concerns encountered by anaemic and celiac patients because of low iron and high protein (gluten) content in wheat bread. The nutritional analysis of the composite flour such as ash, lipid, fibre, carbohydrate, protein, moisture content and iron contents of the mixed flour were determined. Physical properties of the composite bread were determined: loaf weight, loaf volume, loaf height, and loaf specific volume. The incorporation of plantain flour into baking bread became effective because it is economical, better supplies essential nutrients such as iron and protein to humans, and a better overall use of domestic agricultural products such as plantain. Incorporation of higher amount of unripe plantain flour increased loaf weight with a corresponding reduction in specific volume of the bread, which affected the bread making process. It was concluded that organoleptically acceptable bread could be formulated from wheat-unripe plantain composite flours using up to 70:30 mix ratio as maximum acceptable levels of substitution for bread making.
Keywords: Wheat-unripe plantain composite flour, bread, loaf specific volume, proximate composition, iron content, sensory analyses, Nigeria

1. INTRODUCTION

Bread is the result of baking the dough obtained from a mixture of flour, salt, sugar, yeast and water by a chain of processes that comprises mixing, kneading, proofing, shaping and baking (Mebpa *et al*., 2007). Additional ingredients like fats, milk, milk-solids, sugar, egg, and anti-oxidants may be added. Bread is a vital staple food with steady and increasing consumption in Nigeria. It is the most popular among all wheat-based products such as biscuits, cakes, doughnuts, chin-chin, cookies, etc. (Badifu, 2005). It is sometimes not so cheap for an average Nigerian due to the fact that it comes from wheat flour which has to be imported into the country. For this reason, the use of composite flours have been greatly encouraged to decrease the demand for imported wheat flour and make the food available to low income earners and also reduce the amounts of wheat being consumed per head (Giami, 2004).

Although there now exist a substantial amount of available composite bread technology, such bread still require at least 70% of wheat flour to be able to rise (Eggleston, 1992). The predominance of wheat flour for baking of leavened bread is due to the properties of its elastic gluten protein, which helps in producing a relatively large loaf volume with a regular crumb structure. Moreover, only wheat flour dough is capable of retaining gas during proof and baking, and therefore forms a typical aerated foam structure as bread. Other cereals contain similar protein groups, but gas-holding capacity is limited. Although all leavened cereal dough produce gas (CO_2) during proof, wheat dough retains gas much longer even at high temperatures than other cereal flour dough (Hoseney, 1991). Wheat gluten is made up of a mixture of two groups of protein: gliadins and glutenins, which gives different contributions to the viscoelasticity of gluten. The importance of gluten in bread-making cannot be underestimated therefore, wheat flour can only be supplemented with other flours for bread making to improve its nutritional quality, as each flour retain its nutritional value and such bread is also recommended for people with inability to digest gluten (celiac disease).

Unripe plantain is traditionally processed into flour in Nigeria and in other West and Central African countries (Ukhum, 1991). It is however gradually finding applications in weaning food formulation and composite flour preparations (Ogazi *et al*., 1996; Mepba *et al*., 2007). Plantain is a popular dietary staple food due to its versatility and good nutritional value. Unripe plantain fingers are valuable sources of iron and fibre to the body in contrast to the ripe variety which are invaluable source of carbohydrate, comparable in nutritive value to yam or potato, and are useful as a variant on the usual staple foods. Unripe plantain is used to produce plantain flour, since it has high starch content of about 35% on wet weight basis (Simmond, 1976).

Wheat flour can be fortified with unripe plantain flour because of high iron content of unripe plantain flour in contrast to the ripe plantain which is low in iron but high in carbohydrates. Anemic patients require a constant supply of blood to their system whether whole or part. Therefore, their nutrition should be able to supply blood to their body system. Bread fortified with unripe-plantain flour is recommended for this class of people as well as for vegetarians whose nutrition should contain fewer amounts of sugars.

Wheat-unripe plantain composite flour bread with 30% substitution and below were analyzed in this study to understudy the nutritional characteristics of the flour, physical properties of the bread loaves, as well as sensory analysis and acceptability of the bread.

2. MATERIALS AND METHODS

2.1 Materials

Commercially available all-purpose wheat and plantain flours, table salt, and granulated sugar (manufactured by Dangote Group Nigeria Ltd., Lagos, Nigeria) used were purchased from Nteps Shopping Mall in Uyo, Akwa Ibom State, Nigeria. Butter, dry baker's yeast and milk were obtained from Akpan Andem Main Market, Uyo, Akwa Ibom State, Nigeria.

2.2 Flour Analysis

Analysis of flour was conducted on the composite flour made from different combinations of wheat flour and unripe plantain flour at ratios of 0:100, 90:10, 80:20, 70:30 and 100:0, respectively.

2.3 Moisture Content

The moisture content of the flour was determined with the use of a digital moisture analyzer (OHAUS MB45, UK) set at 105˚C. The flour was weighed to 3.0 g ± 0.01 g in a sample plate and measurements were made in triplicate. The moisture analyser was allowed to cool between tests for each powder.

2.4 Bread Production by the Straight Dough Method

The straight dough method was used to prepare the bread. This method involves the addition of all the ingredients (flour, salt, water, sugar, yeast, etc.) at mixing stage and kneading same to obtain the dough (Gisslen, 2012). The different dough samples made from different ratios of wheat:unripe plantain flour were placed in baking pans smeared with butter and covered with poly-ethene for the dough to ferment resulting in gas production and gluten development enabling the dough to rise for about an hour as this shows the swelling power of the dough. The dough was then baked in an oven at 230^{o}C for 30 minutes. The baked loaves were removed from the pans and allowed to cool for analysis.

2.5 Proximate Composition

Proximate composition of the samples were carried out using official AOAC (1984) methods for moisture content, crude fat, crude fibre, ash, crude protein. A nitrogen-to-protein conversion factor of 6.25 was used. Carbohydrate content was calculated by difference.

2.6 Iron Content

The iron content of the bread was determined by using the bread ash earlier used. The ash was placed in porcelain crucibles, then a few drops of distilled water were added, followed by 2ml of concentrated HCl. 10ml of 20% HNO_3 was added, then evaporated on a hot plate. The samples were then filtered through a Whatman filter paper into a 100ml volumetric flask. The mineral element, iron, was determined by an atomic absorbance spectrophotometer (AOAC, 2005).

2.7 Bread Quality Analysis

After cooling, the bread samples were weighed using a digital analytical weighing balance. The loaf volume was measured by seed displacement method (Giami, 2005*)*, using millet grains. The bread sample (5g) was placed in an empty graduated cylinder (100ml) and filled with the millet grains. The cylinder was slightly tapped to ensure that the grains were properly packed. The level of the packed millet grains containing the bread sample in the volumeter was noted and recorded. The bread sample was removed from the volumeter leading to a drop in height of the millet grains. The new level of the millet grain was also noted and recorded. The loaf volume was determined by the difference between the level of the packed millet grains containing the bread sample and the level of the millet grains after the bread sample had been removed:

Loaf volume = $H_0 - H_1$ (1)

Where:

H_0 = height of millet grains with bread sample.

H_1 = height of millet grains after the bread was removed.

2.7.1 Specific Volume

Specific volume (in ml/kg) was obtained by dividing the loaf volume (V) of the bread by its corresponding loaf weight (w_t). Thus,

Specific volume = $\frac{V}{w_t}$ (2)

After moulding, the height of the dough was measured using a meter rule. After baking, the bread samples' heights were also measured and recorded.

2.8 Sensory Evaluation

The four bread samples were coded and presented to a semi-trained panel for sensory evaluation (Ihekoronye and Ngoddy, 1985). The panelists scored the aroma, taste, texture, crust colour, crumb colour, appearance and general acceptability of the bread using a 9 point hedonic scale, where 9 indicates "extremely like" and 1 indicates "extremely dislike".

2.9 Statistical Analysis

All analytical determinations were conducted in triplicates such that means and standard deviations were calculated. The data obtained were subjected to analysis of variance (ANOVA), to assess the properties of the flour and compute their data using GraphPad Prism 5.0 software (GraphPad Software Inc., La Jolla, CA, USA). Means were separated by calculating the least significant difference (LSD) at ($P \leq 0.05$).

3. RESULTS AND DISCUSSION

3.1 Nutritional Analysis

The nutritional composition of the composite flours is presented in Table 1. The results showed an increase of ash content in the composite flour samples per increase in plantain flour. The highest ash content was recorded in composite flour of 0:100 (wheat flour:unripe plantain) which was 3.36 (±0.01) %, showing that plantain flour has more ash content than wheat flour. This result is in agreement with the investigations of Ahmad *et al*. (2001) where low ash content was reported in the quality characteristics of different wheat varieties grown in Pakistan. Ash content is a reflection of the mineral matter in a food sample (Iwe *et al*., 2017). High ash content in plantain flour suggests it contains high mineral matter.

Table 1. Nutritional composition of the flours

Wheat: unripe plantain flour	**Ash (%)**	**Lipid (%)**	**Fibre (%)**	**Carbohydrate (%)**	**Protein (%)**	**Moisture content (% dry basis)**	**Iron (mg/l)**
100:0	1.46±0.11^{e}	2.70±0.11^{e}	2.80±0.11^{e}	73.68±0.02^{e}	13.26±0.01^{a}	6.1±0.2^{d}	2.72±0.14^{e}
90:10	2.18±0.11^{d}	3.00±0.11^{d}	5.09±0.04^{d}	74.15±0.03^{d}	8.33±0.12^{b}	7.3±0.2^{c}	8.53±0.13^{d}
80:20	2.58±0.11^{c}	3.50±0.11^{c}	5.52±0.11^{c}	74.60±0.02^{c}	6.15±0.10^{c}	7.7±0.9^{b}	9.63±0.11^{c}
70:30	2.80±0.11^{b}	3.65±0.11^{b}	5.82±0.00^{b}	75.28±0.00^{b}	4.65±0.03^{d}	7.8±0.3^{b}	9.74±0.04^{b}
0:100	3.36±0.01^{a}	3.80±0.11^{a}	6.51±0.11^{a}	76.03±0.02^{a}	2.30±0.03^{e}	8.0±0.2^{a}	12.00±0.15^{a}

The experiment was done in triplicate and the data are expressed as mean ± standard deviation, different superscripts within each nutrient composition differ significantly at ($P < 0.05$).

The lipid content showed an increase per substitution of more plantain flour, with the lipid content increasing by up to 35% when plantain flour used was increased to 30%. The highest lipid content was recorded in 100% of plantain flour. This reveals that wheat flour has less lipid content than plantain flour. Besides, the fibre content of unripe plantain contained the highest fibre value (6.51±0.11%) while the wheat flour had the lowest fibre content (2.80 ±0.11%), indicating plantain flour is high in fibre. Consequently, there was an increase in fibre content with the increase of plantain flour substitutions. The carbohydrate content showed an increased with substitutions of more plantain flour. The protein content for 100% wheat flour with a value of 13.26% was remarkably massive, but there was a sharp decrease in protein content for 100% unripe plantain flour with a value of 2.30%. A decrease in protein content with substitutions of more plantain flour is sufficiently good to recommend it for bread making. This is because it can be used to substitute part of the wheat flour in bread making as celiac patients do not require much protein from high gluten contents bread (Adegunwa *et al*., 2017). In addition, the result of moisture content did not significantly influence the flowability of the composite flours (see Table 1) as the moisture content was low, ranging from 6.1(±0.2) % of 100:0 wheat-unripe plantain composite flours to 8.0(± 0.2) of 0:100 of wheat-unripe composite flours. Increasing moisture content may make flour not free flowing (cohesive); however, exceeding certain moisture contents the moisture may act as lubricant thus improving the flour (powder) flowability (Mohsenin, 1986).

The iron content of the composite flour is shown in Table 1. The highest iron content was recorded in 100% unripe plantain flour which was about 12.00mg/l. Meanwhile, the lowest value of iron content was found in 100% wheat flour, which was about 2.72mg/l. This result suggests that plantain flour can be a good source of iron, and incorporation of plantain flour in bread making might improve the iron content in the bread. It also reveals that increase in the amount of plantain flour in the mix ratio increased the iron contents of the flour. This favours anaemic patients as consumption of bread made from plantain flour as a wheat flour substitute might help to improve their blood levels.

Table 2. Physical properties of the bread loaves

Wheat: unripe plantain flour	**Loaf weight(g)**	**Loaf volume(ml)**	**Loaf height(mm)**	**Specific volume(ml/g)**
100:0	110.00±0.001	9.00±0.001	104.00±0.000	0.082±0.001
90:10	170.00±0.001	7.00±0.002	79.00±0.001	0.041±0.001
80:20	179.00±0.005	6.00±0.000	74.00±0.000	0.034±0.002
70:30	189.00±0.003	5.50±0.005	70.00±0.000	0.029±0.003

The loaf weight for wheat-unripe plantain flour ranged from 170g (for 90:10 mix ratio, as the lowest) to 189g (for 70:30 mix ratio, as the highest) weight, while 100:0 (control bread) weighed 110g. This revealed that increasing substitutions of plantain flour in bread increased its weight as shown in Table 2.

The loaf volume ranged from 7ml (for 90:10 mix ratio wheat-unripe plantain flour, as the highest) to 5.5ml (for 70:30 mix flour, as the lowest), while 100:0 mix was 9ml as the highest loaf volume as calculated from equation (1). This showed that increasing substitutions of plantain flour in bread reduced its loaf volume as shown in Table 2. The loaf height ranged from 70mm as the lowest to 104mm as the highest, showing that inclusion of plantain flour in bread reduced its loaf height. The loaf volume and loaf height revealed a decrease with substitution of more plantain flour because of the decrease in the amount of gluten to react with the yeast during the proofing time, while increasing its loaf weight. The specific volume of the bread loaves decreased with increase in plantain flour substitution as also seen from Table 2.

Bread samples were subjected to a panel of 10 semi-trained judges comprising males and females using a 9-point hedonic scale of different eating habits. Sensory attributes namely aroma, taste, texture, crumb colour, crust colour, appearance and general acceptability are shown in Table 3. The sensory data for colour scores of composite flour bread and wheat flour bread (as control) are presented in Table 3. The highest score for crumb colour was awarded to 90:10 mix ratio of wheat-unripe plantain flour (6.30), which was not significantly different at (P≤ 0.05) from bread of 100% wheat flour of 7.30 score followed by sample 80:20 (5.6) and sample 70:30 (4.8), which was the lowest.

Table 3. Sensory attributes of composite flour bread

Wheat: unripe plantain flour	**Aroma**	**Taste**	**Texture**	**Crust colour**	**Crumb colour**	**General acceptance**
100:0	$7.60{\pm}0.03^{a}$	$7.50{\pm}0.15^{a}$	$7.30{\pm}0.11^{a}$	$7.20{\pm}0.13^{a}$	$7.30{\pm}0.08^{a}$	$7.60{\pm}0.14^{a}$
90:10	$7.20{\pm}0.01^{a}$	$5.40{\pm}0.19^{b}$	$7.30{\pm}0.17^{a}$	$6.60{\pm}0.07^{b}$	$6.30{\pm}0.18^{a}$	$7.10{\pm}0.16^{a}$
80:20	$5.30{\pm}0.01^{b}$	$4.70{\pm}0.20^{c}$	$5.60{\pm}0.08^{b}$	$5.60{\pm}0.07^{c}$	$5.60{\pm}0.09^{b}$	$5.10{\pm}0.06^{b}$
70:30	$4.40{\pm}0.04^{c}$	$3.50{\pm}0.09^{d}$	$4.60{\pm}0.13^{c}$	$5.10{\pm}0.16^{d}$	$4.80{\pm}0.15^{c}$	$4.30{\pm}0.10^{c}$

The experiment was done in triplicate and the data are expressed as mean ± standard deviation, different superscripts within each sensory attributes differ significantly at (P < 0.05).

The crust colour of the bread followed a similar trend as the crumb colour. Generally, the study revealed that colour scores decreased with increase in incorporation of plantain flour. The desired colour of bread is obtained mainly due to the Maillard browning during baking. Highest aroma and textures scores were obtained for bread made from 90:10 wheat-unripe plantain flour (7.20 and 7.30 respectively); this result was not significantly different at (P≤ 0.05) from bread of 100% wheat flour with regards to aroma and textures respectively. The aroma, texture and taste scores decreased rapidly with increase in amounts of plantain flour as seen from Table 3.

In terms of general acceptance, both 90:10 wheat-unripe plantain flour bread and 100% wheat bread were accepted with no significant difference at (P≤ 0.05). This was followed by 80:20 composite (5.10) and then 70:30 (4.30) mix ratios of wheat-unripe plantain flour.

The general acceptance scores may also be affected by the age group of the taste panelists as older people are seen to prefer bread with higher unripe plantain flour due to nutritional advantages.

4. CONCLUSION

The substitution of wheat flour with some level of unripe plantain flour in bread making was carried out. The addition of unripe plantain flour to wheat flour improved the nutritional composition of the composite flour. The addition of unripe plantain flour also improved the iron content of the bread. Substitution of wheat flour with some level of unripe plantain flour affected the physical properties of the bread such as loaf weight, loaf volume, loaf height and the loaf specific volume as the gluten content of the dough was affected. Increasing levels of plantain flour in bread making was found to result in a decrease in the loaf volume, loaf height, and loaf specific volume. The sensory analysis revealed that 90:10 wheat-unripe plantain flour bread was generally accepted with regards to aroma, texture and crumb colour, with no significant difference from 100% wheat flour bread.

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Development and Promotional Challenges of Inert Atmosphere Silo for Grain Storage in Nigeria

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ABSTRACT

NSPRI inert atmosphere storage system is a technology for preserving food grains and their seeds in an atmosphere of which the original air content has been modified and replaced with nitrogen. The technology was developed in Nigeria by Nigerian Stored Products Research Institute (NSPRI) about three and half decades ago. The capacity coverage of the technology ranges from 100 kg to thousands of tonnes. This system has been used to store various grains and their qualities maintained for over two years without the use of synthetic chemicals. NSPRI's inert atmosphere silo is a suitable alternative in bulk grain storage with 100 % insect mortality potential of all developmental stages without re-emergence. The ultimate goal of any technology developed is to get it across to the appropriate end users through effective technology dissemination process. In spite of dissemination methods deployed, the cost effectiveness, benefits and age of the technology, the adoption rate is still low. The adoption rate recorded has been attributed to difficulties in attitudinal change and high initial capital investment associated with the technology. The aim of the paper is to bring the technology to the fore The current effort to consolidate previous successes recorded is the use of "watch us do it" approach which gives the adopters zero level of risk for scrutiny and investment security. The high rate of adoption of this technology is a panacea to effective bulk storage of grain for safety of life and investment.

Keywords: Inert atmosphere silo, Grain, Storage, Technology, Adoption, Nigeria.

1. INTRODUCTION

NSPRI's inert atmosphere silo is a non-chemical storage facility that works based on principle of controlled atmosphere. It is a safe and residue-free alternative to synthetic chemicals (Ajayi *et al.*, 2016; Carli *et al.*, 2010). The silo is a physical artefact with different components functioning as a system and designed for protecting grains against insect and mould infestations in storage. It is an airtight system with facilities to purge out the air content of the enclosure and replace it with nitrogen gas (N_2), thereby making the system inert and inhabitable for stored products insect pests. It was developed to handle grains and their seeds which cover cereals and pulses. Grains are staple food crops and they play significant roles in ensuring that a nation is food secured. This technology was developed to enhance food safety and security as well as reduce postharvest losses in grains, thereby increasing the economic returns of farmers, marketers and processors in this sub-sector of agriculture. The technology was developed about three and half decades ago to address the challenges in grain storage (Okonkwo *et al.*, 2018; Sowunmi *et al.* 1982; Adesuyi *et al.* 1980; Williams *et al.*1980).

The goal of developing any technology is to address identified challenge(s) associated with the current practice. The development of technology would pass through stages before it could be released to the end users. After series of research studies covering laboratory trials, pilot scale and commercial storage, it has been established that inert atmosphere silo is a promising alternative and means of protecting grains in storage against pests attack under an airtight system (Okonkwo *et al.*, 2018). It is a proven technology that was expected to receive high rate of adoption in Nigeria and beyond. However, this expectation has not been met due to several factors. It has been observed that the innovation capacity of agricultural development actors has not been adequately strengthened to aid the adoption of their proven agricultural technologies and best practices. This could only be achieved if it is effectively facilitated and catalyzed by respective stakeholders (CORAF/WECARD, 2012). Generation of agricultural technologies through research and their transfer to appropriate end users has potential to boost productivity in agriculture of developing countries (Mapila, 2011). Information dissemination, skills transfer, and adoption of technologies can as well enhance the livelihood of the rural dwellers if properly implemented (Birner *et al.*, 2006).

The constraints limiting the functionality of the extension system have been identified as multiplicity of technology transfer systems, lack of farmer focus and feedback, narrow focus of the agricultural extension system and inadequate technical capacity within the extension system. Others are need for intensifying farmer training, weak research-extension linkages, poor communications capacity and inadequate operating resources and financial sustainability (Sinja *et al.*, 2004; MANAGE, 1999). To address these challenges, it is very important to restructure the extension service to increase its technical capacity and expand its subject-matter coverage, while improving its financial sustainability to ensure resultful information dissemination and technology transfer. In addition, it is important to identify aspects of the Agricultural Transfer System (ATS) like dissemination of location specific, system based and sustainable technologies where the public extension system has a comparative advantage. This will encourage the private sector to play an expanding role in the transfer of material technologies to farmers and other stakeholders in the grain value chain.

Some scientists strongly believed that if rural farmers had adopted the new agricultural technology developed by them, food insecurity and increase in poverty would not be a major challenge as being currently experienced in the society (Agwu *et al.*, 2008). It has been observed that the performance and output of national agricultural research and extension system in West and Central Africa have not in any way matched up with the size, scope and level of investment in the system (Arokoyo, 1998). Roseboom *et al.* (2006) identified failure of farmers to adapt to changing circumstances as one of the main issues responsible for low adoption of agricultural technologies. In another perspective, it was pointed out that neither research nor extension system took cognisance of the need to understand the variation in constraints and potentials of the different farming localities as a basis for development of appropriate technology (Purcell and Anderson, 1997).

The concept of top-down approach to agricultural development has prevailed for the last five decades. It is now clear that the adoption of new technologies do not only rely on the available information but also on how such information is transferred as well as the people to make use of the information (Yigezu *et al.*, 2015). Over the last decade, economic and technology strategies have transformed through three different approaches. It was National Agricultural Research System (NARS) before it was changed to Agricultural Knowledge and Information System (AKIS), and finally and recently to Agricultural Innovation System (AIS). It was observed that the three approaches are interlinked and cumulative. The AIS which is the recent one covered knowledge generation, diffusion and application (Agwu *et al.*, 2008).

Regardless of all the information dissemination approaches adopted in promoting NSPRI's inert atmosphere silo, the output has been so low compared to the dissemination and promotional inputs. This paper was therefore put up to appraise previous and present attempts in disseminating the technology to the end users as well as expose it to a large fora of stakeholders.

2. MATERIALS AND METHODS

2.1 Development of Inert Atmosphere Silo

Development of the technology commenced about thirty-five (35) years ago at NSPRI zonal offices at Ibadan and Kano. The first phase of the development was at laboratory level. The success recorded from the laboratory trails stepped up the research to pilot scale and commercial utilization of the technology. The technology is an airtight storage facility with provisions for modification of its environmental conditions to suit control of insect infestation in stored grains. Its major components are bin, plinth, gallery, gas supply network, monitoring devices and handling equipment. The bin is a cylindrical metal structure with conical top coated with food grade paint. It has three outlets for loading, discharging and accessibility. The plinth is a reinforced concrete basement that provides supports for the bin and the gallery. However, capacities from 5 tonnes do not require plinth, but could be supported by point load bearer concrete columns and structural bars. The ladder and walkway constitute the gallery for easy access of the silo. The gas supply system of the silo is responsible for supply of nitrogen to the bin through the following components: gas cylinder, gas line, gas control valve, gas regulators and purging container. The gas line is supported with gas line tray and vertical support. The main storage conditions monitoring devices are pressure gauge and temperature probes. The handling accessories of the silo include grain bunker, grain sampling probe, loading and unloading auger conveyors**.**

2.2 Research Component of the Development

Studies were carried out at different phases of the development to ascertain the level of utilization of the technology as well as its coverage in insect infestation control in storage of grains. The following prominent grains have been successfully stored in the silos under nitrogen; cowpea, maize, wheat, paddy rice and sorghum. The aforementioned crops were exposed to storage duration that ranged from 24 to 48 months at different time and different locations within the country (Okonkwo *et al.*, 2018; Babarinsa *et al.*, 2017). The three phases of the research are laboratory trials, pilot scale storage and commercial/industrial storage.

2.2.1 Laboratory Trials

A number of laboratory experiments were carried out on maize and cowpea to establish the suitability of the technology for grain storage at the laboratory level (Figure 1). These were carried out in Kano (North West) and Ibadan (South West). The latter worked extensively on maize while the former handled cowpea. The Kano experiment which was terminated at 30 months was aimed at revealing the efficacy of the technology in controlling insect pests infestation in stored cowpea as well as its potential to maintain the quality of cowpea stored under such condition. Another study carried out on cowpea at the laboratory level was to establish the effect of insect infestation of cowpea stored under N_2 on biological evaluation of protein quality. One of the experiments carried out on maize storage was laboratory examination of yellow maize stored under nitrogen.

Figure 1. Inert atmosphere silo used for laboratory studies

2.2.2 Pilot Scale Storage

This was the second phase of development of the technology. The laboratory trial was stepped up to a level that is practically achievable in grain storage. The Institute has in its collection of inert atmosphere storage facilities an array of 5 tonnes capacity silos. These silos known as mini silos were used for the pilot scale storage of grains. Maize storage was carried out to determine the susceptibility of the life stages of *Sitophilus zeamais* and *Trogoderma granarium* larvae to nitrogen atmosphere in mini silos. Another investigation carried out was to determine the effect of shading and insulation on performance of the mini silos when used for maize storage.

2.2.3 Commercial Storage

Bulk storage of grains called for further studies on the technology to establish its efficacy for commercial and industrial utilizations. The storage capacity was raised to 50 tonnes. The Institute has a battery of 2 units of 45 tonnes in Ibadan and a battery of 2 units of 50 tonnes in Ilorin and Kano for commercial grain storage research (Figure 2). These facilities sited in different ecological zones of Nigeria have been used to store cowpea, maize, sorghum, wheat and paddy rice for 24, 30, 30, 48 and 24 months respectively.

Figure 2. A battery of two units of 50 tonnes inert atmosphere silo for commercial storage

2.3 Technology Adoption Approaches

Series of promotion strategies have been used to ensure appropriate dissemination and transfer of the technology to the end users. The strategies covered training of stakeholders in postharvest value chain of grains, participation in exhibitions and shows, donation of technology to groups, and rentage of the facilities to the public.

2.3.1 Training of Stakeholders

Different categories of stakeholders of postharvest value chain of grains have been trained on principles of operation and utilization of the inert atmosphere silo. These categories include farmers, grain merchants and aggregators, commercial farm operators, flour mill and feed mill industrialists.

2.3.2 Exhibitions and Shows

The technology has been showcased at different exhibitions and shows held across the country organized either by government agencies or Non-governmental organizations (NGOs). The Institute has a prototype designed for demonstration at workshop, exhibition and fair (Figure 3).

Figure 3. 0.5 tonne inert atmosphere silo for demonstration at exhibitions and shows

2.3.3 Donation to Groups

In order to demonstrate and prove to the stakeholders how effective the technology is in storage of grains and seeds, the Institute through government intervention donated some units of the small capacity inert atmosphere silos to some groups in some major grain producing areas of Nigeria.

2.3.4 Rentage of the Facilities

The silo facilities in the premises of the Institute were basically meant for research work, but not all of them are usually engaged at the same time. As a result of this, the Institute has decided to popularize the technology through rentage of the facilities to individual or corporate organization.

3. RESULTS AND DISCUSSION

3.1 Technology Developmental Achievement

The different developmental phases the technology passed through have shown that it has potential to effectively and efficiently handle wide range of quantity of grains without quality and quantity losses. The storage technology can handle small quantity of grain (100 kg) as well as several thousands of tonnes of grains. The construction materials of the silo are readily and locally available in the country. The principles of operation of the silo are key to its functionality and efficiency. Regardless of the capacity of the silo, the efficacy of the storage structure in handling grains is guaranteed. The superiority of grains stored in inert atmosphere silo over grains protected by phostoxin fumigant in other silos has been demonstrated by several researchers in NSPRI (Sowunmi *et al.* 1982; Adesuyi *et al.* 1980; Williams *et al.*1980). Research has revealed that the silo can be used as long-term storage environment to prevent and control stored products insects and mould (Oyebamiji *et al.*, 2017; Ajayi *et al.*, 2016; Oyebanji *et al.*, 2015). This system of storage has eliminated the general problem of moisture condensation associated with the conventional metal silos. It does not involve use of insecticides; thus absence of residues in stored grains that do cause food poisoning, silo facility operators and their neighbours are also safe from hazards of insecticides. There is elimination of resistance to insecticides by insects that has been reported to be on the high side (Okonkwo *et al.*, 2018; Ileke and Oni, 2011). Its operation only entails the use of nitrogen which is very cheap compared to insecticides and readily available. In addition, the cost of labour and frequency of application is far less compared to what is obtainable in insects control in conventional silos (Oyebamiji, *et al.*, 2017).

3.2 Research Outputs

Success was recorded at the various stages of the technology development. The output has really showed that efficacy and efficiency of the technology is not limited by storage capacity. The results of various studies carried out on maize, cowpea, wheat, paddy rice and sorghum for 30, 30, 48, 24 and 30 months respectively showed that the technology has potential to attack stored products pests regardless of the developmental stages with 100 % mortality, zero mould growth and no re-infestation (Babarinsa *et al.*, 2017; Oyebanji *et al.*, 2015; Can *et al.*, 2012; Agboola, 2001; Sowunmi *et al.* 1982; Adesuyi *et al.* 1980; Williams *et al.*, 1980). Provision of hood as means of insulating the top of the silo prevented moisture migration and condensation that are associated with the conventional metal silos (Akinnusi *et al.*, 1984; Oyeniran *et al.*, 1983; Sowunmi, 1980). The temperature of the grain stored in the silo was kept below 30 ^{o}C despite the high ambient temperature of 36 ^{o}C experienced in Ilorin during the storage experiment. The result further showed that temperature decreases from the top of grain mass towards the floor of the silo (Ajayi, *et al.*, 2016).

The technology is equally effective and efficient in maintenance of seed germinability and nutritional quality of grains (Babarinsa *et al.*, 2017; Oyebanji *et al.*, 2015; Agboola, 2001; Sowunmi *et al.* 1982; Adesuyi *et al.* 1980; Williams *et al.*, 1980;). The study carried out on storage of paddy rice seed revealed that the technology was able to maintain the germinability of the seed above 85% for 3 months (Oyebanji *et al.*, 2015). Likewise, the germinability of cowpea seed stored using the technology for 12 months was maintained above 85% (Babarinsa *et al.*, 2017). Another seed storage investigation on wheat which lasted for 12 months recorded a germinability of 91%. The free fatty acid (FFA) contents of brown cowpea stored using the technology increased from 2.60 to 6.51%, while that of the control experiment skyrocketed and increased to 58.60% (Babarinsa *et al.*, 2017). The sudden increase was attributed to excretory products of the insects that infested the control grains which is not applicable to grain stored using the technology because of its potential in dealing with all stages of development of insects (Oyebanji *et al.*, 2015; Shehata *et al.* 2009; Sowunmi *et al.* 1982; Adesuyi *et al.* 1980; Williams *et al.*, 1980).

3.3 Outputs of the Technology Adoption Approaches

Training is one of the notable means by which information could easily be disseminated to end users. NSPRI has organized series of training on principles of operation and utilization of inert atmosphere silo for different categories of stakeholders in postharvest value chain of grains. Over one thousand five hundred (1500) farmers were trained in seven states of the federation under a capacity building workshop organized and sponsored by International Crop Research for the Semi-Arid Tropics (ICRISAT). The training had utilization of non-chemical technologies for storage of sorghum as one of its major components. Majority of the participants showed interest in adoption of inert atmosphere silo but the financial requirement was a big challenge to them. Another training was organized by the Institute for grain merchants, commercial farm operators and industrialists in flour and feed mill sector across the country on principles of operation and utilization of inert atmosphere as a reliable alternative to use of synthetic chemicals in grain storage.

Participation of NSPRI in exhibitions and agricultural shows has given the Institute opportunity to showcase the technology to the public. It was the result of the participation that aided the decision of the management of Landmark University Commercial Farm located at Omu-Aran in Kwara state of Nigeria to adopt the technology for grain storage. A battery of two units of 250 tonnes capacity silo was fabricated and installed on the farm for efficient and effective storage of grains for feeds production (Figure 4). It has been observed that one of the major factors responsible for the low adoption recorded despite the enormous benefits attached to it, is the investment capital requirement for the construction and installation (Okonkwo *et al.*, 2018). An appreciable number of individuals and corporate bodies that have confidence in the functionality of the technology had rented the facilities for storage of grains in all the locations where they are sited.

In complement to the previous efforts made in promoting and popularizing the technology for adoption, the Institute fabricated and installed some units of 5 tonnes capacity silo for some groups of stakeholders in postharvest value chain of grains. Four units of the silos each were installed at Dawanu international grain market and AFEX premises in Kano state of Nigeria (Figure 5). Despite the availability of the facility in their premise at no cost from their end, the grains merchant group still found it difficult to release grains for storage in the silo for over two (2) seasons after the installation. Their attitude is in line with the submission of Roseboom *et al.* (2006) that identified unwilling attitude of farmers to adapt to changes as one of the main factors contributing to low adoption of technology.

Figure 4. A battery of two units of 250 tonnes inert atmosphere silo installed at the commercial farm of Landmark University in Omu-Aran.

Figure 5. Four units of 5 tonnes inert atmosphere silo installed at Dawanu international grain market in Kano.

3.4 Current Technology Adoption Approaches

In order to further convince end users of the technology on the viability and profitability of their investment if adopted, economic analysis was carried out on the utilization of the technology. All indices of economic analysis adopted showed that the technology is economically viable for storage of grains with a return per unit of investment of 0.44 when utilized for storage of wheat for a period of 48 months (Oyebamiji *et al.*, 2017). The economic benefits of the technology is incomparable to that of conventional silos in terms of frequency of application of pesticides, aeration of grains, turning of grains to prevent caking and high cost of labour. The cost effectiveness has revealed that an investment in the technology would bring huge economic return with a short breakeven period (Okonkwo *et al.*, 2018). Another giant stride taken in the recent time is patent. The technology has been patented by Nigeria Copyright Commission.

Despite the effort of the Institute in dissemination of the technology to the appropriate stakeholders, the adoption output has not been commensurate with the input. The report of Arokoyo (1998) showed that the low adoption recorded is not peculiar to this technology. This has urged the Institute to change the approach for possible improvement in its adoption. The organisation is ready to adopt the "watch us do it" approach. This approach will not expose the prospective adopters to any investment risk until the result is witnessed in their respective domain. Considering the interest that the farmers trained in the seven states of the federation have in the technology, the intervention of the government at all levels through constituency projects will also go a long way in boosting the adoption as well as empower different categories of people that will be involved in achieving such task. It will definitely bring about job and wealth creation. High adoption of agricultural technology usually results in poverty alleviation and improvement in livelihood of the adopters (Agwu *et al.*, 2008).

4. CONCLUSION

The adoption of the inert atmosphere silo has really proved that dissemination and adoption are as important as technology generation. Any developed technology could only fulfill the purpose it was designed for if it has been able to solve the identified problem in the public. It has been recorded that the Institute has done a lot in ensuring that the technology gets to the end users to solve the problem it was developed for, but there are still rooms for better performance. Therefore, the Institute is ready to partner with individuals and corporate organizations to ensure that the technology meets the goals of its development. Appreciable improvement in the adoption rate of this technology will guarantee effective bulk storage of grains for safety of life and investment.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Design and Fabrication of A Two-Row Reciprocating Weeder for Upland Rice Field

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ABSTRACT

Manual weeding is still the common practice in most African countries. Although the use of chemicals for weeding has been adopted in several places, its side effects have been a major concern. In this study, a prototype of motorized weeding machine, actuated by a slider crank reciprocating mechanism was designed and fabricated for use on rice farms. Consideration was given to techno-economic status of the small-scale farmers in the rural communities in the design of the machine. The design features included 20^o rake angle of the cutting blade, a working depth of 25.4 mm, working width of 400 mm for two rows of 250 x 250 crop spacing. The dimensions and the thickness of blades were designed according to the general soil mechanics equation to be 2.29 mm. Other machine elements designed according to PSG TECH procedures include the length of chain which was 1361.4 cm; load on shaft was 8.175 N, diameter of the crank shaft 30 mm and a power requirement of 1.62 kW. The crank radius was designed to be 126 mm. A reciprocation prevented the need to move the blades back and front as this action is automatically achieved in one process. Test result on the weeder indicated a weeding efficiency of 98%, quality performance efficiency of 92.7% and field capacity of $0.03m^2/s$ as against $0.008m^2/s$ with manual weeding. Collaborations is being sought with Materials and Metallurgical Engineering Colleagues to solve the problem of overweight by replacing mild steel with aluminum alloy materials on various identified components of the machine where loads are not concentrated. By the time this work is completed, the problem of weeding of rice field and dependence on imported machines would be solved in the study area.

Keywords: Weeding, machine design, PSG TECH, reciprocating mechanism, rice

1. INTRODUCTION

Rice (*Oryza sativa*), is one of the most consumed staple food for most people in the developing countries (Dowling et al., 1998; Chen and Murata, 2002), especially in Asia and West African Sub region. It is a major staple food that has the fastest growing commodity in Nigeria's food basket (Akande, 2003).

The demand for rice far exceeds the production which in the last 30 years in Sub-Saharan Africa (SSA) has increased by 70% due mainly to land expansion and only 30% due to increase in productivity (Fagade, 2000). Although Nigeria is the largest rice producer in West Africa and produces about 50% of the rice grown in the sub region. Nevertheless, Nigeria still spends a large proportion of its foreign exchange on the importation of rice because of the high demand and consumption rate. According to USAID MARKETS (2008), total consumption of rice stands at 4.4 million tons of milled rice while annual consumption per capita stands at 29 kg. The Challenges being faced by rice farmers include bird infestation and weeding among others.

Weed control is one of the most difficult tasks in agriculture that accounts for a considerable share of the cost involved in agriculture production. Although the use of chemicals for weeding has been adopted in several places, its side effects have been a major concern. Weeding is a major time-consuming operation since the operation must be carried out two or three times before the crops mature. Manual weeding is still the common practice in most African countries, with its attendant drudgery (Jonne Rodenburg et al, 2015). Although a lot of efforts have been made in the past to develop weeders in Nigeria, many of the efforts have not been adopted by the end users i.e. the farmers (Ademosun, 1991, Olukunle, 2010, Manuwa et al, 2009). At this time when the country is considering renaissance of agriculture as the economic mainstay in place of oil and considering the financial capability of the populace, there is the need to foster small-scale farm machinery for improving sustainable agricultural production in South West Nigeria. In this study, a 2-row motorized weeding machine, actuated by a double crank reciprocating mechanism was designed and fabricated for use on rice farms. Also, the machine can be adapted for use on other farms. By the time it is completed, it would serve to reduce the drudgery of weeding on rice farms in the study area.

2. MATERIALS AND METHODS

2.1 The Design of the Components of the Machine

The components of the machine include IC Engine, Frame, Handle, Wheels, cutting blade, Sprocket & chain, Crank shaft, Support wheel and Connecting rod. Parameters designed for include the draught requirement for cutting, the size of the blade, the reciprocating mechanism, the power transmission system and the crank shaft.

2.1.1. Design of the draught requirement of the blade

The draft requirement for the blade was determined according to the general soil mechanics equation as reported by Krishna et al., 2013. This equation (Eq 1) considers different soil properties as well as tool geometry to determine the soil force per unit width of the cutting blade.

$$P = \gamma Z^2 N_\gamma + CZN_c + C_a ZN_{ca} + qZN_q \text{ --------------------------- (1)}$$

Where,

P = Soil force acting at an angle of soil metal friction with the normal to interface, kg per meter width,

γ = Bulk density of soil, $kg.m^{-3}$,

Z = Depth of operation, m,

C = Cohesion of soil, $kg.m^{-2}$,

Ca = Soil-interaction adhesion, $kg.m^{-2}$, and

q = Surcharge pressure on soil from surface above the failure plane, $kg.m^{-2}$.

The draught for the blade was determined using the wide tine procedure. A wide tine was selected for this blade according to Godwin and O'Dogherty (2007) where depth/width ratio < 5. A pre-design weeding operation was carried out to determine the rake angle and from literature, other data required for the design of the cutting blade is as shown in Table 1.

Table 1: Required data for the design of the blade

Rake Angle, $\propto = 20^0$ [for minimum draught, weed cutting below soil surface, good disturbance of weed, both for sparsely and intensely distributed weeds]. Working depth of blade $b = 2.54$cm ϕ = angle of shearing resistance of soil = 30^o δ = angle of soil/interface friction = 10^o c = cohesion = $10\ KNm^{-2}$ C_α = adhesion = $3.5\ KNm^{-2}$ σ = soil unit weight = $17.3\ kN/m^3$ Surcharge pressure = 0 It is assumed that the soil type is plastic loam.

The N factors, Nγ, Nc , Nq and Nca are dimensionless N- factors, which describe the shape of soil failure surface and are thus function of angle of shearing resistance of soil (Φ), angle of soil metal friction (δ) and geometry of loaded interface i.e. rake angle (α).These factors were computed using charts from Hettiaratchi et al (1966). The expression for the actual soil factor, N, is given by N (Eq. 2)

$$N = N_\delta = 0 \quad \frac{[N_\delta = \phi\ ]^{\frac{\delta}{\phi}}}{[N_\delta = 0]} \text{------------------- -------------- (2)}$$

The actual soil weight, cohesion and adhesion factors are calculated to be $1.41, 1.86$ *and* 0 respectively. Therefore, soil force per unit width of blade is given as (Eq. 3)

$$P = \gamma Z^2 N_\gamma + CZN_c \text{ -- (3)}$$

$P = 0.488KNm^{-1}$
The draught per unit width of blade is given as D in Eq. 4:
$D = P\sin(\alpha+\delta) + b\,C_{\alpha}\,cot\alpha$--- (4)
$D = 0.48825KNm^{-1}$
Therefore, draught for a blade of width 420 mm = 0.205065 KN
The power requirement at a velocity of 2 m/s = 0.41013 KW

2.1.2 Design of the cutting blade

The thickness of the blade was determined by assuming that the total vertical force on the blade will act at its centroid and that the thickness should be able to withstand any bending and rotation effects on the blade.
Considering the soil directly on top of the cutting blade in Figure 1 below.

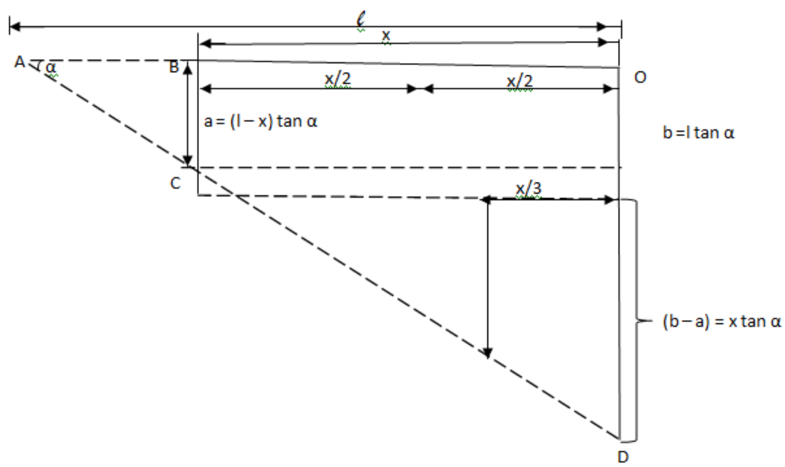


Figure 1: Analysis of the centroid of the tine

From point O, the centroid of the section OBCD, $\bar{X}$is given by:
$\frac{x}{2}(a+b)\bar{X} \ = ax.\frac{x}{2} + {}^{1}/_{2}\,(b-a)\;x \times \frac{x}{3}$---(5)

$$i.e. \quad \bar{X} = \frac{(2a+b)x}{3(a+b)}$$

$$\bar{X} = \frac{(2(l-x)\;tan\propto +l\;tan\propto)x}{3(l-x)\;tan\propto +l\;tan\propto)}$$

$\bar{X} = \frac{(3l-2x)x}{3(2l-x)}$---(6)

Total load acting over the length x of the blade according to Adesoji (1990) is given in Eq. 7

$= \frac{(2W_0L - W_0X)X}{2L}$ -- (7)

and the shearing force at point A

$$= \frac{-W_0X(2L-X)}{2L}$$

∴ The bending moment at point A

$$= \frac{-W_0X(2L-X)(X-(3L-2X)X)}{6L(2L-X)}$$

$i.e.$ The bending moment at point A

$$= \frac{-fx^2(3L-X)}{6L}$$

At $X = l$, the bending moment at point A

$= \frac{-FL^2}{3} = \frac{2}{3}V_tL$-- (8)

$i.e.$ The bending moment for the blade of length l at a force perpendicular to the tine is given as

$M_b = \frac{2}{3}V_t cos\alpha L$-- (9)

To determine the total vertical force on each tine

The total vertical force on the blade is given as

$V_t = Width \times (D\cos(\propto + \delta) + zc_{\propto}$--- (10)

$V_t = 0.105\ (0.488 \cos(20\ + 10) + 0.0254 \times 3.5)$

$V_t = 5.47 \times 10^{-2} KN.$

Hence, the bending moment for the blade,

$$M_b = \frac{2}{3} \times 5.47 \times 10^{-2} \times cos20^0 \times 0.074$$

$$M_b = 2.51 \times 10^{-3} KNM^{-1}.$$

From moment of inertia, $I = \frac{M_bh}{2\sigma} = \frac{Wh^3}{12}$--- (11)

$h = c\left(\frac{12M_b}{2\sigma w}\right)^{0.5}$ --(12)

Where,

w is the width of the blade.

h is the thickness of the blade.

σ is the normal stress for steel.

c is the factor of safety.

Therefore, the actual thickness of the blade is given as $h = 2.29mm.$

2.1.3 Design of the reciprocating mechanism

The design of the reciprocating mechanism involves the determination of the optimum diameter of crank that will allow for weeding with minimum overlapping of the weeding surface. Also, the design correlates the forward travel speed of the weeding machine with the reciprocating motion of the cutting blade, thereby preventing skipping of unweeded portions.

Let the diameter of the wheel be 40 cm and the diameter of crank x mm.

In 1 revolution of the crank, the blade makes 2 strokes.

Therefore in 0.5 revolution of the crank i.e.1 stroke of the blade, the blade travels a linear distance equal to the diameter of the crank x mm.
A wheel of diameter 400 mm was selected
The distance covered by the wheel in 1 revolution = $\pi \times 400$ mm=1260 mm.
To prevent skipping, the length of the crank must be able to cover up the linear distance of travel of the wheel. It is required that the rpm of crank is 5 times that of the wheel so that with 5 revolution of crank the wheel covers = 1260 mm/5 = 252 mm.
Therefore, each stroke the blade makes is 126 mm

2.1.4 Design of the power transmission system

The transmission system comprises of the speed reduction gear, crankshaft, axles, sprockets and chains. The axles rotate on wheels. In order to ease the forward movement of the weeder, two sprockets and chains were installed on the rear ends of the crankshaft to power the rear wheels. This was done to accommodate the middle row of rice during the use of the machine on the field. Also, a foldable support wheel is provided at the back to ease the transport of the machine when the engine is not running. The components of the transmission system were designed according to PSG TECH, 2016. The selected engine speed = 3000 rpm while the selected speed ratio of the reducing gear 15:1. Therefore, the rpm of the crank, which is attached to the shaft of the reducing gear = 200rpm. A speed reduction was achieved by stepping down the crank rpm by 5 with sprocket and chain. Therefore, rpm of wheel will be 40. Corresponding diameters and teeth of the sprockets were designed for. The length of chain was 1361.4 cm, load on shaft was 8.175 N, diameter of the crank shaft 30 mm and a power requirement of 1.62 kW.

2.2 The Description of the Machine

The major components of the weeder include the main frame, speed reducing gear, stanchion, wheels, reciprocating arms, shafts, IC Engine, Chain and sprocket, coupler. When the IC Engine is started, its speed is stepped down by ratio 1 to 15. The reciprocation prevented the need to move the blades back and front as this action is automatically achieved in one process. While designing and in material selection, consideration was given to techno-economic status of the small-scale farmers in the rural communities who are the intended users of the machine. It is simple to operate unlike flaming which require high skills It does not constitute environmental hazards like chemical weeding. Instead of burning up the weeds like in chemical weeding, this mechanical weeder can harvest the weeded material and retain them for manure/mulch purposes. It maintains the seed bed in a good tilth and aeration during the growth of crop by loosening the soil between rows, thus increasing air and water intake capacity. The design considers a rice grown on (250 mm $\times$ 250 mm) row spacing. Given that a space of 50 mm is provided for the rice row in the middle and 25 mm each for the ones at the sides of the weeder. The views of the machine are shown in Figures 1, 2, 3 and 5 while the arrangement of the blade along the rows of a rice field of 250 mm $\times$250 mm row spacing is shown in Figure 4. The blades were made to have overlap of cut of 10 mm per row. Therefore, the total effective width of cut by the blades is 400 mm.

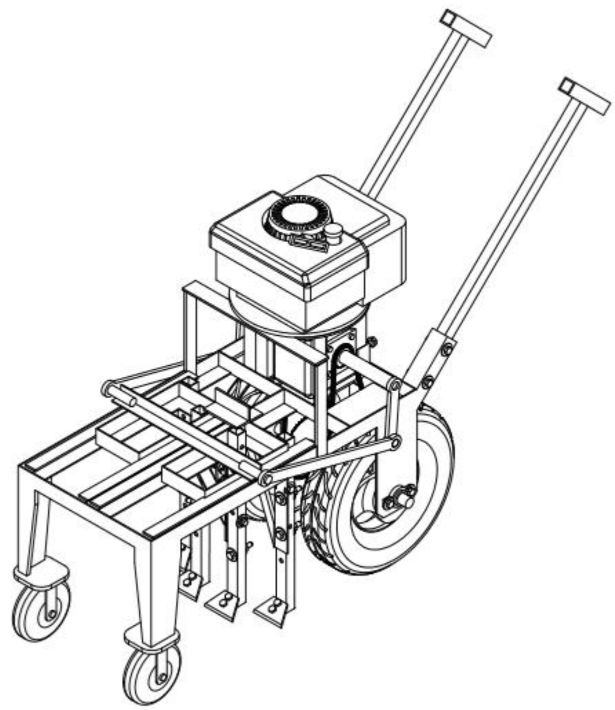
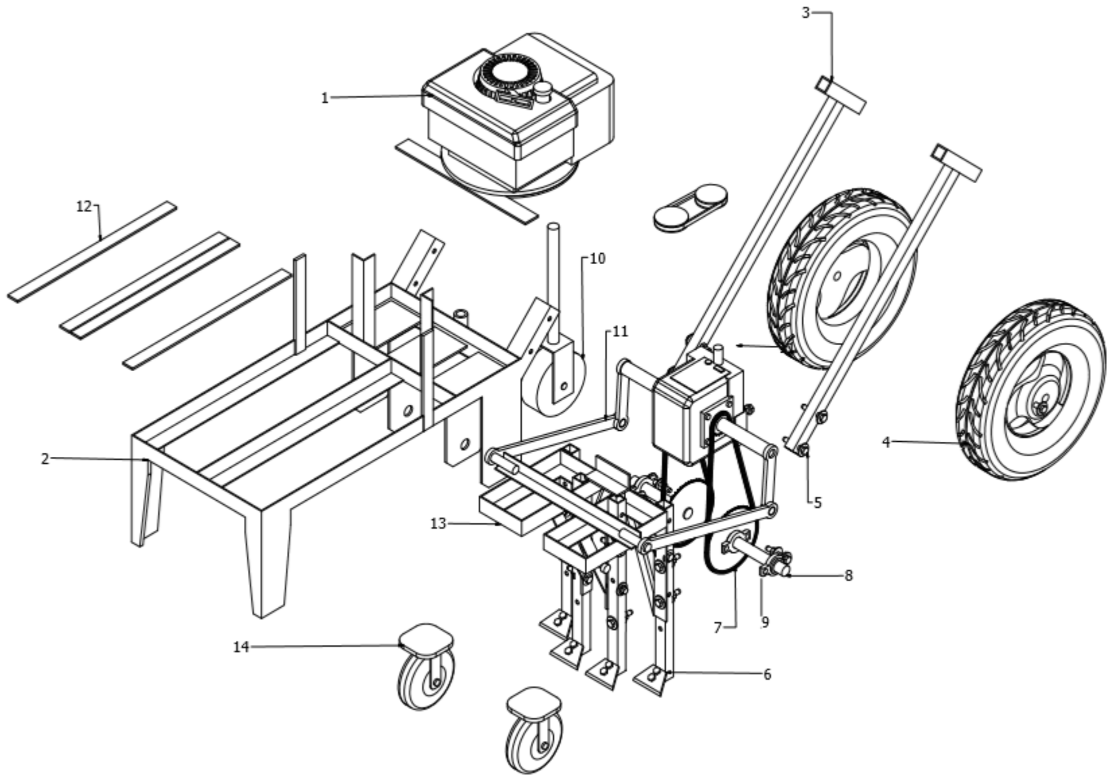


Figure 1: The pictorial view of the machine



LEGEND		
SNO	DESCRIPTION	QTY
1	IC Engine 5.5 Hp	1
2	Frame	1
3	Handle	2
4	Rear Wheel	2
5	Bolts and Nuts	30
6	Cutting blade	4
7	Sprocket & chain	2
8	Pillow bearing	2
9	Crank shaft	1
10	Support wheel	1
11	Connecting rod	2
12	Pair of Rail Guard	4
13	Blade Carrier	1
14	Roller wheel	2

Figure 2: The exploded view of the machine

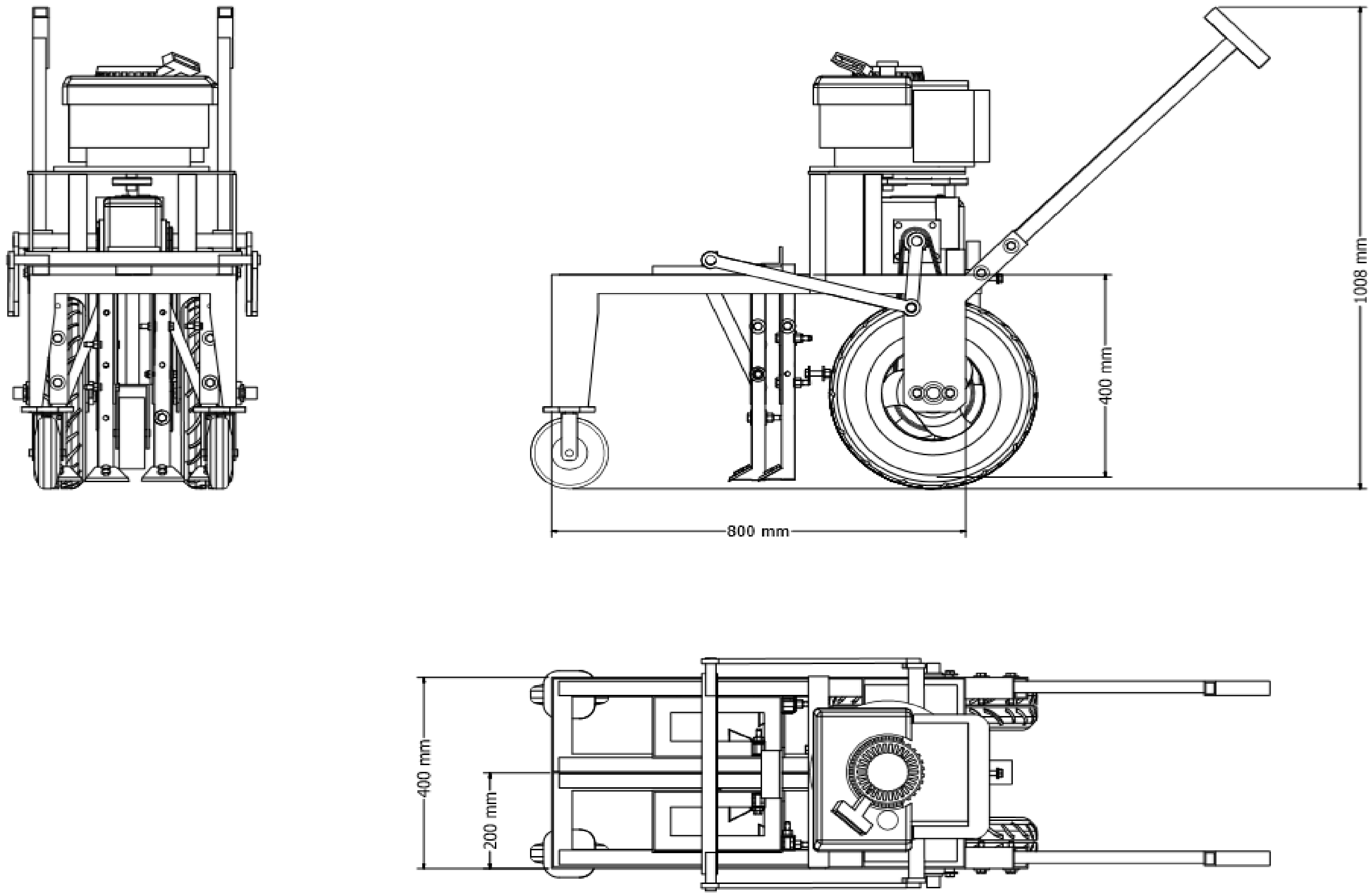


Figure 3: The first angle orthographic drawing of the machine

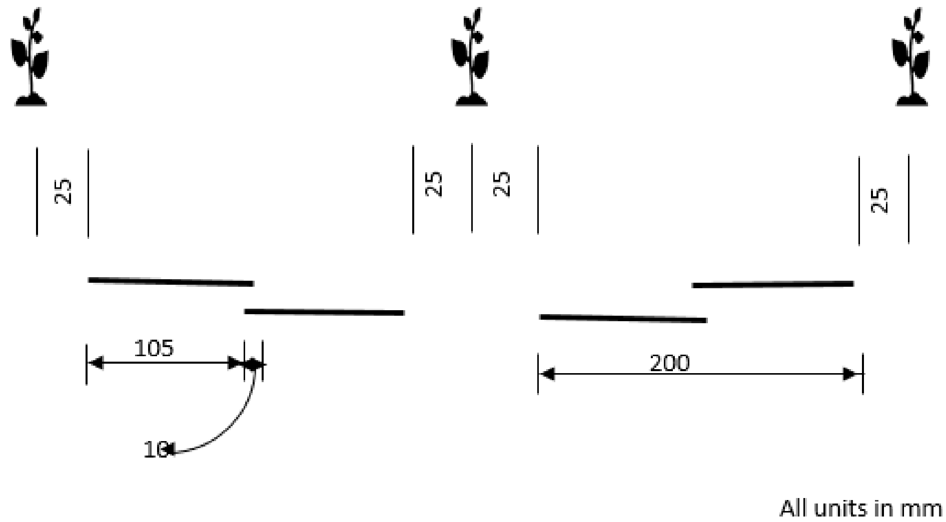


Figure 4: The position of the blades along the rows of a rice field of 250 mm $\times$250 mm spacing

Figure 5: The picture of the weeder

3. RESULT AND DISCUSSIONS

After fabrication and assembly, a preliminary test was performed on the machine on a 1000 x 1000 m^2 field. The test parameters include weeding efficiency and field capacity according to Sabaji et al (2014). Test result indicated a functional efficiency of 98%, and field capacity of $0.03m^2/s$ as against $0.008m^2/s$ with manual weeding. Therefore, the machine performed excellently in removing the weeds. In fact, all weeds within the cutting width of the blade where successfully removed. However, the machine is very heavy due to overweight of the materials used for the frame. The need for materials of appropriate weight cannot be over emphasized. Selecting materials of optimum weight is necessary to be able to achieve the purpose for which it was selected. However, too much weight can result in overloading and excessive power requirement. To overcome this problem, we are considering the possibilities of replacing the heavy mild still that we used with aluminum alloy materials on various identified components of the machine where loads are not concentrated. We are seeking collaborations with Materials and Metallurgical Engineering Colleagues to solve this problem.

4. CONCLUSION

A double row reciprocating weeder was designed and fabricated for rice field. Preliminary test result indicated a weeding efficiency of 98%, quality performance efficiency of 92.7% and field capacity of $0.03m^2/s$ as against $0.008m^2/s$ with manual weeding. Collaborations is being sought with Materials and Metallurgical Engineering Colleagues to solve the problem of overweight by replacing mild steel with aluminum alloy materials on various identified components of the machine where loads are not concentrated. By the time this work is completed, the problem of weeding of rice field and dependence on imported machines for weeding would be solved in the study area.

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The proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Determination of physicochemical properties of Nigeria grown Palmyra Palm fruits (*Borassus aethiopum Mart.)*

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Abstract

Palmyra palm (*Borassus aethiopum Mart.*) has been an underutilized plant specie in Nigeria despite its socio-economic and nutritional qualities. The fruits used for the study were obtained from North Central and South western ecological zones of Nigeria. The physicochemical properties were determined by using AOAC procedures and UICPA methods. The determination of the physical characteristics of the fruits was done by using a vernier caliper and a measuring tape. The range of the mean values for the physical characteristics are diameter13.35 – 14.05cm Thickness of the pulp was 1.00 - 1.57cm Weight of the whole fruit was1.306 - 1.545kg .Percentage of the pulp to kernel, Kernel weight, weight of the pulp and moisture content were 0.22 – 14.63%, 1.129 – 1.383g, 0.003 – 0.226kg and 75.54 – 83.22%, .The physical characteristics and proximate composition of the Nigeria grown Palmyra palm fruit can be used to develop technological options for its processing, storage and utilization. This plant would be a good source of industrial raw materials for entrepreneurship development activities and nutritionally beneficial if domesticated.

Keywords: Palmyra Palm, Morphological properties, Proximate composition

1. INTRODUCTION

Palmyra Palm (*Borasssus aethiopum* Mart) is an underutilised plant specie that is currently growing in the wild in most parts of Africa with Nigeria inclusive but widely known because of its importance in the Asian countries (Bolade and Bello, 2006; Cretenet *et al*. 2002). It grows naturally throughout the semi-arid to sub humid regions of Africa from Senegal to the Central African Republic. (Leakeys1996). It belongs to the *Aracaceae* family and an unbranched palm that could grow to about 20m with a crown of about 8m wide, (Ahmed *et al.* 2010; Muazu *et al.* 2014). This crown has given it the name African fan palm. The fruit from this plant can be eaten as food or supplements, extracted to produce juice and wine, (Adzinyo *et al.*, 2015; Ali *et al.*, 2010). The germinating nuts of this plant produce a good source of starch which can be used in the food, textile, cosmetics, plastic, adhesives, paper, and pharmaceutical industries (Muazu *et al*., 2014; Adzinyo *et al*., 2015). It was reported that the non-wood fibres obtained from this plant can be exploited to produce roofing materials, mats, ropes and when pulped can be used in paper manufacturing by using soda process (Sridach, 2010; Sambou et al., 2002). The shoots, roots and fruits are utilized for medicinal purposes (Akinniyi and Waziri, 2011; Barminas *et al.*, 2008). This study investigated the physical characteristics and physicochemical properties of *Borassus aethiopum* Mart fruits and pulp as a potential source of industrial raw materials for entrepreneurship development activities in Nigeria.

Figure 1: A typical Palmyra Palm Tree

Figure 2: Palmyra Palm Fruits

Figure 3: Palmyra Palm Kernels

2. MATERIALS AND METHODS

Fruit collection and physical characterization

Forty fully matured fruits were harvested from Badeggi in Niger, Okene in Kogi and Owo in Ondo states of Nigeria where the plant thrives very well. A total of one hundred and twenty fruits were obtained. These fruits were sorted so as to separate the damaged from the good ones. After sorting, twenty five fruits were selected from each state giving a total of seventy five fruits selected on the basis of ripeness level, size and shape resemblance. These fruits were washed, weighed, peeled and pulped. The weight of the pulp, the kernel and peelings were measured by using an electronic balance manufactured by Raylabel Instrument Company Limited which has 0.001 sensitivity. Pulp thickness was measured with a vernier caliper and kept inside the refrigerator at 4^0C for further use. The diameter of the fruits was determined by using a measuring tape (Ahmed *et al*.,.2010).

Chemical characterization

Moisture content

The moisture content of the sample were determined according to the Association of Analytical Chemist procedure (AOAC, 1990) Empty moisture dishes were washed and dried in an oven at and cooled in desiccators. The dishes were weighed with covers. Five grams (5g) of the samples was weighed and put in to the dishes and weighed again. The sample with the container were then placed in an air oven at 102^0C and dried for 5 hours till constant weight was obtained. The dishes were then transferred in to desiccators and cooled and then reweighed (W_3). The % moisture content on wet basis was calculated from the relationship shown below

$$\text{\% moisture content on wet basis} = \frac{W_2 - W_1}{W_2 - W_3} X\,100 \qquad (1)$$

W_1 is the weight of the empty dish with cover
W_2 is the weight of the moisture dish and the sample
W_3 is the weight of the moisture dish and the dried sample

Total Ash

Two grammes of the sample was weighed and put in a crucible. The crucible and the sample were placed in muffle furnace (Gallenkamp) at 500^0C for 5 hours until a whitish gray material was obtained. The crucible was then removed and placed in desiccators to cool to room temperature. Each sample was determined in triplicate and the % ash was calculated as shown in the relationship below

$$\text{\% Ash} = \frac{Weight\,of\,\,Ash\,\,X\,\,100}{Weight\,of\,\,Sample} \qquad (2)$$

Minerals

Wet digestion was used for the determination of the minerals. Ground sample of 0.2g was weighed into the digestion tubes. Five millilitres of digestion mixtures containing 1 volume of parchloric acids to 4 volume of nitric acid and 2 volume of sulphuric acid was added respectively and placed in a fume cupboard overnight. The mixture was then digested for 2 hours in Kjedahl digestion block. The digest was allowed to cool and 30ml of distilled water was added and the content was vigorously shaken. It was then filtered through a filter paper in to 100ml volumetric flash and the volume calibrated to 100ml. The digest was then used for determination of Sodium (Na) and Potassium (K) using flame photometer while Calcium (Ca) and Magnessium (Mg) were determined using EDTA complex metric titration and Phosphorus (P) was determined by using Molybdate method with spectrometer.

Total lipid

The total lipid was determined by solvent extraction method using N-Hexane (UICPA 1979).

Two grammes (2g) of sample was weighed in to the thimble and plugged tightly with cotton wool. The thimble was inserted in to a Reflux extractor holder. A 100 ml flat bottom flask of known in which 25ml petroleum ether having a boiling point of 60^0C was poured and fitted in to the extractor. The apparatus was heated by a graduated hot plate at 80^0C for about 4 hours. At the end of extraction, the solvent was removed from the oil by heating in a hot air oven at 105^0C for 30minutes. The flask was cooled in desiccators and reweighed. Percentage oil was calculated as shown below

$$\% \text{ Oil} = \frac{Weight\,gained\ by\ the\ \ flask\,X\ 100}{Weight\ of\ \ Sample} \qquad (3)$$

Soluble sugar

Soluble sugar was measured by putting a drop of the fruit extract on the prism of the digital refractometer and the soluble sugar was read in Brix according to Fisher and Stein (1961) method.

Crude protein

Ground samples of 0.2g was weighed in to Kjeldahl digestion flask and a tablet of Kjeldahl catalyst was added. Five millilitres of concentrated H_2SO_4 was added in to the flask. The content of Kjeldahi digestion flask was heated in a digestion chamber contained in a fume cupboard for about 4 hours until a clear digest was obtained. The sample was allowed to cool then 10ml of distilled water was added to the content. Ten millilitres of boric acid containing 5 drops of methyl red indicator was added to the digest until 50ml of distillate was obtained. The distillate was then standardized using 0.1 NHCL until pink colour was observed. The % crude protein was calculated as shown

$$\%\text{N} = \frac{S - B\,X\,0.1\,X\,14.01\,X\,100}{Weightofthesample} \qquad (4)$$

% crude protein = % N X 6.25

S = Sample titre value

B = Blank titre value

Crude fibre

The crude fibre is defined as the indigestible part of the food sample. It was determined as the fraction remaining after digestion with sulphuric acid and sodium hydroxide.

Two grammes of defatted material with petroleum ether was boiled under reflux for 30 minutes with 200 ml of solution of 1. 25MH_2So_4. It was filtered through a filter paper washed with boiling water until there was no trace of acid. The residues were transfer to a beaker and again boiled for another 30minutes with 200ml of 1.25NaoH and again filtered through another filter paper with washing until there was no NaoH present in the defatted material. The final residue was then transferred to a crucible and dried in an oven and the dried weight was taken. This was transferred to a furnace for ashing and the weight was also determined. The crude fibre was then calculated as shown

$$\% \text{ Crude fibre} = \frac{Dry\,weight - Ashing\,weight}{Weight\,of\ sample} X\,100 \tag{5}$$

Vitamin C

Vitamin C was determined by the 2,6-dichlorophenol indophenol (DCPIP) titration procedure based on the method of Cassana *et al.,* (2002). The 0.1g powdered sample was extracted with 20ml of 4% oxalic acid. Then the material was centrifuged at 10,000rpm for 30minutes. 10ml of the sample's aliquot and 10 ml of 4% oxalic acid were taken in a conical flask and titrated against 2,6 diclorophenol indophenols (DCPIP) dye (v_2) until the appearance of a faint pink colour that persisted for a few minutes. Another 5ml of 100ppm solution of ascorbic acid and 10ml 0f 4% oxalic acid were taken and also titrated against (DCPIP) dye (v_1) the ascorbic acid content (mgg^{-1}) was determined using the formula

$$\text{Amount of Ascorbic acid } (mgg^{-1}) = \frac{0.5\,X\,v_1\,X\,220}{v_2\,X\,10\,X\,0.1} \tag{6}$$

$v_1 =$ dye consumed by 0.5mg ascorbic acid
$v_2 =$ dye consumed by 10ml of test solution.

Phosphorus

A sample of 2 to 5ml of aliquot of the fruits was pipetted Olsen extracts(in to a 25ml volumetric flash or a marked test tube. And approximately 10ml of distilled water was added. 4ml of reagent B was added and make up to volume with distilled water and allow the colour to develop for 15minutes and determine phosphorus (P) content in solution in a spectrophotometer at 88mμ.

3. RESULTS AND DISCUSSION

Physical characteristics of the fruits

The determination of the physical characteristics was done for each of the 75 fruits selected out of the 120 harvested from Niger, Kogi and Ondo states in Nigeria. The means of the three replicates are presented in Table 1. The physical characteristics of the fruits showed that mean diameter is about 14cm for the three states and the highest value of the pulp thickness of 1.57cm was recorded for Niger state while those of Ondo and Kogi states were about 64 and 93% of this value. The kernel and the pulp weight of the fruits from the three states constitutes about 49.8 and 38.6% respectively while the remaining 11.62% is the weight of the peelings. The values obtained for these fruits were higher than those of Palmyra palm (*Borassus aethiopum* Mart) harvested from the Northern part of Cameroun, (Ahmed *et al*., 2010). This is an indication that there will be increased product yield resulting from the variation in the size of the Nigerian grown Palmyra palm fruits.

Table 1. Physical characteristics of Nigeria wildly grown Palmyra Palm (*Borassus aethiopum* Mart) fruits

Parameter	Ondo	Kogi	Niger
Mean Diameter (cm)	13.550	14.05	14.60
Thickness of the pulp (cm)	1.000	1.460	1.57
Weight of the whole fruits (Kg)	1.386	1.306	1.545
Weight of the pulp (Kg)	0.535	0.504	0.596
Weight of the Kernel (Kg)	0.690	0.650	0.769
Weight of peelings (Kg)	0.161	0.152	0.180
Percentage of the pulp (%)	38.600	38.350	38.88

Physicochemical Attributes

The physicochemical characteristics were carried out on the pulp of the twenty five fruits from each of the states and the results are presented in Table 2. The moisture contents of the Palmyra palm fruits (*Borassus aethiopum* Mart) were between 75.54 to 83.22%. These values were higher than that of licuri palm fruits (74.48) (Paula-Filho *et al*., 2015), in the range of those determined for Shea nut pulp (77.4 – 81.11%) (Mbaiguinam *et al.*, 2007) but lower than that of Pumpkin pulp (92.03%) (See *et al.*, 2007). Srivastava *et al.*, (2014) reported that consuming fruits with high moisture content like the pulp of this fruit that contains minimal calories hydrates the body effectively than water or any sport drink.. The total ash of the fruits ranged between 0.93 to 1.41g/100g. The variation in the Ash content may be attributed to varietal and geographical differences in cultivation of the fruits. The ash content values compares with the value obtained by E-Demery (2001) for round pumpkin pulp (1.5g/100g) but lower than that of cylindrical pumpkin pulp (2.14 – 4.26g/100g) (Nwofia, *et al*., 2012). The ash content value obtained for Palmyra palm fruits is an indication that it will have a high concentration of the various mineral elements which are expected to speed up metabolic processes thereby improving growth and development of the body (Elinge *et al*., 2012). The analysis of the ash content of these fruits revealed that 100g of the pulp contains Sodium, 429.8 to 440.7 ppm, Potassium 536.67 to 546.16ppm, Magnesium 4.96 to 5.73g/100g, Calcium 2.16 to 2.50, Phosphorus 100.22 to 196.89 ppm

Table 2: Proximate Analysis of the Palmyra Palm (*Borassus aethiopum* Mart) fruits

Parameter	Ondo	Kogi	Niger
Moisture content (%)	75.54	81.23	83.22
Crude Fibre (%)	8.08	7.80	6.81
Total Ash (%)	1.36	0.93	1.41
Crude Protein (%)	2.40	3.86	4.21
Energy Value (Kcal/100g)	27.74	32.99	27.28
Carbohydrate (%)	12.32	5.64	4.01
Total lipid (%)	0.29	0.29	0.34
Sodium (Na) (ppm)	429.80	440.70	429.80
Potassium (K) (ppm)	536.67	546.16	547.3
Magnesium (Mg) (%)	4.96	5.73	4.97
Calcium (Ca) (%)	2.16	2.50	2.37
Phosphorus (P) (ppm)	100.22	196.89	123.32
Total Solid (%)	24.39	18.60	16.79
Soluble Solid %	2.96	2.80	3.72
Total Sugar %	5.18	4.23	5.45
Vitamin C (mg)	361.17	337.64	468.38

%represents the content (g)/100g of fresh consumable product

The value of the crude fibre is from 6.81to 8.08. The least value was recorded for Niger state and the highest recorded for Ondo state. These values are higher than the values obtained for Palmyra palm fruits harvested from Northern Cameroun 5.72 to 7.89 (Ahmed *et al.*, (2010). The fibres in the fruit pulp helps to maintain the health of gastrointestinal track, (Ubwa *et al.*, 2014). The crude protein contents were 2.40 to 4.21 g/100g. This value is higher than the EU/WHO (2000) recommended limits of 1g/100g and it is lower than that of Shea butter nut pulp (4.19 to 4.62% (Mbaiguinam *et al.*, 2007). The Carbohydrate contents of the Palmyra palm fruit pulp were between 4.01 to 12.32%. These values were in the range of those reported for licuri palm fruit pulp (7.6 to 10.38%) (Paula-Filho, 2015). Total lipid had low values ranging from 0.29 to 0.34%. Values for Palmyra palm fruit pulps are slightly higher than those of mango pulps reported by Ubwa *et al*., (2014). Fruits with low lipids have been reported to be a good food for people suffering from obesity (Nwofia *et al.*, 2014). Consumption of Palmyra palm pulps could be a good remedy for weight reduction. Total solid value varied from 16.39 to 24.39% which compares favourably with the values reported for mango fruit pulps 17.3 to 20.75% (Ubwa *et al*., 2014). This parameter is an index used to determine the maturity of fruits and a strong indication of harvesting time (Ubwa *et al*., 2014). Total sugar had values ranging from 4.23 to 5.45 g/100g. This value is close to that of the fruits of (*Areca cathecu Linnaeus*) 3.88 – 4.88g/100g and lower than that of the fruits of Date palm (*Phoeniv dactilyfera* L.) 64.71g/100g (Ahmed *et al*.,.2010). The value of vitamin C in the present study was between 337.64 to 468.38g/100g is higher than the minimum vitamin C requirement (15mg/100g and 80mg/100g) recommended by EU/WHO for fruit groups. Vitamin C plays an active role in human health and welfare mostly as an antioxidant (Nwofia *et al*., 2012).

4. CONCLUSION

The Palmyra palm (*Borassus aethiopum* Mart) fruits analysed in this work showed that the nutritional quality of the fruits is excellent. It contains vitamin C, sugars,, minerals like Sodium, Potassium, Calcium which are needed for human health improvement. It presented a reasonable level of dietary fibres and lipids. It was observed that these properties were affected by agroclimatic regions where the fruits were harvested. The pulp can be used to produce a wide range of natural products such as wine, jam and candies. The nutritional value presented by this plant could make it an important tool for reducing food insecurity.

5. RECOMMENDATION

It grows presently as a wild plant in Nigeria so research efforts should be geared towards domesticating it by producing fast growing breeds in order to harness its potentials as an economic crop where entrepreneurial activities for self sustenance can be developed.

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The proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Influence of Thickness on the Drying Characteristics and Quality of Dried Cashew (*anacardium occidentale l.)* Apple Slices

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ABSTRACT

This study investigated the effect of slice thickness on the drying characteristics and quality of dried cashew apple slices. Fresh cashews were harvested and dried at 5, 7, and 9mm thickness using hot –air convective dryer at a constant air velocity of 0.8 *m/s* and two different temperatures of 55° C and 65° C. During drying the weight loss was measured initially at an interval of 0.5 hour for the first five hours and later at 1hour interval. The analysis of minerals content: (Magnesium and calcium), and proximate analysis which include: pH, colour, vitamin C content and tannin content were performed. In addition, sensory evaluation for taste, texture, aroma, appearance and overall acceptability was carried out according to the 9-point hedonic scale using raw cashew apple as control. The Drying process took place in the falling rate period. The time required to reduce the moisture content increases with increase in thickness. Water loss and weight loss decreased with increase in slice thickness, the loss in Vitamin C, was lower at 7mm thickness in general. Mechanical drying at an air temperature 55 °C of 7mm thickness, and air velocity of 0.8 m/s gave the best quality with Vitamin C content of 68.46g. From the sensory evaluation the general accepted sample was at an air temperature 55 °C of pretreated 7mm thickness.

Keywords: Drying, thickness, cashew apple, drying characteristics, quality, sensory evaluation, Nigeria.

1. INTRODUCTION

Cashew apple which is a pseudo fruit of the cashew tree (*Anacardium Occidentale L.*) is from the humid or tropical region, it is considered originally to be a native of the Northern part of South America. India, Nigeria, Mozambique and Tanzanian are also large producers of cashew. Africa produces more than 6 million MT of cashew apples per year (Ogunjobi and Ogunwolu, 2010a). Latin Americans, Brazil, West Indians and some African countries like Mozambique and Tanzania sometimes process cashew apples in to juice and or ferment

the juice into wine (Akinwale, 2000; Pereira *et al.*, 2011). However, there are no such Industry in Nigeria, this result in wastage of the pseudo fruit.
Cashew apple is said to contain five times Vitamin C than any citrus fruit and ten times of pineapple which make it more nutritious (Ogunjobi and Ogunwolu, 2010b). It has a number of medicinal uses from remedy of sore throat to treating chronic dysentery, stopping bleeding and so on. But it astringency is high due to the high tannin content and these limit the consumption of the fresh apples (Falade *et al.*, 2003). Cashew apple is highly perishable fruit because it deteriorates faster than any other fruit (Azoubel *et al.*, 2009). To avoid the losses and wastage of the apple it can be dried or dehydrated to increase the shelf life of the fruit.

Drying has been the oldest form of preserving foods in the world (Maskan, 2000). It brings about the extensive reduction in weight and volume which minimize packaging, storage and transportation cost. There are over four hundred types of dryers made for different crops and drying methods existing in the world today. Of this methods hot-air drying is one of them, where heat is applied by convection at atmospheric pressure and by dielectric heating where only the water of the product is heated (Sharma *et al.*, 2005), there are several factors which has an effect on the hot.-air drying of food, factors like: temperature of air, air velocity, moisture diffusion, load density, thickness of the slices, shape of the product to be dried (Antonio Vega *et al.*, 2007; Wang and Xi, 2005). Drying is a complex thermal process in which unsteady heat and moisture transfer occur simultaneously (Wankhade *et al.*, 2013) During drying, vegetables and fruits undergo physical, structural, chemical, organoleptic and nutritional changes that cause quality degradation (Di Scala and Crapiste, 2008; Roberts *et al.*, 2008). There are two phases in drying, which is the constant rate phase period and the falling phase period (Dissa *et al.*, 2008; Doymaz, 2008).In past literatures, it was observed that falling rate phase occurs mostly in the drying of fruits and vegetables (Kamil Sacilik and Elicin, 2006; A Vega *et al.*, 2007).Even though cashew apple is extremely nourishing and is high in Vitamin C content, most of the cashew apples in Africa are left to rotten after harvesting because of the wide production and processing of the nut (ACA, 2009), and dried cashew apple can be use to produce wine (Ogunjobi and Ogunwolu, 2010a), produce confectioneries (Ogunjobi and Ogunwolu, 2010b) etc. However, there is no information on the hot-air drying of cashew apple slice and no much information on the influence of thickness on the drying characteristics and quality of fruit and vegetables. The aim of these research is to evaluate the effect of thickness on the drying rate, drying time and on the nutritional value of the dried cashew slices.

2. MATERIALS AND METHOD

2.1 Description of Mechanical Dryer

The drying experiments were conducted in the Agricultural Engineering laboratory which housed the locally fabricated mechanical cabinet dryer (Olalusi, 2011) the dryer was designed and fabricated in the Department of Agricultural Engineering, Federal University of Technology, Akure. It is operated by electric current of 220 volts for hot air drying with a motor power of 0.75 kw. Four sample baskets made of stainless steel are suspended in the drying chamber. The heating chamber has two heating element which each has a power rating of 1.5kw i.e. 3kw in total. This provides heat which is used in drying agricultural materials. The exhaust air escapes out of the drying chamber through a chimney located on top of the dryer. The entire dryer was insulated to avoid heat losses and substantial temperature differences across the test sections. Dry bulb temperature of the air stream was measured by means of thermocouples and controlled by a power regulator and a thermometer to check accuracy. Air velocity was measured by means of a vane anemometer sensor.

2.2 Sample Preparation

Ripe matured fruits (yellow variety) were harvested manually at a local cashew farm in Oro-Ago Village, Kwara state Nigeria and they were transported to Akure, Ondo State Nigeria by placing them inside egg crate and then refrigerated at temperature of 6° C. The nuts were detached from the apple manually and the apples were sorted, weighed and washed with running tap water and left inside a plastic crate for it to drain. The cashew apples were then sliced into three different thickness sizes which are 5, 7, and 9 mm, these similar procedure was used by Kajuna *et al.* (2001) , for the drying of cassava root cubes, Hoque *et al.* (2013) , for the drying of ginger rhizome. They were sliced with sharp stainless-steel knife in longitudinal position when the cashew is in a resting position and it is then placed on a net for drying processes.

2.3 Drying Procedure

The moisture content of the three different thickness slices of the cashew apple were measured by oven dry method (Rangana, 1986) and was expressed as amount of water/ mass of dry matter. The dryer was run idle for about 30 minutes to achieve a steady state in respect of pre-set experimental drying condition before each drying run. 30 g of the cashew slices of different thickness were uniformly spread on the net and placed in the basket inside the drying chamber. The weight of each of the sample (cashew apple slices) was measured at intervals of 30 minutes within three hours using a precision weighing balance and later increased to 1 hour. Drying was stopped when there was no noticeable change in the weight of the slices sample and the moisture content of the dried sample was found at 120° C (Hart, 1959). Drying was conducted at 0.8 m/s air velocity and 55° C and 65° C air temperature; these drying conditions are used mostly for hot-air drying of biological materials (Goyal *et al.*, 2007; Nguyen and Price, 2007). The procedure was followed for each run in three replicates.

2.4 Analytical Method

Subsequently the dried cashew apple slices were milled for the analysis of pH, ascorbic acid, tannin, ash, colour, magnesium, calcium and moisture content were determined according to the AOAC method (Horwitz and Latimer, 2000). Analysis was done on the raw cashew apple to serve as control.

2.5 Organoleptic Properties

Ten panelists where chosen from the university community to assess some organoleptic properties of the dried cashew in a granular form. Questionnaires were given to this panelist for assessing the dried cashew powder. The product was evaluated on quality characteristics of texture, appearance, aroma, taste and general acceptability on a 9-point Hedonic scale rating with 9 as like extremely and 1 as dislike extremely.

2.6 Statistical Analysis

The data gotten from the drying experiment, proximate analysis, mineral content, and questionnaire gotten from the organoleptic properties were analyzed using Microsoft Excel 2010 and IBM SPSS version 19. Using the IBM SPSS and ANOVA (Analysis of Variance) the means were compared and post hoc tests were performed. The post hoc tests used were Duncan and LSD.

3. RESULT AND DISCUSSION

3.1 Effect of slice thickness on the drying characteristics of cashew apple slices.

The graph of the drying rate against moisture content (wet basis) 55^0C is shown on Figure 1a and 1b for 5, 7, and 9 mm, while that of 65^0C is shown on Figure 2a and 2b. On the graphs, the effect of slice thickness at various temperatures are compared. For the 5mm thicknesses, the drying time was shorter resulting in higher drying rate compared to the other thickness of the cashew slices. The drying curves show one phase of drying i.e. the falling rate period, similar result were obtained by Demirel and Turhan (2003) ; Doymaz (2004) . The temperature had a significant effect on the drying characteristics of the slices as the thicknesses increases. For the 7 mm thicknesses, the drying time was a bit longer than that of the 5mm and the drying rate curve was stable than that of 5mm drying rate curve, as the slice thickness reduces the drying rate decreases similar result were obtained by Madamba *et al.* (1996) in the thin layer drying of garlic slices and also by (Ertekin and Yaldiz, 2004). The 9mm thickness has the longest drying time, this is due to the decrease in surface area which provides less contact with the heating air and less surface from which moisture can escape and also increase the distance to which the heat and moisture travels within the matter (Sharma *et al.*, 2005).

Similar results were obtained by Kajuna *et al.* (2001) , the smaller thickness of the cassava roots dried faster with increasing temperature, K Sacilik and Unal (2005) got similar result for garlic slices. The dehydration rate increased with an increase in the air temperature and with a decrease in the sample thickness (Atarés *et al.*, 2009).

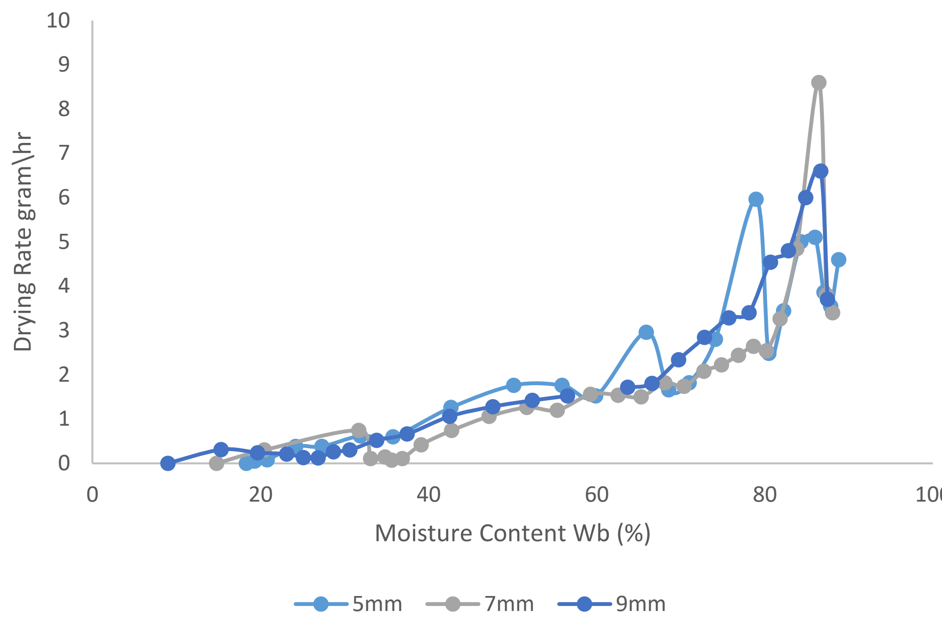

Figure 1: Drying rate curves for cashew apple slices at 55° C

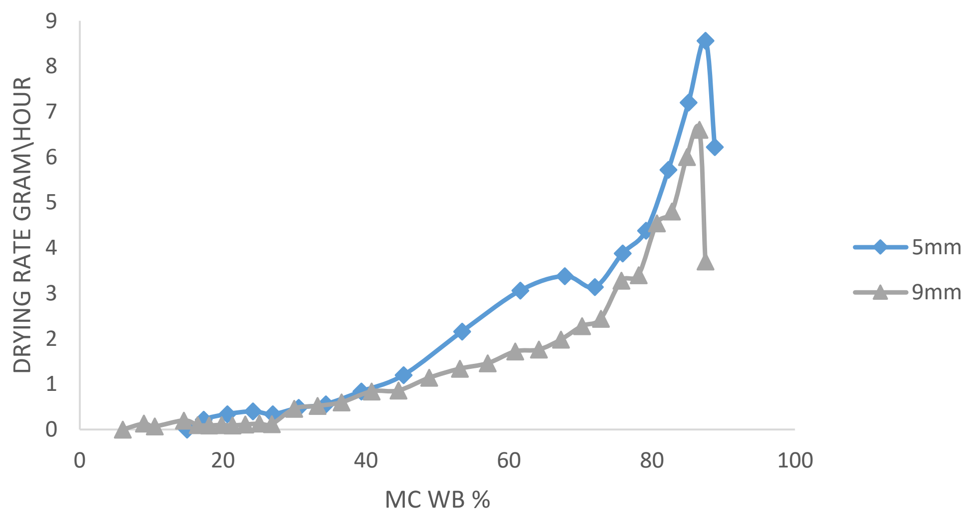

Figure 2: Drying rate curves for cashew apple slices at 65° C

3.2 Effect of Slice Thickness on the Quality of Cashew Apple Slices

From the summary of the data analysis from Table 1 to 3 it was observed that thickness has a little effect on the quality of the cashew apple slices. Of the three thicknesses i.e. 5, 7, and 9 mm, 7mm gave the best quality for both the physio-chemical analysis and organoleptic properties. This is because appropriate heat is dissipated on the 7mm material. For 5mm material, it slimness allows the material to be more expose to heat. Also, for the 9mm material, it chunkiness allows the material to stay much longer under heat, heat is a degrading factor during drying, it breaks down many nutrients of a particular material subjected to drying especially, reducing the quality or value of the material (Kumar *et al.*, 2014). Slice thickness had no significant effect on the colour and pH, similar result was gotten from the drying of eggplant (Ertekin and Yaldiz, 2004). The data showed that Vitamin C was very sensitive to heat damage, the Vitamin C content of dried cashew apple slices was on average 42% lower than that for the fresh ones, similar result was obtained by Khazaei *et al.* (2008) . The loss of Vitamin C was higher at 5mm-55° C and 9mm-65° C, at 7mm-65°C the Vitamin C loss was lower. The Tannin content extremely reduce in all the thicknesses as shown in Table 2. 7mm gave the best colour, best vitamin C content, better pH, better Ash, better in all the mineral content.

Table 1: Analysis of Ash, PH and Colour in fresh and dried cashew apple samples

Thickness	Ash	PH	Colour
5mma	$7.154^{f} \pm 0.001$	3.66^{bc}	$1.333^{b} \pm 0.577$
7mma	$6.267^{e} \pm 0.001$	$3.79^{d} \pm 0.01$	1^{a}
9mma	5.229^{b}	$3.853^{e} \pm 0.012$	$1.333^{b} \pm 0.577$
5mmb	$5.02^{b} \pm 0.001$	$3.647^{b} \pm 0.006$	$1.333^{b} \pm 0.577$
7mmb	$5.666^{d} \pm 0.001$	$3.677^{c} \pm 0.006$	$1.333^{b} \pm 0.577$
9mmb	$5.537^{c} \pm 0.001$	$3.51^{a} \pm 0.01$	2^{c}
Fresh	4.34^{a}	$4.3^{f} \pm 0.1$	1^{a}

Similar letters in the exponential in the same row show there are no significant differences (p-value 0.05) a is 55° C while b is 65° C.

Table 2: Analysis of Tannin and Vitamin C in fresh and dried cashew apple samples

Samples	Tannin	Vitamin C	Mg	Ca
5mma	$0.357^{c} \pm 0.001$	$38.773^{b} \pm 0.577$	0.3^{a}	0.7^{b}
7mma	$0.201^{a} \pm 0.001$	$52.46^{d} \pm 0.01$	$0.533^{e} \pm 0.058$	$1.2^{f} \pm 0.1$

9mma	$0.377^{d} \pm 0.001$	$41.95^{c} \pm 0.01$	0.3^{a}	$0.7^{b} \pm 0.1$
5mmb	$0.304^{b} \pm 0.001$	$69.94^{e} \pm 0.01$	$0.333^{b} \pm 0.058$	$0.667^{a} \pm 0.058$
7mmb	$0.454^{e} \pm 0.001$	$70.44^{f} \pm 0.01$	0.4^{cd}	$0.767^{bc} \pm 0.058$
9mmb	$0.499^{f} \pm 0.001$	$38.46^{a} \pm 0.01$	$0.533^{e} \pm 0.058$	$1.133^{de} \pm 0.058$
Fresh	$261.3^{g} \pm 1.114$	$122.443^{g} \pm 1.027$	$0.63^{f} \pm 0.01$	$42.667^{g} \pm 0.577$

Similar letters in the exponential in the same row show there are no significant differences (p-value 0.05) a is 55° C while b is 65° C.

Table 3: Analysis of the organoleptic properties of fresh and dried cashew apple samples

Thickness	Taste	Texture	Appearance	Aroma	General Acceptability
5mma	$7^{bc}\pm1.16$	$5.5^{b}\pm0.71$	$5.8^{a}\pm0.92$	$5.4^{b}\pm1.27$	$7.1^{c}\pm1.1$
7mma	$6.9^{b}\pm0.88$	$5.3^{a}\pm0.95$	$5.8^{a}\pm0.63$	$5.4^{b}\pm0.84$	$6.9^{b}\pm0.32$
9mma	$6.8^{a}\pm0.79$	$5.7^{c}\pm1.06$	$5.5^{a}\pm1.35$	$5.4^{b}\pm0.97$	$6.4^{a}\pm0.52$
5mmb	$6.8^{bc}\pm0.92$	$5.5^{d}\pm0.53$	$5.5^{cd}\pm0.53$	$5.5^{b}\pm1.27$	$6^{cdef}\pm0.47$
7mmb	$7^{b}\pm0.82$	$5.1^{cd}\pm0.74$	$6^{bcd}\pm0.94$	$5.2^{b}\pm1.4$	$6.1^{cdef}\pm0.32$
9mmb	$7^{b}\pm0.82$	$5.4^{cd}\pm0.52$	$5.8^{bcd}\pm0.63$	$5^{b}\pm1.56$	$5.7^{ef}\pm1.06$

Similar letters in the exponential in the same row show there are no significant differences (p-value6 0.05). a is 55° C while b is 65° C.

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Preliminary Evaluation of the Physical Properties of Two Coffee Varieties

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ABSTRACT

In order to improve coffee production in Nigeria the current drudgery associated with primary processing should be alleviated with a view to achieving indigenous grading standards to meet international requirements. As a necessary first step some physical properties of two coffee varieties were determined. The average length, breadth and thickness for hulled Arabica beans, Robusta parchment and dried Robusta berry were 9.963 ± 1.553 mm, 6.636 ± 1.398 mm, 3.871 ± 1.081 mm; 9.965 ± 0.683 mm, 6.951 ± 0.669 mm, 5.416 ± 0.643 mm; and 11.846 ± 0.820 mm, 10.496 ± 0.743 mm, 7.804 ± 0.455 mm respectively. The respective values of Arithmetic Mean Diameter are 6.823 ± 1.215 mm, 7.444 ± 0.415 mm and 10.049 ± 0.540 mm while the values of Geometric Mean Diameter were 6.307 ± 1.265 mm, 7.190 ± 0.399 mm and 9.892 ± 0.526 mm. The corresponding mean values of the bulk density were 422.667 ± 8.628 Kg/m^3, 597.333 ± 5.963 Kg/m^3, 441.333 ± 5.578 Kg/m^3 while the respective average true density values were 704.968 ± 156.067 Kg/m^3,773.03 ± 187.915 Kg/m^3, 811.921 ± 195.957 Kg/m^3. The values of the static coefficient of friction showed increasing trend on mild steel, plywood, galvanized steel, plain glass, Perspex glass and stainless steel for all the coffee samples investigated. These properties are useful in designing equipment for handling, processing, sorting and sizing.

Keywords: Physical, properties, wet, dry, processing, coffee, Nigeria

1. INTRODUCTION

The coffee plant is a woody perennial evergreen dicotyledon that belongs to the Rubiaceae family. It is more accurately described as a coffee tree because it grows to a relatively large height. Two main species of coffee - *Coffea arabica* and *Coffea canephora* - are widely cultivated among several different cultivars. *Coffea Arabica,* known as Arabica coffee, accounts for 75-80 percent of the world's production while *Coffea canephora*, known as

Robusta coffee, accounts for about 20 percent (Pochet and Flemal, 2001). *Coffea canephora* differs from the Arabica coffee in terms of taste due to the high altitude in which Arabica is grown and partly owing to the higher caffeine content of Robusta. Arabica trees normally produce berries 8 to 15 mm in diameter while robusta produces berries approximately 10 mm in diameter. Post harvest process for the coffee bean is a tedious process. All coffee berries do not mature at the same time and invariably rely on some measure of human selection at harvest. Coffee berries, whether dry or wet processed, require drying and cleaning at some stage because irrespective of the harvesting method, green coffee beans and overripe coffee cherries inevitably are mixed up with the perfectly, ripe cherries and must be separated during coffee processing (Coffee Research Institute, 2006). Overripe coffee cherries, undeveloped coffee cherries, stick and leaves float in water. Ripe coffee beans and green coffee cherries are dense and sink, therefore the first step in coffee production consists of separating the “floaters” from the “sinkers”. Furthermore, for parchment coffee to attract high premium in the international market, it has to meet certain size, shape, appearance and other cup quality parameters. Either wet or dry processed the production of parchment coffee involves fluid – particle interaction at some stages.

In recent times the status of Nigeria as a coffee producing country has suffered setback because of the poor quality coffee traded in Nigeria. To make the situation worse majority of the coffee beans produced in Nigeria are transported to neighbouring West African countries such as Cote D’Ivoire where they undergo further processing and exported to Europe and America. The coffee of Nigerian origin thus exported through the backdoor eventually but erroneously boosts the production figures of other African countries. Nigerian coffee farmers do not get a premium on their coffee beans owing to poor quality due to the unwholesome practices in the post harvest handling and processing of coffee. As mentioned above coffee has to meet stringent physical quality parameters to attract a premium at the international market among other factors. Therefore, the knowledge of the post-harvest physical properties of coffee in its various forms is a useful tool in mitigating the current problems bedeviling coffee production which apart from laying the foundation for indigenous coffee grading standard is a major requirement in the design and fabrication of primary processing equipment. The varietal variability of highland and lowland coffee (Arabica and Robusta coffee respectively), the wet and dry processing techniques required of coffee traded internationally and the associated stringent grading standards justify the study of relevant physical properties. Successful determination of the physical properties would furnish important parameters useful in the design and fabrication of machines for the post-harvest handling and processing of coffee. This would no doubt enhance improved coffee production while the associated drudgery experienced by coffee farmers will be alleviated through the appropriate technologies developed. The objective of the current study therefore is to conduct preliminary investigation on some physical properties of Robusta (*Coffea canephora*) and Arabica coffee (*Coffea arabica*).

2. MATERIALS AND METHODS

2.1 Sample preparation

Robusta cofee (*Coffea canephora)* berries were harvested from the field at the Cocoa Research Institute of Nigeria (CRIN), Ibadan. Fresh ripe berries were handpicked and dried on concrete platform. They were dried until the coffee beans embedded in the berries made cracking sound when pressed between the teeth i. e. moisture content range of 9 – 11% wb. This was done to simulate what obtains on the field where farmers harvest coffee and dry to safe moisture levels for storage. The dried robusta coffee berries were packed and stored in jute bags after drying. The ripe coffee berries were cleaned of twigs, leaves, overripe coffee berries, unripe coffee berries, immature coffee berries and other foreign matter after harvest. Prior to drying the coffee berries samples of the ripe berries were pulped with a manual laboratory pulping machine. The pulped coffee beans were then soaked in water to ferment during which the mucilage was removed. The fermentation was terminated just when abrasion between the beans was perceptible when rubbed between hands. The wet processed coffee was also dried until the coffee in parchment was safe for storage as mentioned above.

Arabica coffee (*Coffea arabica*) samples were obtained from the Cocoa Research Institute of Nigeria (CRIN) substation at the Kusuku-Mambilla, Taraba state. Fresh ripe Arabica coffee was harvested and dry processed as stated above for Robusta coffee. Samples from the dried Arabica berries were taken and hulled to remove the dry pulp, parchment and silver skin to obtain polished Arabica coffee beans. The three materials obtained from the processing of the two coffee varieties were wet processed robusta coffee (**parchment coffee**), dry processed **Robusta coffee berries** and dry processed **hulled Arabica coffee beans** as shown in figures 1, 2 and 3 below.

2.2 Determination of physical properties

To determine the axial dimensions of the coffee samples 100 seeds were picked randomly. The weight of each seed was measured using an electronic balance measuring to 0.001 g. The length (L, mm), breadth (B, mm) and thickness (T, mm) were measured with a digital micrometer screw gauge reading to 0.001mm. From the measurements obtained the geometric mean diameter (D_g), arithmetic mean diameter (D_a), aspect ratio (AR) and sphericity (φ) of the three coffee samples were calculated. The parameters were computed by the following relationships (Mohsenin, 1986; Tarighi *et*. *al*., 2011; Ghamari *et*. *al*., 2014):

$$D_g = (LBT)^{1/3} \quad (1)$$

$$D_a = (a + b + c) / 3 \quad (2)$$

$$\Phi = (LBT)^{1/3} \quad (3)$$

$$AR = B / L \quad (4)$$

Sacilik *et al*. (2003) computed the surface area S, (mm^2) of seeds of the same geometric mean diameter as a sphere, using the following relationship:

$$S = \pi D_g \qquad \text{----------------} \qquad (5)$$

The static coefficient of friction was determined against six structural surfaces viz mild steel, galvanized steel, stainless steel, plywood, perspex glass and plain glass. A hollow metal cylinder 60 mm diameter and 60 mm depth was used. The cylinder was filled to the brim with the sample while placed on the incline. The cylinder was slightly raised in order not to make contact with the platform. The adjustable tilt surface was then gradually raised until the cylinder just began to slide (Yahya *et*. *al*., 2013; Bayram *et*. *al*., 2017). The adjustable surface was then held in place with a screw while the angle of friction was read off the graduated scale. The angle of repose was determined by using a wooden box 150 x 100 x 95 mm. The open box was fitted with a removable front door. The door was quickly opened allowing the coffee samples achieve a natural slope. The angle with the horizontal at which the material stood when piled was calculated. The bulk density was determined by filling an empty beaker of known volume and net weight by pouring the seeds from a constant height. Similar methods of determining the bulk density was reported by Varnamkhasti *et al*. (2008), Wojtowicz *et*. *al*. (2015) and also adopted by Gharibzahedi *et al*. (2010). The modification to the technique was that the filling of the beaker was stopped just as the seeds reached the maximum capacity of the beaker. The ratio of the mass of the seed to the volume of the beaker expressed the bulk density. The true density was determined by weighing individual components of each of the three coffee samples on a sensitive balance. The volume of each components was determined by displacement in toluene. The density was computed by mass-volume ratio (Eze and Oluka, 2014) One thousand seed mass was determined by picking 100 coffee components from each of the samples. The 100 grains were weighed on a digital balance reading to 0.001 g. The resulting mass was multiplied by 10 to obtain the mass for 1000 grains. The experiment was repeated ten times and the average 1000 grain mass was obtained.

3. RESULTS AND DISCUSSION

3.1 Weight

Table 1 shows the mean and standard errors of the weight, axial dimensions and the geometric characteristics of the coffee samples. The difference in the average weight of dried Robusta berry and Robusta parchment is instructive. The mean weight of robusta parchment is about half of the mean weight of dried Robusta berries. This among other factors could positively influence separation when a mixture of dried Robusta parchment and dried Robusta berry is passed through a vertical or horizontal stream of air owing to the marked difference in their expected terminal velocities. When coffee berries are pulped by employing the wet processing technique a few of the berries may escape unpulped. When the pulped coffee berries are dried, the lot would contain dried berries; this constitutes a serious defect and would lead to a reduction in price of the parchment coffee. The difference in weight could also enhance effective separation on gravity separators. The average weight of the hulled Arabica (0.177 ± 0.024 g) beans is much higher than the Robusta parchment's (0.154 ± 0.026 g) despite the removal of the silver skin and parchment, the outer coverings of the Arabica beans. This conforms to the widely accepted fact regarding the morphology of Arabica coffee berries regarded as bigger than lowland cultivated Robusta coffee (Pochet and Flemal, 2001).

3.2 Dimensions of coffee components

The average length (L), breadth (B) and thickness (T) of hulled Arabica beans and robusta parchment are 9.862 ± 1.789 mm, 6.636 ± 1.398 mm, 3.870 ± 1.081 mm; 9.965 ± 0.683 mm, 6.951 ± 0.669 mm and 5.416 ± 0.643 mm respectively. The axial dimensions of the Robusta parchment were similar to the values obtained for Robusta coffee seeds (Olukunle and Akinnuli, 2012). It could be observed that while the length and breadth of Robusta coffee parchment is only slightly higher than those of hulled Arabica beans, thickness of robusta parchement is much higher than that of hulled Arabica beans. This is due to the fact that the void between the parchment and the embedded bean of Robusta coffee is much thus contributing to a larger surface area, S, than that of hulled Arabica beans. The slightly larger geometry of parchment Robusta coffee which contributes to the larger surface area could influence the drag to facilitate separation in an airstream. The somewhat larger geometry of the robusta coffee parchment notwithstanding, it could be observed that weight of hulled Arabica coffee beans is greater which shows that the proportion of the weight of the parchment is much less than the weight of the bean in Robusta coffee, hence the parchment could be easily separated from the coffee beans in a stream of air. By contrast the average weight of the dried Robusta coffee berry is more than twice that of the parchment Robusta coffee. This shows that the pulp, parchment and silver skin constitute a significant proportion of the dried Robusta berries. This is similar to the result of an earlier study of the physical properties of fresh ripe coffee berries (Mofolasayo, 2012).

3.3 Aspect ratio

The mean aspect ratios for hulled Arabica beans, Robusta parchment and dried Robusta berry are 0.723 ± 0.065, 0.699 ± 0.0649 and 0.929 ± 0.409 respectively. The highest correlation between the medium (B) and major dimensions (L) was obtained for dried Robusta berry. This connotes the tendency to roll rather than slide, a characteristic which could be put to effective use while separating foreign materials from dried Robusta parchment. Hulled Arabica beans have a higher aspect ratio than Robusta coffee parchment. This may be due to the fact that individual bean edges had been smoothened owing to abrasion in the machine during hulling operation. Mofolasayo *et al.* (2013) reported similar aspect ratio values for unskinned nut and skinned kola nuts. The arithmetic and geometric mean diameters values computed from the measured axial dimensions showed hulled Arabica beans have the least values for the reasons earlier discussed.

Table 2 shows the range of values of the aforementioned physical properties. The range of values for the axial dimensions as depicted by the size characteristics (i. e. AMD, GMD) show a significant variation of the coffee samples. The coffee samples used in the experiments were randomly picked from ungraded lots which have been rightly reflected in the large variation in sizes. Coffee classification is an important parameter in coffee trade.

3.4 Friction properties

Table 3 shows the angle of repose and the coefficient of static friction on six material surfaces. The coefficient of static friction was determined for all the coffee samples on mild steel, galvanized steel, stainless steel, plywood, Perspex glass and plain glass. There was a similar trend of increment in the values of the static coefficient of friction on the surfaces for all the coffee samples viz: mild steel, plywood, galvanized steel, plain glass, Perspex glass and stainless steel. The values of the friction coefficient were highest on mild steel and lowest on stainless steel. This could be attributed to the fact that despite the different nature of the coffee samples adhesive force of grains of mild steel was strongest while that of stainless steel was the least. The information on the values of friction coefficient are useful in the design of bins and hoppers. The angle of repose of hulled Arabica beans were similar to that obtained for Robusta parchment. The values show the aforementioned coffee samples will easily stand in a pile or heap than dried Robusta berry.

3.5 Density

The bulk and true densities of the coffee samples are shown in table 4. The mean bulk densities of hulled Arabica beans, dried Robusta berries and Robusta parchment are: 441.333 ± 5.578 Kg/m^3, 597.333 ± 5.963 Kg/m^3 and 422.667 ± 8.628 Kg/m^3 respectively. The respective values of the true densities are 811.921 ± 195.957 Kg/m ^{3}, 773.03 ± 187.915 Kg/m^3 and 704.968 ± 156.067 Kg/m ^{3}. A practical importance of the use of bulk density values which is often jettisoned is in material transport. In Nigeria at present, there is no standard for haulage of agricultural materials. The choice of vehicles to transport agricultural materials is usually based on experience which is usually subjective. The available space in vehicles to transport the agricultural materials could be measured in terms of volume. Once the bulk density of the product is known at particular moisture content, the weight of the material to be transported from on farm processing sites could be determined. The weight could then be matched with the design capacity of the vehicle and informed decisions made. This would improve safety on the road by preventing overloading especially on rough rural roads that characterize the vast majority of farming communities in Nigeria. In addition farmers and processors would be able to make better informed decisions as regards the cost to incur on transportation; for instance farmers can pool their coffee products together and hire a vehicle of appropriate capacity to leverage on bulk transportation to achieve reduced cost among other factors.

3.7 Porosity

It was observed that the porosity (45.6 %) of hulled Arabica beans was the highest of the coffee samples studied. The porosity of Robusta coffee parchment was 40% while that of dried Robusta berry was 32.3 %, the least of the values. The higher values of porosity could be attributed to more void space between the beans of hulled Arabica and Robusta coffee parchment which increased the bulk volume (Gharibzahedi *et. al.,* 2010; Igwillo *et. al*., 2017).

4. CONCLUSION

Some physical properties of samples of *Coffea canephora* and *Coffea arabica* were determined. The average weights (W) were 0.177 ± 0.024 g, 0.154 ± 0.026 g and 0.366 ± 0.073 g respectively for hulled arabica beans, robusta parchment and dried robusta berry. The corresponding values for the length (L), breadth (B) and thickness (T) of the three coffee samples are 9.963 ± 1.553 mm, 6.636 ± 1.398 mm and 3.871 ± 1.081 mm; 9.965 ± 0.683 mm, 6.951 ± 0.669 mm and 5.416 ± 0.643 mm; 11.846 ± 0.820 mm, 10.496 ± 0.743 mm, 7.804 ± 0.455 mm. The bulk densities for robusta parchment, dried robusta berry and hulled Arabica beans are 422.667 ± 8.628 Kg/m^3, 597.333 ± 5.963 Kg/m^3 and 441.333 ± 5.578 Kg/m^3 respectively. The corresponding values for true densities are 704.968 ± 156.067 Kg/m^3, 773.03 ± 187.915 Kg/m^3 and 811.921 ± 195.957 Kg/m^3. The static coefficients of friction were determined on six material surfaces. The values of the static coefficient of friction showed increasing trend on mild steel, plywood, galvanized steel, plain glass, perspex glass and stainless steel for all the coffee samples investigated. The angle of repose for hulled Arabica beans and Robusta parchment are similar while the lower value obtained for dried Robusta berries showed it has the least tendency to stand in a pile. Further work on the moisture dependent characteristics of the full complement of both coffee cultivars need to be undertaken.

Figure 1. Robusta parchment

Figure 2. Hulled Arabica beans

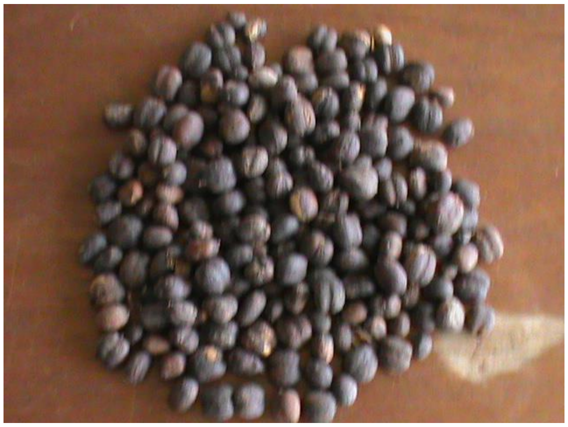

Figure 3. Dried Robusta coffee berries

Table 1. Means and standard errors of dimensions, weight and diameters of coffee samples

	Hulled Arabica beans (Dry processed)	**Robusta parchment (Wet processed)**	**Dried Robusta berry (Dry processed)**
W,g	0.177 ± 0.024	0.154 ± 0.026	0.366 ± 0.073
L, mm	9.963 ± 1.553	9.965 ± 0.683	11.846 ± 0.820
B, mm	6.636 ± 1.398	6.951 ± 0.669	10.496 ± 0.743
T, mm	3.871 ± 1.081	5.416 ± 0.643	7.804 ± 0.455
AR	0.644 ± 0.093	0.699 ± 0.065	0.888 ± 0.692
AMD, mm	6.823 ± 1.215	7.444 ± 0.415	10.049 ± 0.540
GMD, mm	6.307± 1.265	7.190 ± 0.399	9.892 ±0.526
Φ, mm	0.630 ± 0.069	0.723 ± 0.030	0.837 ± 0.035
S, mm^2	19.818 ± 3.974	22.591 ± 1.256	31.081 ± 1.652
$\mathbf{M}_{1000}$, g	159.131± 10.44	135.811± 13.42	299.541±16.90

Table 2. Range of values of dimensions, weight and diameters of coffee samples

	Hulled Arabica beans (Dry processed)	**Rosbuta parchment (Wet processed)**	**Dried Rosbusta berry (Dry processed)**
W,g	0.106 – 0.234	0.106 – 0.208	0.207 – 0.542
L, mm	6.145 – 12.958	7.906 – 11.8	9.613 – 13.539
B, mm	2.686 – 9.247	5.667 – 8.409	8.018 – 12.501
T, mm	1.33 – 5.927	4.034 – 6.984	6.757 – 8.96
AR	0.415 – 0.435	0.542 – 0.858	0.693 – 4.916
AMD, mm	3.853- 8.492	6.161- 8.509	6.739 – 11.169
GMD, mm	2.783- 8.803	6.020- 8.129	5.538- 10.963
Φ, mm	0.418- 2.974	0.659- 0.832	0.751- 0.912
S, mm^2	9.373- 5.402	18.916- 25.542	17.401-34.447
$\mathbf{M}_{1000}$, g	155.8- 168.39	101.87- 153.6	286.72- 308.06

Table 3. Coefficient of static friction and angle of repose of coffee samples

	Hulled Arabica beans (Dry processed)	**Robusta parchment (Wet processed)**	**Dried Robusta berry (Dry processed)**
Coefficient of friction			
Mild steel	0.416	0.443	0.424
Galvanized steel	0.337	0.370	0.329
Stainless steel	0.277	0.272	0.266
Plywood	0.390	0.452	0.402
Perspex glass	0.321	0.313	0.311
Plain glass	0.364	0.333	0.348
Angle of repose, **º**	24.20 ± 0.94	24.202 ± 0.94	19.93 ± 1.27

Table 4. Bulk density, true density and porosity of coffee samples

	Robusta parchment (Wet processed)	Robusta Berry (Dry processed)	Hulled Arabica beans (Dry processed)
Bulk density, Kg/m^3	422.667 ± 8.628	597.333 ± 5.963	441.333 ± 5.578
True density, Kg/m^3	704.968 ± 156.067	773.03 ± 187.915	811.921 ± 195.957
Porosity	40.04	32.28	45.64

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Numerical Analysis of Two Term Model using Newton's Method on Drying Kinetics of an Improved Cowpea *(IT 97K-56S-IS)*

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ABSTRACT

Invention of computers has made numerical methods prevalent and widely accepted. Different numerical methods exist but all aid in solving large numbers of tedious arithmetic calculations involving complex differential equations and so an analytical solution cannot be applicable, hence, computer simulations and numerical solution become functional. IT 97K-56S-IS, a high yielding, multiple disease resistant cowpea variety with maturity date of 60Days was gotten from the International Institute of Tropical Agriculture (IITA). Experiments were carried out on samples after harvesting at maturity in a convective dryer at drying temperature of 55, 65, 75 and 85ºC and drying kinetics was performed utilising the Two term model. The model was numerically solved using Newton Raphson's iterative method on account that it is a non linear equation, its fast convergence to the roots and requirement of a single guess. A well structured algorithm was written. The performance of the models was evaluated using the coefficient of determination (R^2) and root mean square error (RMSE) showing the relationship between the experimental and predicted moisture ratios. The result shows that Newton Raphson's method would be suitable for Two-Term model if used with a multiplication factor or constant.

Keywords: Two term model, Newton Raphson, Numerical solution, Drying kinetics, *IT 97K-56S-IS*, Maturity date, Modelling, Nigeria.

1. INTRODUCTION

Numerical methods are techniques by which mathematical problems are formulated so that they can be solved with arithmetic operations. Although there are many kinds of numerical methods, they have one common characteristic which is that they invariably have large numbers of tedious arithmetic calculations. Hence, with the development of fast, efficient digital computers, the role of numerical methods in engineering problem solving has increased dramatically in recent years (Steven and Raymond, 2010).

The purpose of modelling is to allow engineers to select the most appropriate method of drying for a given product as well as to determine the most suitable conditions (Aremu *et al.*, 2013). The principle of modelling is based on having a set of mathematical equations which can satisfactorily explain the system. Models are often used to study the variables involved in the process, predict drying kinetics of the product and to optimize the operating parameters and conditions (Karathanos and Belessiotis, 1999; Raji and Olanrewaju, 2015). They predict the drying times of several products and also generalize drying curves (Meisami-asl *et al.*, 200; Raji and Olanrewaju, 2015).

A mathematical model can be broadly defined as a formulation or equation that expresses the essential features of a physical system or process in mathematical terms. Differential equations can be used in describing nearly all systems undergoing change (Steven and Raymond, 2010). Thin layer drying process of food products has been described by many mathematical models according to Ojediran and Raji (2010) and these include: cowpea (Jianfang *et al.*, 2013; Raji and Olanrewaju, 2015), green bean and onion (Yaldiz and Ertekin, 2001), millet (Ojediran and Raji), 2010), soybean (Gely and Santalla, 2000), Grains (Tagawa *et al.*, 1996).

High yielding, multiple disease resistant cowpea varieties with varying maturity periods as well as different seed colours, adapted to various Nigerian agro-ecological zones have been developed in IITA, in collaboration with several National Research Institutes and Universities. Several of these varieties have been released in Nigeria and are promoted by the State Agricultural Development Projects (ADPs), farmers' groups and seed companies (Boukar and Ajeigbe, 2010). The most important factor in crop production is the choice of a good variety. Varieties that have resistance to the prevailing biotic and abiotic stresses in the areas should be planted. Maturity, growth pattern, market value, seed size, and seed colour should also be considered in variety selection (DPP, 2011).

The demand for quality farm products increases, therefore, mechanical drying becomes more popular and acceptable as the advantages outweigh the disadvantages. Matured cowpea can thus be harvested promptly and subjected to mechanical drying so as to reduce harvest moisture content to safe level for proper storage (Yakubu *et al.*, 2012). Also, the error present in the solution of models is dependent on how the problem is solved. Numerical methods are used when evaluating empirical information such as experimental data. Such data, no matter how exact and regulated the experiment was conducted, will involve some degree of error. It would be a waste of time to employ exact analytical techniques in such a situation because the answer can never be more "correct" than the input data (Swick, 2013). Therefore, this work investigated the drying kinetics of an improved variety cowpea (IT 97K-56S-IS) at varying drying temperature using the application of numerical method for a complex uncommonly used model (Two term model) thereby developing an efficient algorithm for finding its successive better approximations to the solutions of the complex model.

2. MATERIALS

2.1 Sample preparation

A high yielding cowpea, disease resistant, IT 97K-56S-IS with a maturity date of 60days was gotten from the International Institute of Tropical Agriculture (IITA). It was propagated by seeds during the period of a partially wet season on 5th of May, 2014 at the

Demonstration Area, Research Farms Unit, IITA, Ibadan, also as stated by Raji and Olanrewaju (2015) and Raji and Olanrewaju (2016). This was to ensure that the seeds tested were harvested at the period needed. For each drying experiment, two hundred (200) grams of the freshly harvested sample was used according to Aremu and Akintola (2014); Tunde-Akintunde and Afon (2009); Raji and Olanrewaju (2015); Raji and Olanrewaju (2016). Each experiment was replicated three times (Aremu *et al.*, 2013) and triplicate samples were spread out in thin layer and placed in the dryer. The drying temperature used for the experiment were 55, 65, 75, 85°C which are within the range of temperatures used by Mario *et al.* (2003), Mc Watters *et al.* (1988) and Wilton *et al.* (2008) for drying of cowpea. The drying process was monitored by weighing the samples every 10mins for the first one hour; then every 30mins for the next three hours and every 1hr for the next three hours till the end of drying according to Ojediran and Raji (2010) Raji and Olanrewaju (2015); Raji and Olanrewaju (2016).

Weighing continued until constant weights were obtained being the period that equilibrium with environment was assumed to have been reached and the test was terminated. Moisture content determined at this point is the dynamic equilibrium moisture content. With the initial moisture already known, weight loss was used to calculate the moisture content using the equation used by Ojediran and Raji (2010) given as:

$$M_t = \frac{M_i m_i - w_i}{m_i - w_i} \qquad 2.1$$

where, Mt is the moisture content (m.c.) at time t, (% w.b.), M_i ,the initial m.c. (%w.b.), m_i, the initial weight, (g) and w_i is the weight loss at time, t (g). The moisture ratio (MR) of the samples during the thin layer drying experiments was calculated using Equation 2.2 according to Ojediran and Raji (2010):

$$MR = \frac{M - M_e}{M_o - M_e} \qquad 2.2$$

Matured pods were harvested by hand at period of harvest of 60 Days After Planting (DAP) in line with the recommendation of Directorate Plant Production (DPP, 2011) and to avoid shattering of the pods. Freshly harvested cowpea pods were then cleaned and sorted to remove foreign materials. The initial moisture content of the samples was determined using the drying method. Samples of known weight (200g) were measured with the use of a top loading Scout Pro sensitive weighing scale and were placed in the cabinet tray dryer at 130°C for about 16 – 18 hours as required by ASABE standards (ASABE, 2003) as stated also by Raji and Olanrewaju (2015) and Raji and Olanrewaju (2016).

3. METHOD

3.1 Iterative methods

Iterative methods can be used in solving equations by methods of successive approximations to the roots (variable or parameter that satisfy a single nonlinear equation). Three methods of successive approximations include; Newton-Raphson's formula, Bisection method and an algebraic method. Each successive approximation method relies on a reasonably good first estimate of the value of a root being made. One way of determining this is to sketch a graph of the function, say y=f(x), then determine the approximate values of roots from the points where the graph cuts the x-axis. Another way is by using a functional notation method. This method uses the property that the value of the graph of f(x)=0. It changes sign for values of x just before and just after the value of a root (John, 2003).

3.2 Reasons for the choice of Newton Raphson's method

Newton Raphson method was chosen for numerical solution of the Two Term Model due to the following reasons:

1. It can be used for solving nonlinear equations.
2. It converges fast to the roots, if it converges.
3. It requires only one guess.

3.3 Newton's method

The Newton–Raphson's formula, often referred to as Newton's method, may be stated as follows:

If $r_1$is the approximate value of a real root of the equation $f(x) = 0$, then a closer approximation to the root r_2 is given by:

$$r_2 = r_1 + \frac{f(r_1)}{f'(r_2)} \qquad 3.3.1$$

The advantages of Newton's method over other methods of successive approximations is that it can be used for any type of mathematical equation (i.e. ones containing trigonometric, exponential, logarithmic, hyperbolic and algebraic functions), and it is usually easier to apply than other methods (John, 2003).

3.4 Newton Raphson's Iteration

Let x_0 be a good estimate of r and let r = x_0 + h. Since the true root is r and h = r - x_0, the number, h, measures how far the estimate x_0 is from the truth.

Since h is 'small,' we can use the linear (tangent line) approximation to conclude that

$$0 = f(r) = f(x_o + h)0 \approx f(x_0) + hf'(x^0) \qquad 3.4.1$$

Therefore, unless f' (x_0) is close to 0,

$$h \approx -\frac{f(x_0)}{f'(x_0)} \qquad 3.4.2$$

It follows that,

$$r = x_0 + h \approx x_0 - \frac{f(x_0)}{f'(x_0)} \qquad 3.4.3$$

Then the new improved estimate of r is therefore given by;

$$x_1 = x_0 + \frac{f(x_0)}{f'(x_0)} \qquad 3.4.4$$

The next estimate x_2 is obtained from x_1 in exactly the same way as x_1 was obtained from x_0:

$$x_2 = x_1 + \frac{f(x_1)}{f'(x_1)} \qquad 3.4.5$$

Continuing in this way. If x_n is the current estimate, then the next estimate x_{n+1} is given by:
n+1is given by;

$$x_{n+1} = x_n + \frac{f(x_n)}{f'(x_n)} \qquad 3.4.6$$

3.5 Computer Programming and Algorithm

Computer programs are merely a set of instructions that direct the computer to perform a certain task. A well-structured algorithm is easier to debug and test, resulting in programs that take a shorter time to develop, test, and update. Structured programming is a set of rules that prescribe good style habits for the programmer. It is flexible enough to allow considerable creativity and personal expression. A key idea behind structured programming is that any numerical algorithm can be composed using the three fundamental control structures: sequence, selection, and repetition (Steven and Raymond, 2010). To keep this description generic, pseudocode was employed.

4. RESULTS AND DISCUSSIONS

4.1 Results

The non-linear model of the form (Two Term model):

$$Y = \alpha e^{-k_0 t} + \beta e^{-k_1 t} \qquad 4.1.1$$

Solving the non-linear regression model using Newton Raphson's Method, the parameters can be estimated using the non-linear least square method, the sum of squares is given as:

$$F(x) = \sum (y_i - (\alpha e^{-k_0 t_i} + \beta e^{-k_1 t_i}))^2 \qquad 4.1.2$$

The partial derivatives with respect to the parameters `were found and also their second derivatives.

Recall from equation 3.3.1, the Newton Raphson formula is given as:

$$x^{n+1} = x^n - \frac{f(x^n)}{f^{u}(x^n)}$$

This can be rewritten as:

$$y^{n+1} = y^n - \frac{g(y^n)}{H(y^n)} \quad 4.1.3$$

Therefore,

$$y^{n+1} = \alpha e^{-k_0 t_n} + \beta e^{-k_1 t_n} - \frac{g(y^n)}{H(y^n)} \quad 4.1.4$$

4.2 Discussions

4.2.1 Drying kinetics of an improved variety cowpea (IT 97K-56S-IS)

The initial moisture content and equilibrium moisture content of (IT 97K-56S-IS) at period of harvest of 60DAP and at drying temperatures of 55, 65, 75 and 85°C is presented in Table 4.1 according to (Raji and Olanrewaju, 2015).

The moisture ratio decreased exponentially with time and the time required to reaching equilibrium moisture content decreases with increasing temperature as illustrated in Figure 4.1. This is a general trend reported for other food products e.g. mulberry, tomatoes, sweet pepper and peach slices. (Doymaz, 2004; Doymaz, 2007: Vengaiah and Pandey, 2007; Kingsly et al., 2007, Raji and Olanrewaju, 2015).

4.2.2 Model Fitting

The model constants and the coefficients for the Two term model at period of harvest of 60DAP and at 55, 65, 75 and 85°C is presented in Table 4.2. The model fittings are illustrated as presented in Figure 4.1a-d.

4.2.3 Limitation of Newton Raphson's Method

Often times, the Newton Raphson's method is very efficient but sometimes there are situations when it performs poorly especially in special case of multiple roots. There is tendency of the Newton Raphson technique to oscillate around a local maximum or minimum. Such oscillations may persist, or as a near-zero slope is reached, whereupon the solution is sent far from the area of interest. Obviously, a zero slope [f(x) = 0] is not suitable because it causes division by zero in the Newton-Raphson formula, it implies that the solution shoots off horizontally and never hits the x axis. Therefore, there is no general convergence criterion for Newton-Raphson. Its convergence depends on the nature of the function and on the accuracy of the initial guess. An initial guess sufficiently close to the root may be required (Steven and Raymond, 2010).

5. CONCLUSIONS

To select and apply the most appropriate method for a particular problem, it requires a good understanding of the characteristics of the method and of the problem being solved (Craft, 2010). However, from the results gotten from this research it can be concluded that Newton Raphson's method will be suitable for numerically solving Two-Term model but due to its limitation a multiplying factor (constant) was applied. Other numerical methods may also be applied.

Table 4.1 Initial moisture content and equilibrium moisture content of (IT 97K-56S-IS) at period of harvest of 60DAP and at 55, 65, 75, 85°C

Period of Harvest	Initial M.C. (X100%d.b.)	Equilibrium M.C. (X100%d.b)			
		55°C	65°C	75°C	85°C
60	2.26	0.039	0.028	0.030	0.021

Table 4.2 Drying constants and coefficients of the models for IT 97K-56S-IS at period of harvest of 60DAP

	Multiplication factor	Constants and coefficients	Two term model
55°C	4.1354	a	0.3050
		k	0.6377
		b	-0.0632
		r	0.4128
R^2			0.9423
RMSE			0.0015
65°C	3.3847	a	-0.0716
		k	0.7419
		b	0.3670
		r	0.9754
R^2			0.9053
RMSE			0.0025
75°C	3.5064	a	-0.0684
		k	0.6513
		b	0.3536
		r	0.8861

R^2			0.9839
RMSE			0.0008
85°C	3.4130	a	0.3617
		k	0.7728
		b	-0.0687
		r	0.5356
R^2			0.9946
RMSE			0.0002

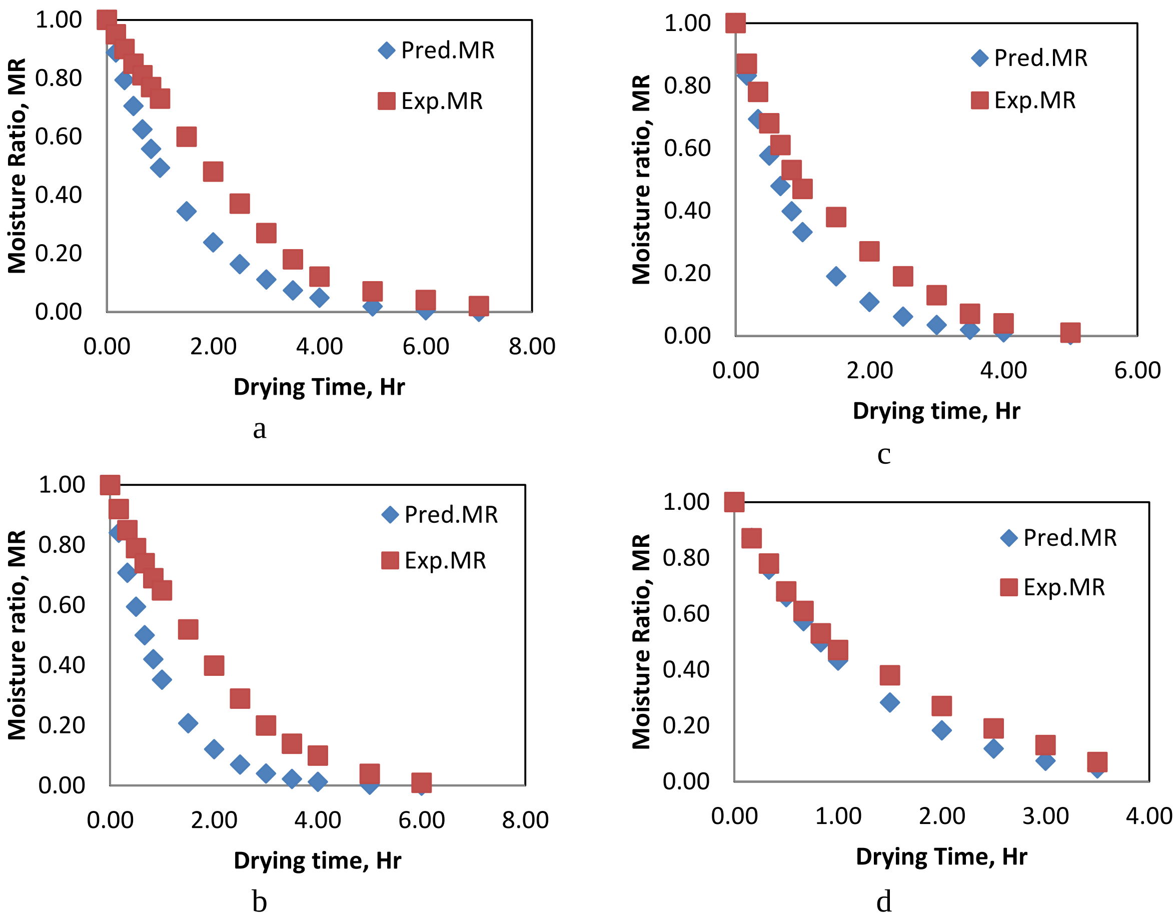

Figure 4.1a: Drying model fittings at period of harvest of 60DAP at 55°C
b: Drying model fittings at period of harvest of 60DAP at 65°C
c: Drying model fittings at period of harvest of 60DAP at 75°C
d: Drying model fittings at period of harvest of 60DAP at 55°C

6. ACKNOWLEDGEMENT

Special thanks to the International Institute of Tropical Agriculture for the privilege given to the authors to carry out this research in their institute.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Effects of Moisture Content and Processing Pretreatments on Strength Properties of *Mucuna Flagellipes* Nut

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ABSTRACT

This study investigated some mechanical properties of *Mucuna flagellipes* nuts under different processing parameters of frying, roasting, parboiling and moisture content levels of 12.3 %, 17.3 %, 23.5 % and 27.2 %: using the Testometric Universal Testing machine (UTM) loaded laterally and longitudinally. The properties studied include The strength properties of the seeds Compressive stress at yield, Compressive load at yield, Maximum Compressive stress, Energy at Maximum Compressive stress, Energy at Compressive load at Maximum Compressive stress, Compressive extension at Maximum Compressive stress, Compressive stress at Break, Compressive load at Break, Compressive extension at Break, and Energy at Break. Results showed all the above mechanical properties varying in an inconsistent way as it relates with increase in moisture content. The behaviour of the nut strength properties with moisture content was not consistent as sometimes it increased with moisture content and then other times it decreased with moisture content, still other times, both happened. The results of the mechanical properties of lateral loading were higher than the values obtained for longitudinal loading which showed that more energy is needed to break the cell structure of seeds at longitudinal position than those at lateral as sometimes the curves indicate linearity and no linearity relationships between moisture and the strength properties at the pretreatment levels.

Keywords: Mucuna flagellipes nut, moisture content, strength properties, pretreatment, loading orientations.

1. INTRODUCTION

Mucuna is an unconventional plant species having promising nutritional, pharmaceutical and cosmaceutical bioactive constituents. The demand for *Mucuna* is increasing day by day due to its pharmaceutical potency. Approximately 120 species have been reported from worldwide and 15 species from India. Most of the species had been studied for its nutraceuticals potential and few reported for its pharmaceutical values. *Mucuna pruriens* had been evaluated and concluded as a potential medicinal herb in terms of anti cholestrolemic, antiparkinson, antidiabetic, aphrodisiac and antimicrobial. It is found mainly in the Tropical Rainforest of Nigeria and was noted to be grown as an important food crop in other parts of Africa and Asia (Dako and Hill, 1977; Iyayi and Egharevba, 1998). The nut contains a kernel with approximately 20% protein and 70% carbohydrate and an oil content of 3.77 % (Ajayi *et al*., 2006). The kernel therefore serves as a very good source of protein and edible oil. Gum extracted from *Mucuna flagellipes* kernel was shown to possess high emulsion properties and pseudoplasticity (Onweluzo *et al*., 2004), which suggests its suitability as a stabilizer and emulsifier in oil-water emulsions like mayonnaise and salad dressings as well as in meat emulsions and as thickening agent in foods (Nwokocha and Williams, 2009). As a result, the flour of *Mucuna flagellipes* kernel is usually applied as a thickening agent in soups (Anumnu 1990; Ene-Obong and Carnovale, 1992).

Fig. 1 *Mucuna flagelipes* nuts

The species of *mucuna flagellipes* is commonly known as 'okobo' in Igbo land, Eastern part of Nigeria. It is a very strong forest climber, having a long stalk of about 10 cm and hanging downwards. It is reported to contain useful phytochemicals of high medicinal values of human and veterinary importance and also constitute as an importance raw material in Ayurvedic and folk medicines. Roots of *mucuna* are used to relieve constipation nephophathy, strangury, dysmenorrrhoea, ulcer, dropsy, general debility. The seed of *Mucuna flagellipes* constitute as a good source of several alkaloids, antitumor and antibacterial compounds. The kernel serves as a very good source of protein and edible oil (Aviara *et al*., 2013).

The processing of *Mucuna flagellipes* nut involves cracking using a hard object to extract the kernel. This is then boiled in water, ground and mixed with palm oil to form a yellow loose powder which is packaged in transparent polyethylene bags for marketing or use as thickening agent in soup. The present methods of carrying out the above operations are not only labour and time consuming but also wasteful. A proper understanding of the mechanical properties of *Mucuna flagellipes* nut is necessary in the design and development of its postharvest processing machines and equipment. Several investigators (Anazodo 1982; Anazodo and Chikwendu, 1983; Dinrifo and Faborode 1993; Abbott and Massie, 1995; Cenkowski *et al*., 1995; Abbott and Lu, 1996; King, 1996; Maw *et al*., 1996; Khazaei and Mann, 2004; Mamman *et al*,. 2005;

Rybinski *et al.*, 2009; Aviara and Ajikashile 2011; Manuwa and Muhammad, 2011) studied the mechanical properties of different agricultural and food materials. (Anazodo and Norris, 1981) noted that the modulus of elasticity, crushing strength and modulus of toughness of corncob decreased with increase in moisture content. Misra and Young (1981) showed that the modulus of elasticity of soya bean decreased parabolically with increase in moisture content. Hence, this research work aims at investigating the effects of moisture content and processing pretreatments on strength properties of *mucuna flagellipes* nut.

2. MATERIAL AND METHODS

2.1 Collection and Preparation of Sample

For the purpose of this work, a bulk quantity of *Mucuna flagellipes* nut was purchased from Bodija Market, Ibadan, Oyo State, Nigeria. The nuts were cleaned and graded by hand picking to separate the good from the damaged ones. The separated nuts were preserved at the initial moisture condition by putting them in air tight polythene bags and stored in that condition for about 24 hrs. This was to enable stable and uniform moisture content of the samples to be achieved.

2.2 Experimental Procedure

The bulk nut was divided into 4 batches and three batches were conditioned by soaking in water for 3, 6 and 9 hours, the first batch was not conditioned as the market stable storage moisture content seed. After conditioning, the seeds were dried under the roof in a closed room without ventilation for some hours and then the seeds were poured into labeled polythene bags according to their moisture contents, sealed and stored in several layers of air tight polythene bags to prevent moisture loss and then they were processed after 24 hours. Three processing pre-treatments such as roasting, frying and parboiling were carried out on 4 nuts of *Mucuna flagellipes* for 5, 10, 15 and 20 minutes on each pre-treatment processing. The nuts was divided into two 2 nuts and loaded in different loading orientation, i.e. longitudinal and lateral on Universal Testing Machine (UTM) to determine the nut strength properties and draw deformation curve.

2.2.1 Determination of Moisture Contents of the Seed Samples

To determine the amount of moisture available in the different batches of the seeds, the samples were weighed using an electric precision weighing balance and placed in an oven set at 105^{o}C with weight loss monitored on for 6 hours until values of mass was obtained for each sample. The moisture content was then calculated from the relation used by Aviara *et al*., 1999.

$$M_{wb} = \frac{W_i - W_f}{W_i} \quad \text{...} \quad (1)$$

M_{wb} = moisture content at wet basis.

W_i =initial weight (g)

W_f = final weight (g)

It was converted to dry basis moisture content by using the relation:

$$M_{db} = \frac{M_{wb}}{1 - M_{wb}} \times 100 \quad \text{..} \quad (2)$$

Where M_{db} = moisture content at dry basis.

M_{wb} =moisture content at wet basis.

Processing parameters are operations carried out in the process of dehulling the nut; it involves conditioning the nut to various aspects. Conditioning the nut simplifies the process of dehulling. For the experiment to obtain good result, the nuts were subjected to three different pretreatments which include frying, roasting and parboiling.

2.2.2 Frying
A portion of the prepared seed samples in each of the four batches ranging from the batch at market storage moisture content to the second moisture content, third and fourth were fried in clean sand in a pan on fire for 5, 10, 15 and 20 minutes respectively. The seeds were then packaged in labeled polythene bags for each of the batches and stored in several layers of air tight polythene bags to prevent moisture loss.

2.2.3 Roasting
Portions of each prepared or conditioned nut samples for each of the four batches were also gotten from the stored conditioned samples. 4 samples for each batch or moisture content were roasted in open air in a pan on fire, for each moisture content; four samples were roasted for 5, 10, 15 and 20 minutes respectively. The nuts were then packaged carefully in well labeled polythene bags and stored in several layers of airtight polythene bags to prevent moisture loss.

2.2.4 Parboiling
This process involves treating water to boiling point and then immersing the nuts into the boiled water. 16 samples were placed at boiling point, for each of the moisture contents and 4 nuts were removed after 5, 10, 15 and 20 minutes in each case. The nuts were allowed to cool to room temperature and then they were packaged in labeled polythene bags and stored in several layers of airtight polythene bags to prevent moisture loss.

2.3 Evaluation of the Compressive Strength of Mucuna flagellipes Nuts
The test was carried out in the Centre for Energy Research Development, Obafemi Awolowo University Ile Ife, using the Universal Testing Machine (UTM) in Figure 2 which is controlled by a micro-computer. Compression tests were conducted on nuts at different moisture levels using the Universal Testing Machine (UTM). Two loading orientations namely longitudinal and lateral were used. The nuts were compressed at the cross head speed of 20 mm/min. As the compression began and progressed, a loaded formation curve was plotted automatically in relation to the response of each nut to compression. This was replicated two times. The results, statistical data and deformation curves obtained at each loading orientation and moisture levels were analyzed for: Compressive stress at yield; Compressive load at yield; Maximum Compressive stress; Energy at Maximum Compressive stress; Energy at Compressive load at Maximum Compressive stress; Compressive extension at Maximum Compressive stress; Compressive stress at Break; Compressive load at Break; Compressive extension at Break and Energy at Break.

(a)

(b)

Fig. 2: Universal Testing Machine: (a) longitudinal loading of the *Mucuna flagellipes* nut (b) lateral loading of the *Mucuna flagellipes* nut

3. RESULTS AND DISCUSSION

3.1 Moisture Content

The average moisture content of the four samples MC_1, MC_2, MC_3 and MC_4 were found to be 12.3%, 17.3%, 23.5% and 27.2% respectively. Sample MC_1 with moisture content level of 12.3% was the market moisture content.

3.2 Processing Variables

Figure 3 presents the regression equations for the plots of force deformation curves of strength properties against moisture contents. The mechanical properties of *Mucuna flagellipes* nuts to moisture content levels were related. The equations used are polynomials of second-order. In many cases, equations have very high coefficients of determination (R^2> values are different i.e 0.9 to 1), which indicates that the plots describe the data points reasonably. The equations are of the form:

$$Y = ax^2 + bx + c \text{ ……………… (3)}$$

Where Y= mechanical property; a, b, c = regression coefficients, and x = moisture content, (% d b)

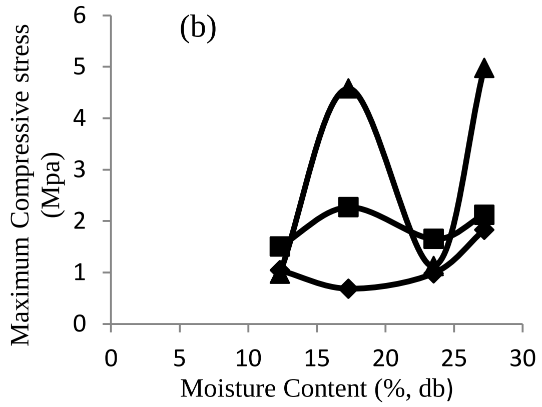
3.3 MECHANICAL PROPERTIES OF *MUCUNA FLAGELLIPES* NUT

3.3.1 Maximum Compressive stress

The variation of the maximum compressive stress of Mucuna flangellipes nuts with moisture content when subjected to different pretreatments under compression at lateral and longitudinal loading orientation is represented in Figures 3(a) and 3(b) below. The highest (4.9754 Mpa) and lowest (0.6850 Mpa) maximum compressive stress were obtained in roasting at moisture content of 27.2 % and frying at moisture content of 17.3 % respectively under lateral loading orientation while the highest (2.1416 Mpa) and lowest (0.2998 Mpa) maximum compressive stress were obtained in roasting at moisture content of 12.3% and frying at moisture content of 17.3% respectively under longitudinal loading. This implies that frying at lower moisture content gives lower maximum compressive stress which reduces the energy required to crack mucuna flagelipes nut when loaded longitudinally.

3.3.2 Energy at Maximum compressive Stress

Figure 4a and 4b show the effects of moisture contents and pretreatment on Energy at maximum compressive stress of *Mucuna flagellipes* nut under lateral and longitudinal loading respectively. It can be observed from the Figures that there is no linear relationship between the energy at maximum compressive stress and moisture content and pretreatment considered but has effect on longitudinal loading orientation. This means that the change in the mean of energy can be attributed to pretreatment under longitudinal loading orientation but none of the factors is attributed to change in mean of energy at maximum compressive stress under lateral.



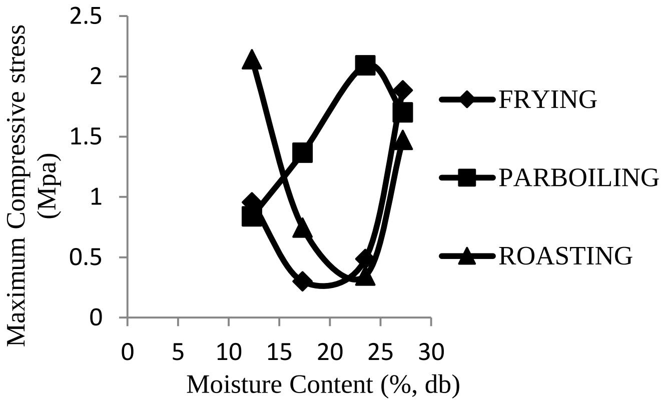
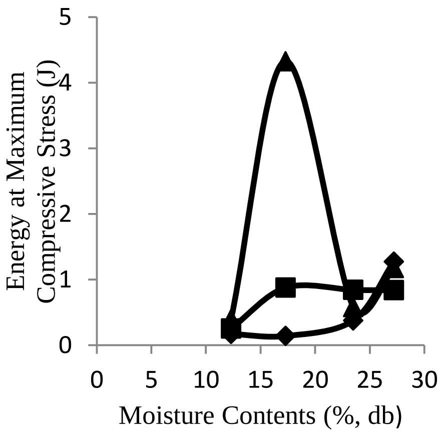


Fig. 3: Effects of Moisture contents and frying on Maximum Compressive stress of *Mucuna flagellipes* nut: (a) lateral loading, (b) longitudinal loading

(a)



(b)

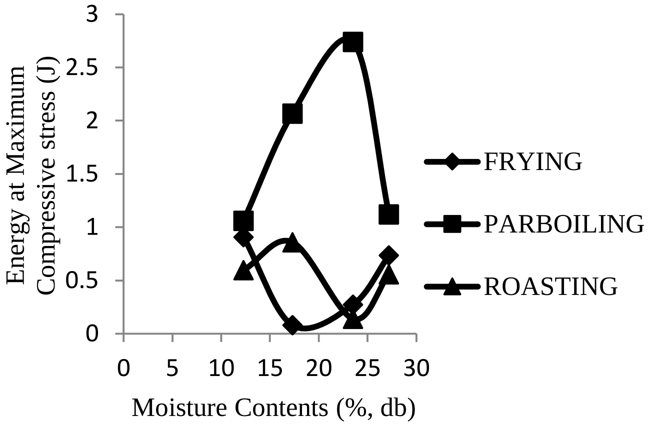
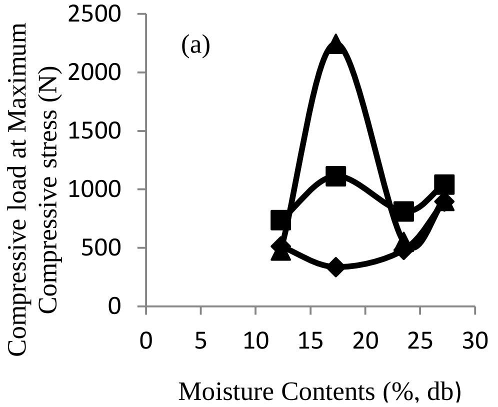


Fig. 4: Effects of Moisture contents and Pretreatment on Energy at Maximum Compressive stress of *Mucuna flagellipes* nut under: (a) lateral loading, (b) longitudinal loading

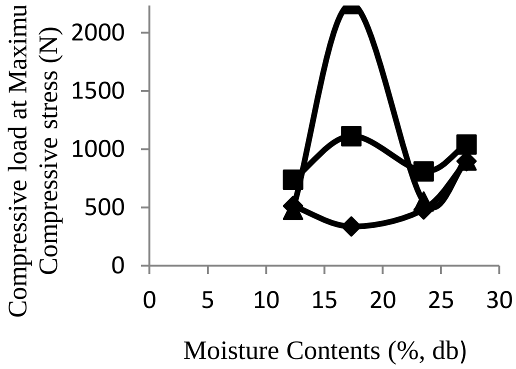
3.3.3 Compressive load at Maximum Compressive stress

Figures 5(a) and 5(b) above show the effects of Moisture contents and pretreatment on Compressive load at Maximum Compressive stress of *Mucuna flagellipes* nut on lateral loading and longitudinal loading orientation respectively. It can be seen from figure 5a at frying treatment under lateral loading that moisture content and pretreatment are not significant for compressive load at maximum compressive stress but interaction of moisture and pretreatment is significant under longitudinal loading orientation.



(b)

Fig. 5: Effects of Moisture contents and frying on Compressive load at Maximum Compressive stress of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading



3.3.4 Compressive Extension at Maximum Compressive stress

Figures 6a and 6b show the graphical representation of Moisture contents and pretreatment on Compressive extension at Maximum Compressive stress of *Mucuna flagellipes* nut under lateral and longitudinal loading orientation respectively.

(a) (b)

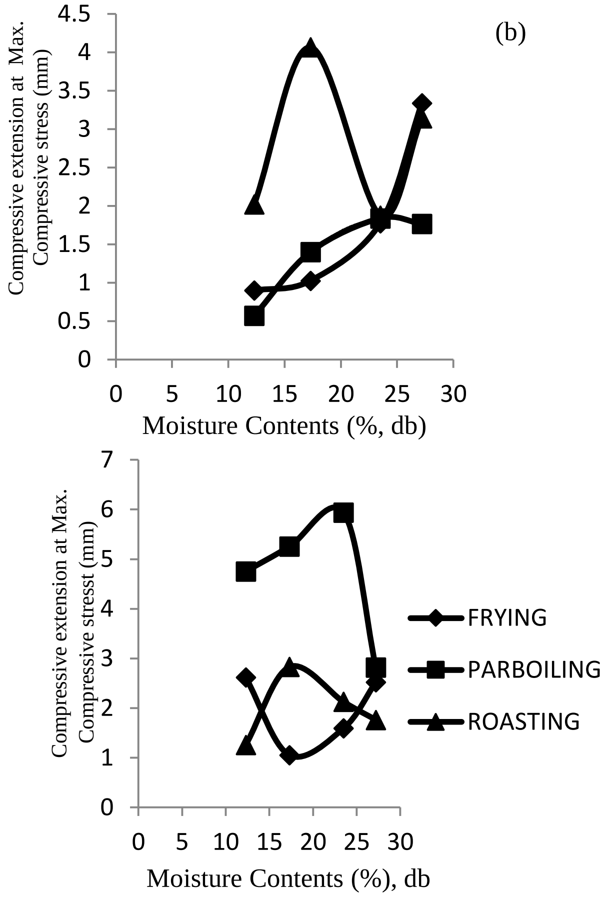
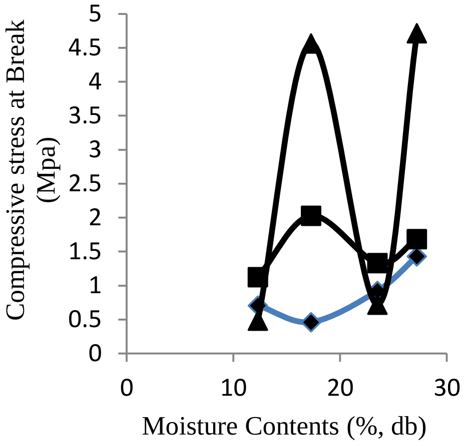


Fig. 6: Effects of moisture contents and pretreatment on compressive extension at maximum compressive stress of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading

3.3.5 Compressive stress at Break

Figures 7a and 7b show the curves of Compressive stress at Break with moisture content at different pretreatment of *Mucuna flagellipes* nut under lateral and longitudinal loading orientation respectively.

(a)



(b)

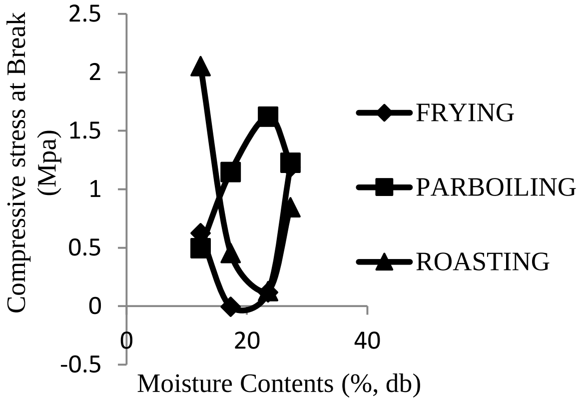


Fig. 7: Effects of Moisture contents and frying on compressive stress at break of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading

3.3.6 Compressive load at Break

Figures 8a and 8b show the moisture and compressive load at break curve of different pretreatment of *Mucuna flagellipes* under lateral and longitudinal loading orientation respectively.

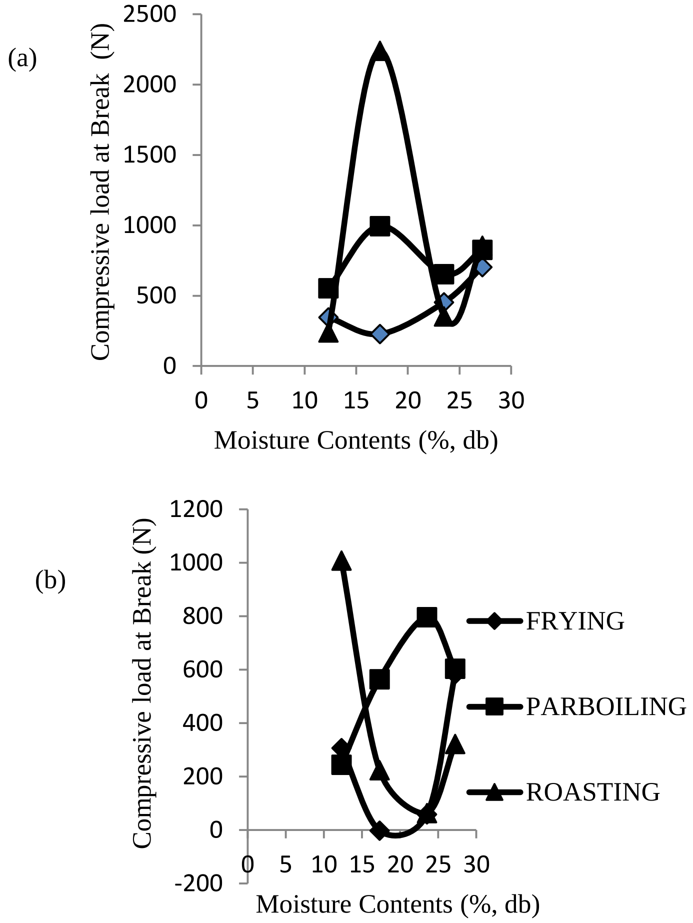


Fig. 8: Effects of Moisture contents and frying on compressive load at break of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading

3.3.7 Compressive Extension at Break

Figures 9a and 9b show the moisture and compressive extension at break curve of different pretreatment of *Mucuna flagellipes* under lateral and longitudinal loading orientation respectively. The curves indicate no linearity relationship between moisture and Compressive extension at Break at the pretreatment levels.

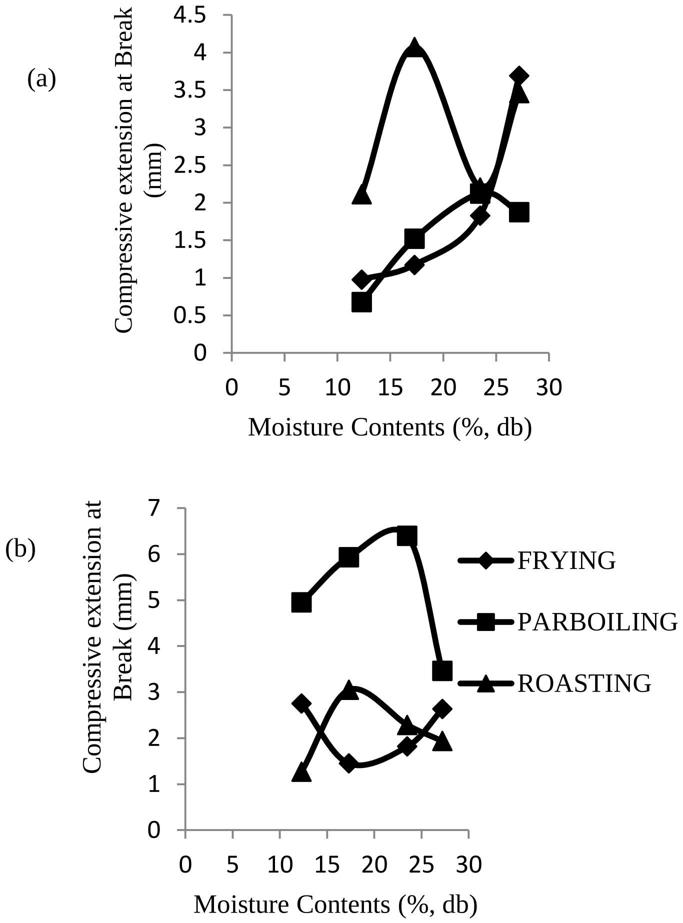
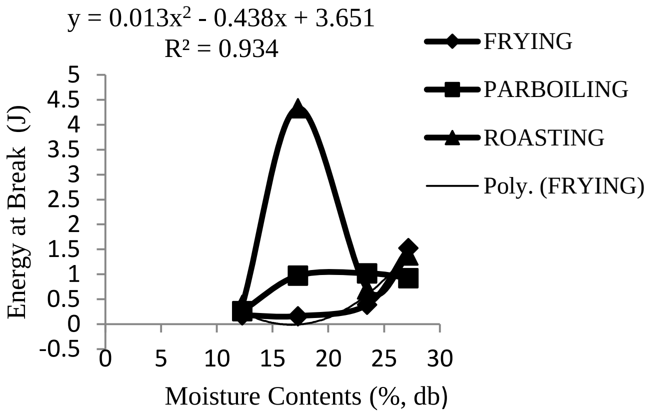


Fig. 9: Effects of Moisture contents and frying on compressive extension at break of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading

3.3.8 Energy at Break

Figures 10a and 10b show the moisture and energy at break curve of different pretreatment of *Mucuna flagellipes* nut under lateral and longitudinal loading orientation respectively. The curves indicate no linearity relationship between moisture and energy at break at the pretreatment levels.

(a)



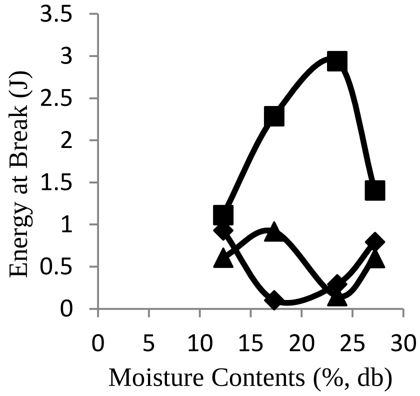


Fig. 10: Effects of Moisture contents and pretreatment on energy at break of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading

3.3.9 Compressive stress at yield

Figures 11a and 11b show the moisture and compressive stress at yield curve of different pretreatment of *Mucuna flagellipes* under lateral and longitudinal loading orientation respectively. The curves indicate no linearity relationship between moisture and compressive stress at yield at the pretreatment levels.

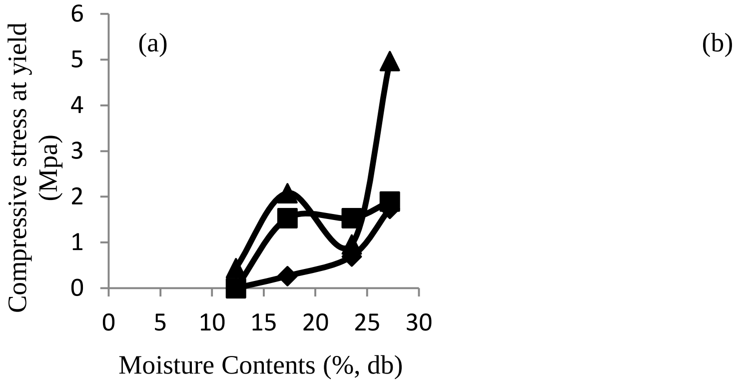
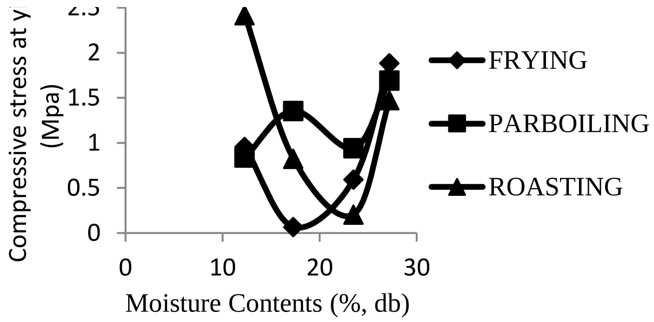


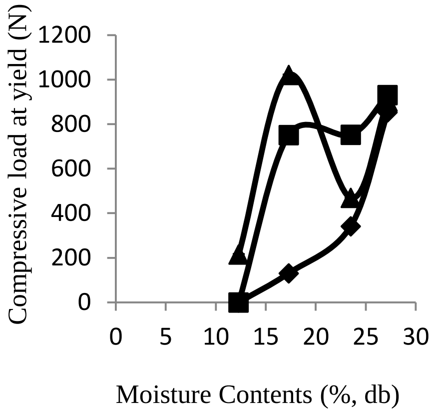
Fig. 11: Effects of moisture contents and pretreatment on compressive stress at yield of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading



3.3.10 Compressive load at yield

Figures 12a and 12b show the moisture and compressive load at yield curve of different pretreatment of *Mucuna flagellipes* under Lateral and Longitudinal loading orientation respectively. The curves indicate no linearity relationship between moisture and Compressive load at yield at the pretreatment levels.

(a)



(b)

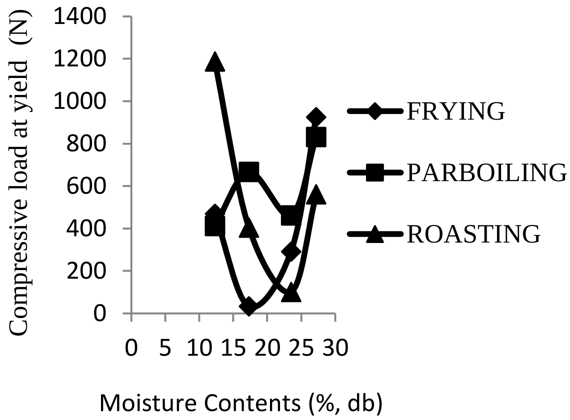


Fig. 12: Effects of moisture contents and pretreatment on compressive load at yield of *Mucuna flagellipes* nut: (a) lateral loading (b) longitudinal loading

4. CONCLUSIONS

The behaviour of the seeds strength properties with moisture content was not consistent as sometimes it increases with moisture content and then other times it decreases with moisture content, yet other times, both happened. \The strength properties of *Mucuna flagellipes* nut against moisture content and its variation with pretreatment time compressed on lateral axis and longitudinal axis varied as sometimes the curves indicated linearity and no linearity relationships between moisture and the strength properties at the pretreatment levels. Also, the Analysis of variance of strength properties of *Mucuna flagellipes* nut against moisture content and its variation with pretreatment on lateral axis and longitudinal axis show that the moisture contents and pretreatment and interaction have no significant effect at 5% confidence level at lateral loading but only pretreatment has significant effect at 5% confidence level at longitudinal loading orientation and vice versa.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Assessment of workers Level of Exposure to Work-Related Musculoskeletal Discomfort in Dewatered Cassava Mash Sieving Process

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ABSTRACT

This work was undertaken to assess the level of exposure of processors to work-related musculoskeletal disorder when using the locally developed sieve in the sieving process. Quick ergonomic checklist (QEC) was used in this assessment and data was obtained from a sample of one hundred and eight (108) processors randomly selected from three senatorial districts of Rivers state, 36 from each zone comprising of 14 males and 22 females. The result shows that the sieving posture processors adopt and the sieve aperture currently used in traditional sieving process, exposes them not only to the discomfort of pain but also put them at high risk of musculoskeletal disorder at a level of 66% QEC rating. The result indicates a need for immediate attention and a change to an improved method.

Keywords: exposure, traditional sieve, musculoskeletal disorder, Quick ergonomic checklist

1. INTRODUCTION

Dewatered cassava mash (DCM) sieving process using traditional method, is considered to be labour intensive and hence consumes time and energy (Agbetoye and Oyedele , 2007; Adetunji, et al., 2013, Abubakar et al., 2014, Ahiakwo et al., 2015, Abiodun et al., 2016). It takes two hours thirty minutes to sieve 60kg of dewatered cassava mash on a traditional sieve of dimension 600 x 700mm with 2.87mm average sieve aperture. On the average commercial cassava processors using traditional sieve spends 5 hours daily in sieving operation (Ahiakwo, 2018).
Also, the cardiovascular response of the processors to the rigours of the sieving process is not static. Research has shown that processors utilizing the traditional sieving process give up energy at the rate of 3.17 – 3.52KJ/min (Asiru et al.,2010; Ahiakwo, 2018). This energy depletion over time together with the awkward posture incidental to this sieving process gives rise to work-related discomfort that may cause a disorder in the processor’s musculoskeletal system.

There are limited literatures on the level to which processors are exposed to when using the traditional sieving process. However, there are methods that are designed to assess the exposure of workers to occupational discomfort. These methods includes use of ergonomic questionnaire and postural evaluation method using: Quick Ergonomic Checklist (QEC), Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Ovako Working Posture Assessment System (OWPAS), (Alan 2005, Joanne, 2007;Sandiq 2014, and Mohsen *et al*., 2015). Among these methods of exposure assessments, the quick ergonomic checklist (QEC) offers an advantage of quickly assessing the exposure of workers to the risks of work-related musculoskeletal discomfort (WMSDs) (Anas *et al.,* 2012). This is because it gives an evaluation of a workplace and of equipment design, which facilitates redesign and helps to prevent many kinds of WMSDs from developing and educates users about WMSD risks in their workplaces (Samuel *et al*., 2016; Neville, 2005).

Also, assessment of workers exposed to work-related musculoskeletal disorder (WMSD) has been done in other fields where energy, time consumption and awkward posture are involved, as it is in the traditional sieving process. Simonson and Rwamamara (2009), examined ergonomic exposures from the use of conventional and self-compacting concrete; Oladele (2012) carried out study on discomfort levels in four working postures used during Gari frying, Anas et al., 2012, carried out ergonomic study of WMSD among the workers working in typical Indian saw mills, Ismail and Darshak,(2016) carried out anthropometric measurement for design of students' furniture in India, Samuel et al., (2016) carried out anthropometric studies for designing to fit gari-frying workers. These studies revealed the need to give attention to the levels to which workers are exposed to WMSD and make early adjustment where necessary for safety.
Considering that the traditional sieving process is labour intensive and consumes energy, it will implies that processors' using this method of sieving are exposed to work–related discomfort. But, to what extent or level of work-related musculoskeletal disorder (WMSD) are processors' using the traditional sieving process exposed? It is important to determine this level of exposure to the risk factor, to enable a quick action to be taken on redesigning and educating processors' to change to a safer method of accomplishing this sieving task. Redesigning besides reducing and where possible eliminating the risk factors will enhance high productivity in this unit operation. It is therefore the objective of this research, to assess the level of exposure of processors to work-related musculoskeletal disorder when using the locally developed sieve in the sieving process using Quick ergonomic checklist (QEC).

2. METHODOLOGY

A quick ergonomic checklist was carried out to assess if processors using a locally developed sieve as constructed by the local craftsmen were exposed to WMSD as a result of the posture adopted during sieving process and the level of exposure. To do this, a sample of one hundred and eight subjects (108) randomly selected from three senatorial districts of Rivers state, 36 from each zone 14 males and 22 females were used.

2.1 Assessment procedure

Before the assessment, the procedure was explained to each of the subjects involved. They got the following material ready: the dewatered cassava mash (DCM), locally made sieve, receptacle and wooden chair. Three observers were trained to cover the three respective zones and were provided with a weighing scale and a video camera. The weighing scale was for taking the maximum weight of DCM sieved in a single task while the video camera was used to record the posture and activities [sieving process]. The observers carried out assessment on the basis of back posture, back movement, shoulder/arm position, wrist/hand deviation from neutral position, motion pattern and head/neck posture as shown in figure 1. The processors were assessed on the basis of maximum weight handled, average time on task, maximum force level exerted by one hand, visual demand, difficulty in keeping with the work and level of stress.

Figure 1: A processor performing sieving task in the traditional posture

In each of the cases, the observers' assessment and the processors' assessment were tabulated.

2.2 Data analysis

The resulting scores were presented in table of exposure score and analyzed based on ergonomic exposure formula expressed by Neville, (2005) :

$$E_i = \frac{x}{x_{max}} \times 100\%$$

Where x = actual total exposure score

X_{max} = maximum possible total exposure ($X_{max\ MH}$ = 176% for manual handling,)

3. RESULT AND DISCUSSION

3.1 Observers' assessment

Table1 shows the measured back posture deviation from the normal position of 66 women processors who were observed performing sieving task using the locally developed sieve. The average back posture deviation for the three zones is 37^0.

Table 1: Observers average assessment processors for the three zones

	Male Processor in zone				Female Processor in zone			
Parts assessed	A	B	C	Grand mean	A	B	C	Grand mean
Back Posture (θ)	35^0	37.9^0	27.9^0	34^0	45^0	38^0	28^0	37^0
Back movement (no of times)	3.2	4	3.4	3.5	3.95	4.18	3.5	3.88
shoulder arm task position (mm)	42	46	41	43	37	41.2	41.5	40
Seating height (mm)	44	46	40.4	43	41	41.3	40.4	41
Wrist hand deviation (θ)	21.6	26	17.4	21	22	23	21	22^0
motion pattern per minute	62	57	61.8	60	62	57	61.8	60

The back movement of the processors as they carry out the sieving task is 4 times. The positions of the arm and the seating height while performing the sieving task are 40 mm and 41mm respectively. This indicates that the task was performed at about waist height. The average wrist hand deviation from normal was 22^0 and average movement of arm back and forth in a minute was 61 times. Table 1 show also the measured back deviation from the normal position of men processors who were observed performing the sieving task using the locally developed sieve. The average deviation considering the three zones was 34^0. The back movement of the processors' as they carry out the sieving task is 3 to 4 times. The positions of the arm and the seating height while performing the sieving task are 43 and 43 respectively. This indicates that the task was performed at about waist height. The wrist hand deviation from normal is 21^0 and the number of times the arm was moved back and forth in a minute was 60 times.

3.2 Processors assessment

Table 2 shows the result of assessment of 66 female processors carrying out sieving task with the locally developed sieve. The average maximum weight handled was 2.1kg, the average time spent per day on this task was 5 hours and the maximum force exerted was 1.5N.

Table 2: Processors' average assessment

	Male processors in zone				Female Processor in zone			
Parts assessed	A	B	C	Grand mean	A	B	C	Grand mean
Max. weight handled(kg)	2.3	2.3	2.2	2.2	1.8	2.2	2.2	2.1
Average time spent per day (hr.)	4.5	5.1	5.1	4.9	4.6	5	5.4	5
Max force exerted (N)	1.9	1.3	1.6	1.6	1.5	1.4	1.6	1.5

Table 2 also shows the result of assessment of 42 male processors carrying out sieving task with the locally developed sieve. The average maximum weight handled, the average time spent per day on this task and the maximum force exerted is 2.3kg, 4.9 hours, and 1.6N, respectively. The inferences drawn from observers' assessment and processors' assessment presented in tables 1 and 2 are expressed in tables 3 and 4.

3.2.1 Inferences on observers' assessment

Table 3, shows the inferences from table 1 with respect to QEC for observers assessment.

Table 3: Inferences on observers' assessment and QEC rating

Parts assessed	Observation	Inference	Rating
Back	1) Back at $37^0 > 20^0$	Back is moderately bent	A2
	2) the back movements was around 3 times per minutes	Back movements is infrequent	B3
	3) Task height ≈ seating height (40mm ≈ 41mm)	Task is performed at or below waist height	C1
	4) Shoulder-arm moved about 61 times per minute	Shoulder arm movement is repeated frequently	D2
Wrist/hand	1) Wrist is at $22^o > 15$	Task is perform with bent wrist	E2
	2) Task is repeated 61 times per minute	Task is performed with similar repeated motion more than 20 times per minute	F3
Head/neck	$20^0 >$ head/neck $< 60^0$	Head and neck is bent Continuously	G3

From the observers' assessment, processors' back deviation is > 20. The inference of this from QEC is that the back is moderately bent and the recommended rating is A2. Back movement is around 3 times, the inference is that the back movement is infrequent and the rating is B3. The task is performed at a height approximate to the seating height. This means from QEC that the task is performed at waist height and the rating is C1. The shoulder arm movement is about 61 times per minute and the inference from QEC is that shoulder arm movement is repeated frequently and the rating is D2. Because the wrist deviation is > 15 the task is performed with a bent wrist. The sieving task is performed with similar repeated motion > 20 times per minutes, the rating is F3. The head and neck are considered to be bent continuously at $20^0 >$ head/neck $< 60^0$ and is rated G3.

3.2.2 Inference on processors assessment

Table 4, shows the inference from table 2 with respect to QEC for workers assessment.

Table 4: Inference on workers assessment and QEC rating

Assessment	Assessment result	Inference	Rating
Maximum Weight handled	2.1kg	Maximum weight handled is light (5kg or less)	H1
Average time spent on task per day	5hrs	Task is performed more than 4hrs	J3
Maximum force level exerted by one hand	1.5N	Force exerted by one hand is medium (1 to 4kg)	K2
Visual demand	Low	Almost no need to view fine details	L1
Difficult keeping with task	workers response	sometimes	P2
How stressful task is	worker response	mildly stressful	G2

A weight handled is considered to be light because the maximum weight handled by the processors' falls at weight of ≤ 5kg. The QEC rating is H1. The inference drawn from the average time spent in the task is that the task is performed more than 4 hours with a rating of J3. Force exerted by one hand is considered to be medium because it falls between 1 to 4kg and it is rated K2. The visual demand for the sieving task is low because there was almost no need to view fine details during the sieving process and this is rated L1. The workers acknowledge sometimes having difficulty keeping up with the sieving task using the locally made sieve. This is rated P2 from the QEC. Also, the workers acknowledge having mild stress while using the locally made sieve and the rating is G2

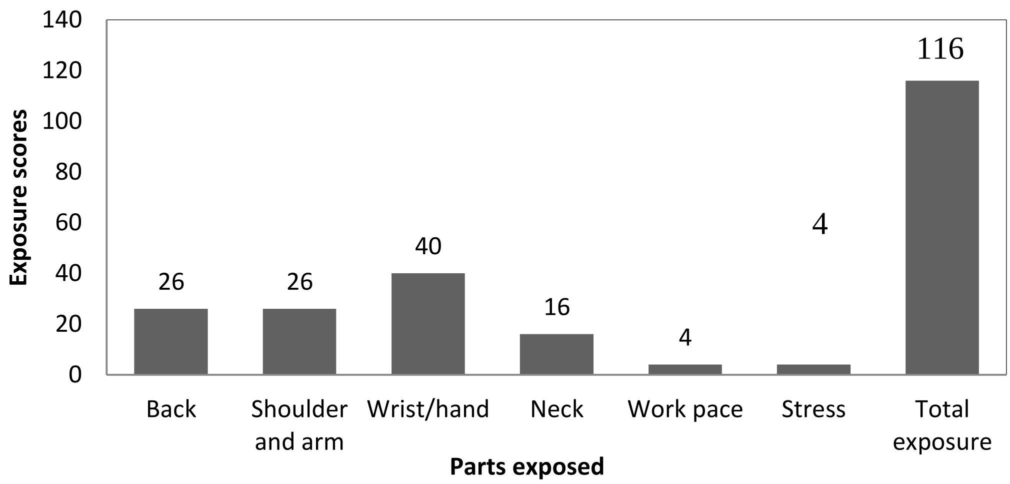
3.3 Ergonomic exposure scores for traditional sieving method

Table 5 shows the interaction between the observer's rating and the rating of workers' assessment with resulting scores.

Table 5: Exposure score – traditional sieving method

	Back	Shoulder/arm	Wrist/hand	Neck	Work pace	Stress
	A2H1= 4	C1H1 = 2	F3K2 = 8	G3J3 =10	P2= 4	Q2= 4
	A2J3 = 8	C1J3 = 6	F3J3 = 10	L1J3 = 6		
	J3H1 = 6	J3H1 = 6	J3K2 = 8			
	B3H1= 2	D2H1= 4	E2K = 6			
	B3J3 = 6	D2J3 = 8	E2J3 = 8			
Total	26	26	40	16	4	4

From the ergonomic exposure score sheet and table 5, the total back exposure of the processors using the traditional sieve in terms of QEC score is 26. The shoulder/arm exposure is 26, the wrist/hand exposure score is 40 where as the neck exposure score is 16. The exposure of processors body parts to WMSD while using the traditional sieve is presented in the chart in figure 2.



From figure 2, notice that the total exposure is the sum of the individual exposures. This gives overall percent exposure or total exposure "E" of 66%. From table 6 for preliminary action, the score indicates a need to investigate and change soon.

Table 6: Preliminary action levels for the QEC

QEC score (E) percentage total	Action Equivalent
≤ 40%	acceptable
41 – 50%	investigate further
51 -70%	investigate further and change soon
>70%	investigate and change immediately

The result of data collection by a survey of processors exposure to WMSD to find out the level of exposure of cassava processors to work-related musculoskeletal discomfort

(WMSD) while using the traditional method of sieving was analyzed and presented in tables 1 to 6.

4. CONCLUSION

Cassava processors involved in DCM sieving process using traditional method are exposed to WMSD to a scale level of 66% QEC rating. The highest risk of discomfort occurred at the region of the wrist/hand, with highest exposure score of 40, followed by back with exposure score of 26, shoulder/arm with exposure of score of 26, and neck exposure score of 16. Processors therefore should be made to be aware that the sieving posture they adopt and with the sieve aperture currently used in traditional sieving process, exposes them not only to the discomfort of pain but also put them at high risk of musculoskeletal disorder over a period of time and therefore need to change to an improved or motorized method as soon as possible.

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Effects of Some Process Conditions on Mechanical Properties 0f Poultry Litter Pellets

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ABSTRACT

In this study, a 5.5 hp poultry litter pelleting machine was developed at the Centre for Agricultural Development and Sustainable Environment (CEADESE) of the Federal University of Agriculture, Abeokuta and used to investigate the effects of some processing conditions on durability, hardness and bulk density of poultry litter pellets. The parameters considered were machine speeds of 210, 250, 290 rpm, die diameters of 0.04, 0.06, 0.08 m, feed rates of 80, 100, 120 kg/hr, moisture content of conditioned litter at 0.405, 0.425, 0.445 wb. The durability, hardness and bulk density of the pellets were significantly ($p < 0.05$) affected by the process factors (moisture content, die diameter, shaft speed, feeding rate) and by some of the interactions between them. Durability of the pellet was not significantly affected by the moisture content, machine speed and feed rate. However, pellet durability decreased with increased die diameter. Pellet hardness decreased with increased feed rate and increased with increased die diameter. The pellet bulk density reduced with increase moisture content.

Keywords: poultry litter, pellet, durability, hardness, bulk density.

1. INTRODUCTION

Poultry litter is bulk solid and biomass feedstock, which is a combination of accumulated poultry manure, feathers and bedding materials found in poultry houses (Bernhart, 2007). Materials contained in poultry litter include feaces, straw, sawdust, wood shavings, shredded paper and peanut or rice hulls. Fresh poultry litter has high moisture content, bulky to haul, spread and have a repulsing odor (Bolan *et al*., 2010). These make the material difficult to handle. Concerns by poultry farmers about disposal and pollution problems of waste including manure and litter from poultry farms has necessitated the need for environmentally and economically sustainable management practices for the poultry waste utilization.

Pelletizing, a management practice for poultry litter, is the process of forcing materials through a specially design opening (Ugoamadi, 2012). It is the process of compressing or moulding a material into the shape of a pellet. A pellet is a small, compressed, hard chunk of mass. Pellets made from poultry litter are of lower weight and moisture content, as well as less odour and with minimal pathogens. Pelletizing results into lower transportation and storage costs. Knowledge of the mechanical properties of the pellets is important for transportability and storageability. The objective of this research work is to investigate the effect of the speed of the machine, die diameter of the extrusion plates and the moisture content of conditioned poultry litter on the durability, hardness and bulk density of poultry litter pellets.

2. MATERIALS AND METHODS

The materials used for this experiment are classified into two groups namely: the digested poultry litter and poultry litter pelletizing machine powered by a 5.5 hp electric motor. Digested poultry litter was obtained at a local farm in Abeokuta, Nigeria. The digested poultry litter was air-dried locally. The dried digested poultry litter was milled using an NCAM fabricated hammer mill. The initial moisture content of the poultry litter was determined by oven dry method, the samples were dried at 105^0 in a conventional oven for 24h following the ASABE (2003) procedure. The samples were weighed before and after drying and the moisture content was expressed on a wet basis. Using water to aid binding, the poultry litter samples were conditioned by wetting to the required moisture content using Equation 1 as used by Adejumo and Oje, (2008).

$$M = \left[\frac{100-M_p}{100-M_g}-1\right]\times W_g \qquad (1)$$

Where;
Mp = Present moisture content, g
Mg = Required moisture content, g
Wg = Weight of sample in grams, g

2.1 Variation of die diameter

Three sets of die plates with 4, 6 and 8 mm hole diameters were used to vary the diameter of the pellets produced. The area of the hole on the die plates were the same. Consequently, the same volume of pellets can be produced from each die. This allowed for adequate and unbiased comparism.

2.2 Speed Variation

Three single grooved pulley of 300, 336, and 380 mm diameter were constructed and connected to another single grooved pulley of diameter 60 mm on the electric motor of 1,450 rpm in order to vary the speed of the machine at 210, 250 and 290 rpm

2.3 Variation of feeding rate

After the machine capacity test, it was discovered that for continuous feeding, the best feed rate ranged between 80kg/hr and 120 kg/hr.

2.4 Durability measurement

Durability is the ability of the pellets to withstand destructive loads during transportation. An existing tumbling machine constructed in NCAM as used by Adejumo and Oje, (2008) was used for the determination of the durability of the pellets.

This was achieved by loading 1kg sample of the pellets into the canister of the tester. The experiment was replicated three times. The impeller was run for 10min at 50rpm (ASAE Standards 2002). Durability is expressed as the percent ratio of crumbled pellet (retained on sieve hole) after tumbling to the original sample mass. It is mathematically expressed as by Equation 2.

$$D_p = \frac{M_{pat}}{M_{pbt}} \times 100 \qquad \text{(ASAE Standard, 2002)} \qquad (2)$$

Where;
D_p= Durability of Pellet (%).
M_{pat} = Mass of the Pellet after tumbling (grm).
M_{pbt} = Mass of the Pellet before tumbling (grm).

2.5 Hardness measurement

Hardness is the measure of the strength of the pellets. The Testometrics Universal Testing Machine (Model M500 50KN) was used to determine the hardness of the pellet at a speed of 10mm/min.

2.6 Bulk density measurement

This is the mass of group of individual pellets divided by the space the entire mass occupied; including the air space. The bulk density of the pellet was measured using a cylindrical container 300mm in diameter and 310mm high (ASAE Standards 2002). The pellets were filled into the container and the net mass measured.

2.7 Data Analysis

The durability, hardness and bulk density of the pellets were measured at three levels of moisture content, die diameter, machine speed and feed rates as stated in section 2.1 to 2.3. The Central Composite Design (CCD) of the Response Surface Method (RSM) was used for the study. The face center CCD design matrix in coded values was obtained from Design Expert 10.1 software (Stat-Ease, 2016). The CCD design was randomized and replicated thrice at each experimental condition and response surfaces were used to depict interactions between variables. The Analysis of Variance (ANOVA) was used to determine the significant effects of independent variables on the responses considered in the experiment.

3. RESULTS AND DISCUSSION

3.1 Durability

Table 1 presents the ANOVA output table for durability of the pellets, it was observed that the die diameter of the extrusion plates as a single factor, as well as the interactions between shaft speed and die diameter, die diameter and feeding rate significantly ($p<0.05$) affected the durability of the pellets produced. Moisture content, shaft speed and feeding rate as independent factors did not have significant effect on the durability of the durability of the pellets.

The durability of the pellet decreased with increasing die diameter as shown in Figure 1. This implies that die with 0.08 diameter had the lowest durability. This is in support of with the findings of Adejumo (2008) that more durable pellets resulted from using small dies and less durable pellets resulted from large dies. This may be as a result of low binding force produced when the area of contact increase during compression, because larger die diameters will give room for increase in area of contact while small die diameter will give decrease in the area of contact.

Figure 2 shows a response surface plot for durability. It is observed that with increase in shaft speed at a small die diameter of 0.04 m, there was an increase in the durability of the pellets. However, at 0.08 m diameter there was no significant change in the durability of the pellet. There was decreased durability as die diameter and feed rate increased. However, the durability decreased at a faster rate with the lowest level of the feed rate.

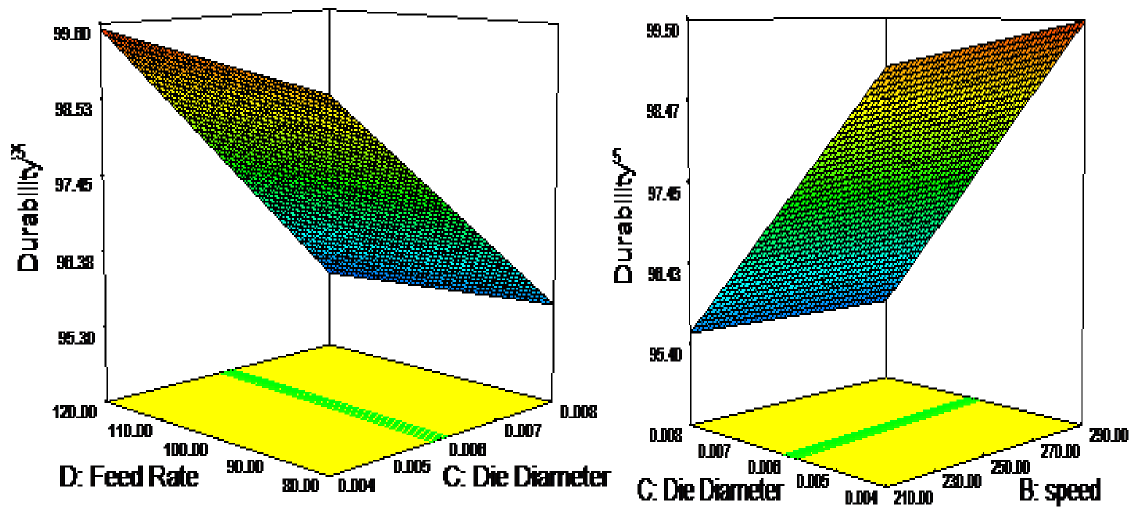


Table 1. Analysis of variance output for Durability

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	Remarks
Block	0.50	2	0.25			
Model	192.46	10	19.25	85.52	< 0.0001	Significant
A-Moisture content	*0.25*	*1*	*0.25*	*1.13*	*0.2918*	
B-Shaft Speed	*0.56*	*1*	*0.56*	*2.49*	*0.1187*	
C-Die diameter	*187.79*	*1*	*187.79*	*834.47*	*< 0.0001*	Significant
D-Feed rate	*0.33*	*1*	*0.33*	*1.45*	*0.2320*	
AB	*0.10*	*1*	*0.10*	*0.45*	*0.5053*	
AC	*0.067*	*1*	*0.067*	*0.30*	*0.5855*	
AD	*0.48*	*1*	*0.48*	*2.13*	*0.1482*	
BC	*0.91*	*1*	*0.91*	*4.03*	*0.0481*	Significant
BD	*0.053*	*1*	*0.053*	*0.24*	*0.6278*	
CD	*1.92*	*1*	*1.92*	*8.53*	*0.0046*	Significant
Residual	17.33	77	0.23			
R-Squared	0.9174					

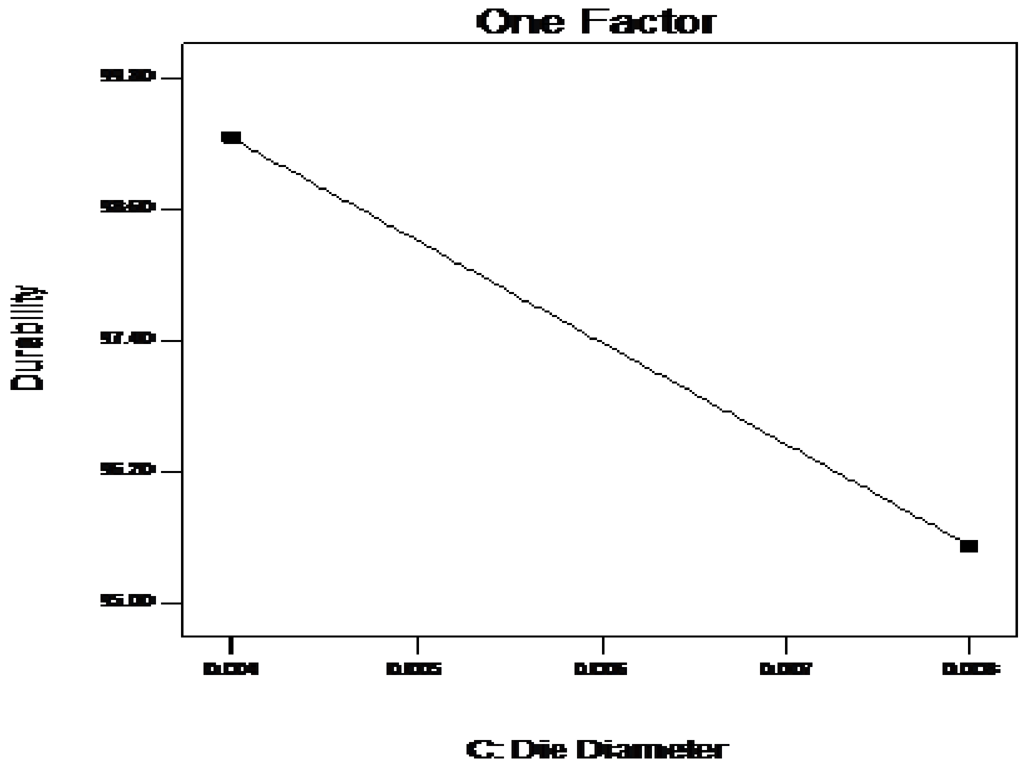


Figure 1 Effect of the die diameter on the durability of the pellets**.**

Figure 2 Response surface plot for durability as a function of interactive factors

3.2 Hardness

The ANOVA output for pellet hardness is shown in Table 2. It can be seen that the die diameter of the extrusion plate and the feeding rate as single factors as well as the interactions between moisture content and die diameter, shaft speed and feeding rate, die diameter and feeding rate were significantly ($p<0.05$) affected the pellet hardness.

Figure 3 shows that pellets hardness increased with increased die diameter. This shows that the hardest pellets were from 0.08m die size. Thus, the highest pellet hardness which is at die diameter 0.08m might be as a result of the high compressive force required to break a bigger material. Pellet hardness decreased with increased feed rate as depicted in Figure 4. That is, the feed rate is inversely proportional to the mean hardness of the pellets. This may be attributed to the fact that the conditioned sample had very little resident time in the pelletizing unit, thus resulting to improper compression before they are extruded from the dies.

Table 2. Analysis of variance output (ANOVA) for hardness

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	Remarks
Block	2.317E+005	2	1.158E+005			
Model	1.482E+008	10	1.482E+007	285.08	< 0.0001	Significant
A-Moisture Content	*1.281E+005*	*1*	*1.281E+005*	*2.46*	*0.1206*	
B-speed	*7017.84*	*1*	*7017.84*	*0.13*	*0.7143*	
C-Die Diameter	*1.460E+008*	*1*	*1.460E+008*	*2807.31*	*< 0.0001*	Significant
D-Feed Rate	*6.824E+005*	*1*	*6.824E+005*	*13.12*	*0.0005*	Significant
AB	*6821.10*	*1*	*6821.10*	*0.13*	*0.7182*	
AC	*2.919E+005*	*1*	*2.919E+005*	*5.61*	*0.0203*	significant
AD	*29950.02*	*1*	*29950.02*	*0.58*	*0.4502*	
BC	*57.64*	*1*	*57.64*	*1.109E-003*	*0.9735*	
BD	*3.353E+005*	*1*	*3.353E+005*	*6.45*	*0.0131*	significant
CD	*7.781E+005*	*1*	*7.781E+005*	*14.96*	*0.0002*	significant
Residual	4.004E+006	77	51998.03			
R-Squared	0.9737					

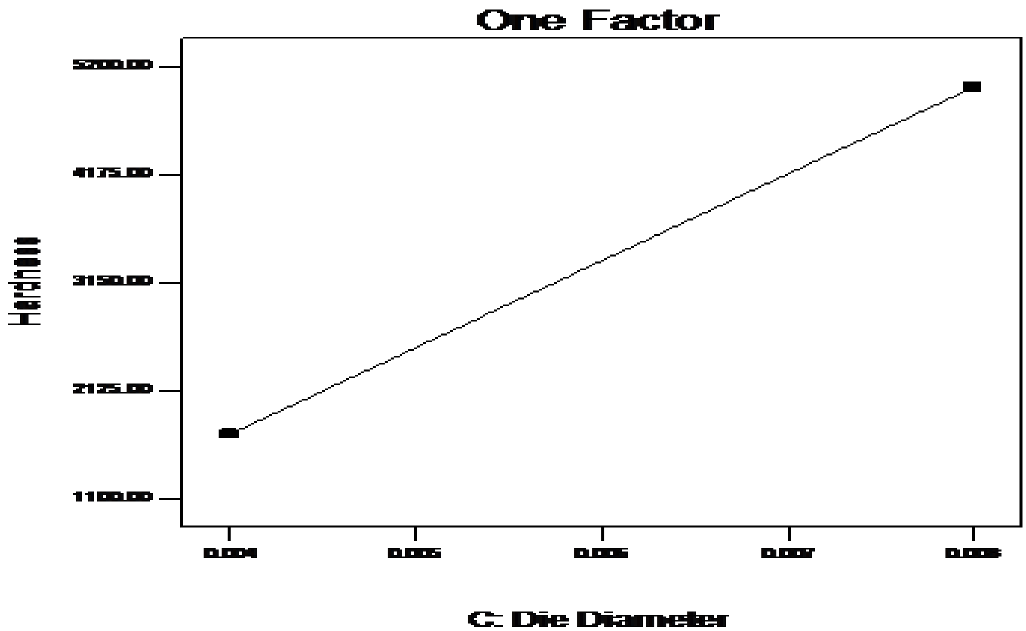


Figure 3 Effect of the die diameter on the hardness

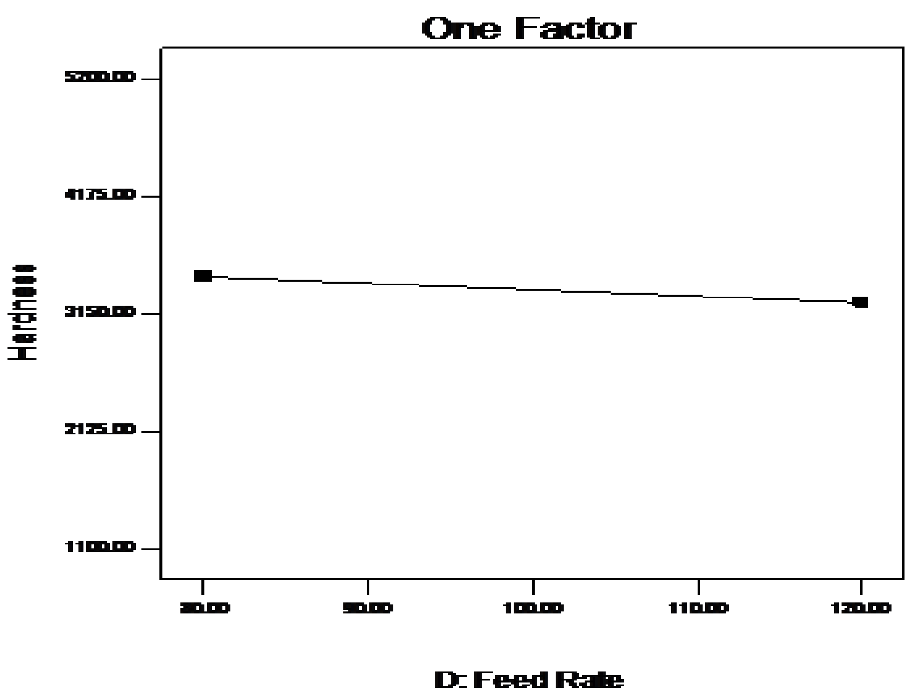
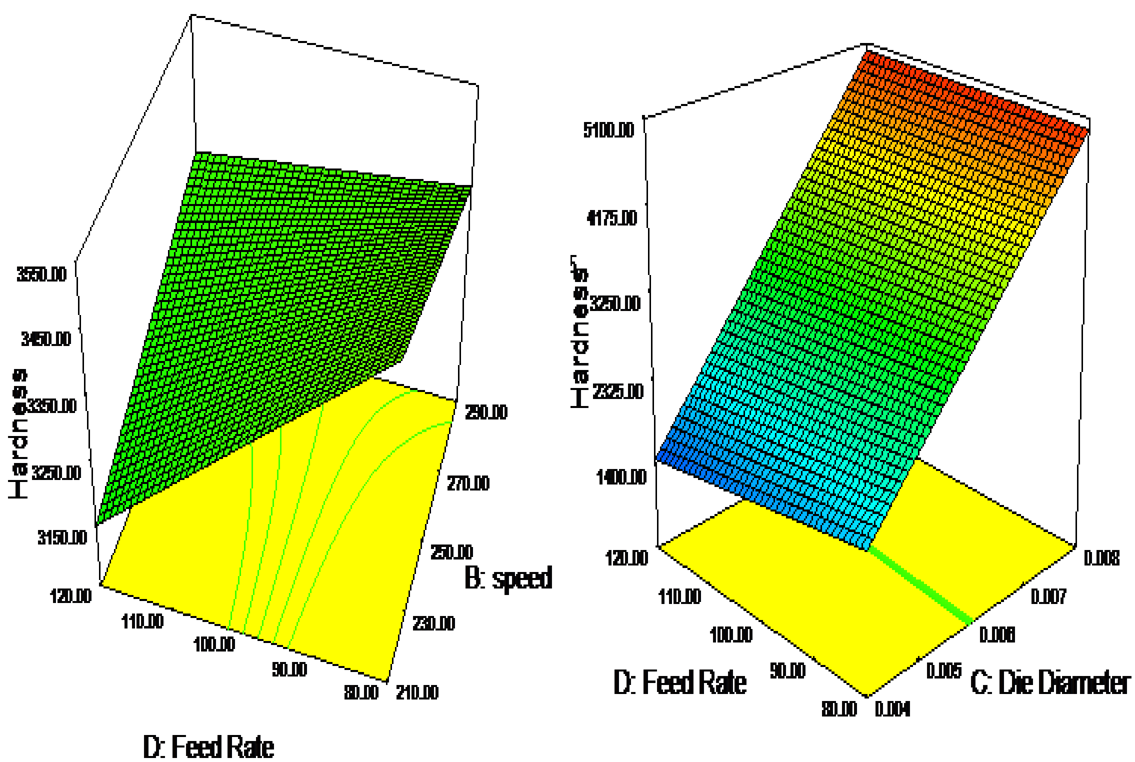


Fig 4. Effect of the die diameter on the hardness

Interactions between the factors are shown in the response surface plots for hardness in Figure 5. Interaction between moisture content and die diameter on pellet hardness showed that at 0.04 m die diameter, hardness increased with increased moisture content. Whereas, at 0.08 m die diameter, with increased moisture content, there was a slight decrease in hardness. As shaft speed increases, at 80 kg/hr feed rate there was a slight decrease in pellet hardness, however, at feed rate of 120 kg/hr with increased shaft speed, there was increase in hardness. A negative interaction exists between die diameter and feed rate. There is decreased hardness as die diameter and feed rate increases. This might be due to the attraction force which is caused by the Vander Waal's electrostatic or magnetic force. This is high because of the high area of contact between the particles of the pellet produced, compared to the area of contact between the pellets produced at moisture content levels 0.40 wb, which had a low magnetic force due to smaller quantity of moisture added. Nevertheless, as for the moisture content level 0.445% wb, the binding force is loose and the area of contact is highly affected due to higher quantity of moisture added. This is supported by the findings of Adejumo and Oje (2008).

3.3 Bulk density

The Analysis of Variance (ANOVA) output for bulk density on moisture content, shaft speed, die diameter and feed rate as main factors as well as all possible interactions is as shown in Table 3. It was observed that the moisture content of the poultry litter as well as the interactions between moisture



content and shaft speed, moisture content and die diameter, moisture content and feed rate, shaft speed and die diameter and shaft speed and feed rate were

Figure 5 Response surface plot for hardness as a function of interactive factors

significantly ($p<0.05$) affected the bulk density of the poultry litter pellets produced. Bulk density decreased with increased moisture content as shown in Figure 6. Bulk density was highest at moisture content of 0.405wb and lowest at moisture content of 0.445 wb.

Figure 7 shows a response surface plot for bulk density. The interaction between moisture content and shaft speed on bulk density showed that bulk density reduced with increased moisture content and shaft speed. At a shaft speed 290 rpm with increased moisture content, there was a faster reduction in bulk density than at a shaft speed of 210 rpm. The significant decrease in bulk density by increasing the screw speed from 210 rpm to 290 rpm, due to the high increase in mechanical energy inside the pelletizer barrel, by the fraction, pressure and temperature, that caused high cooking of the raw materials and increase in material gelatinization by the high temperature around, all of this reasons make the produced pellets to be expanded, that is mean increasing of pellets volume with constant mass. This is in line with the findings of Morad (2007). The interaction between moisture content and die diameter on bulk density depicts that bulk density decreased with increased moisture content and die diameter. At 8mm die diameter with increased moisture content, there was a faster reduction in bulk density than at 4mm die diameter. This reduction in bulk density could be as a result of the decrease in the pressure inside the pelletizing unit as a result of the larger orifice from the increased die diameter. The interaction between moisture content and feed rate on bulk density

Table 3. Analysis of variance output (ANOVA) for bulk density

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	Remarks
Block	1016.53	2	508.27			
Model	30320.55	10	3032.05	30.09	< 0.0001	Significant
A-Moisture Content	*23939.83*	*1*	*23939.83*	*237.59*	*< 0.0001*	Significant
B-speed	*9.13*	*1*	*9.13*	*0.091*	*0.7642*	
C-Die Diameter	*196.07*	*1*	*196.07*	*1.95*	*0.1670*	
D-Feed Rate	*251.56*	*1*	*251.56*	*2.50*	*0.1182*	
AB	*1240.93*	*1*	*1240.93*	*12.32*	*0.0008*	Significant
AC	*1343.14*	*1*	*1343.14*	*13.33*	*0.0005*	Significant
AD	*1148.38*	*1*	*1148.38*	*11.40*	*0.0012*	Significant

BC	*1159.75*	*1*	*1159.75*	*11.51*	*0.0011*	Significant
BD	*725.93*	*1*	*725.93*	*7.20*	*0.0089*	Significant
CD	*305.82*	*1*	*305.82*	*3.04*	*0.0855*	
Residual	7758.76	77	100.76			
R-squared	*0.7962*					

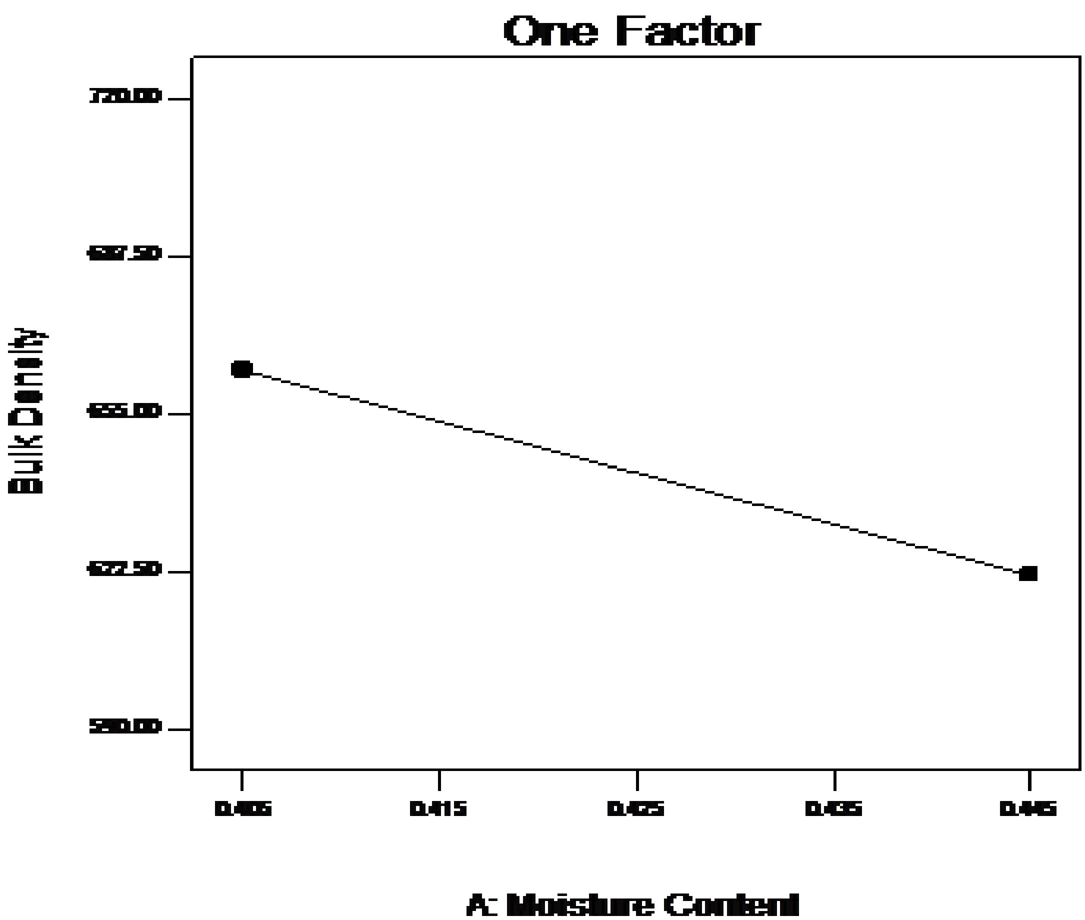
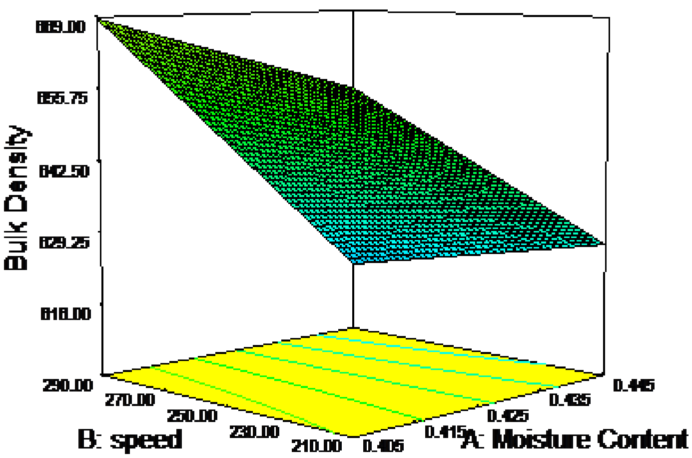
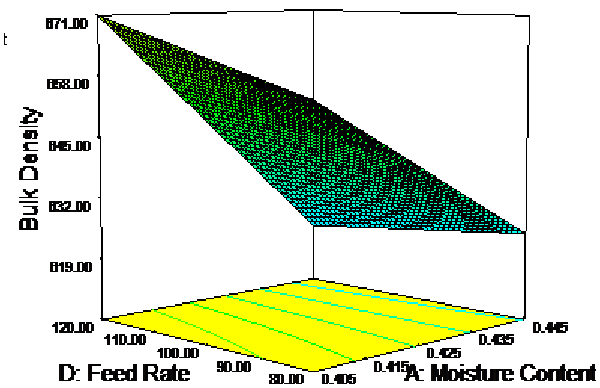
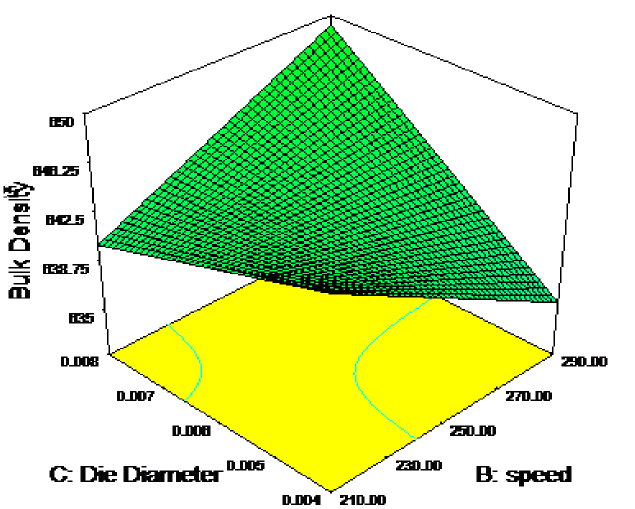
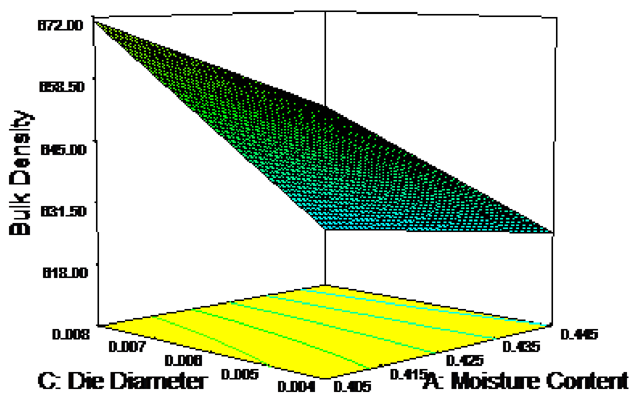


Figure 6 Effect of the die moisture content on the bulk density


Bulk Density
855.75
842.50
829.25
818.00
B: speed
290.00
270.00
250.00
230.00
210.00
A: Moisture Content
0.405
0.415
0.425
0.435
0.445


Bulk Density
871.00
858.00
845.00
832.00
819.00
D: Feed Rate
120.00
110.00
100.00
90.00
80.00
A: Moisture Content
0.405
0.415
0.425
0.435
0.445


Bulk Density
850
846.25
842.5
838.75
835
C: Die Diameter
0.008
0.007
0.006
0.005
0.004
B: speed
210.00
230.00
250.00
270.00
290.00


Bulk Density
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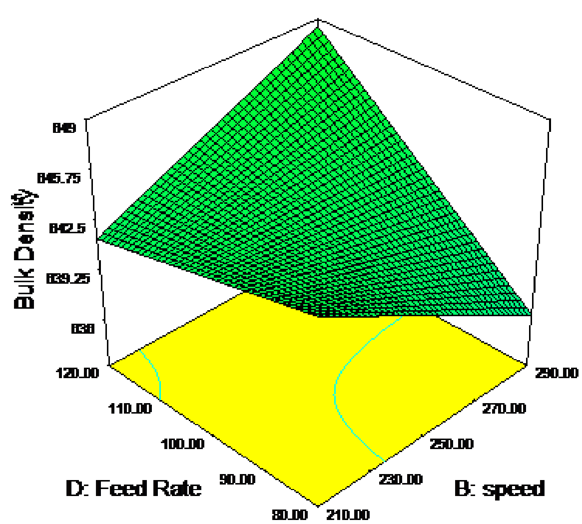
858.50
845.00
831.50
818.00
C: Die Diameter
0.008
0.007
0.006
0.005
0.004
A: Moisture Content
0.405
0.415
0.425
0.435
0.445


Bulk Density
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845.75
842.5
839.25
836
D: Feed Rate
120.00
110.00
100.00
90.00
80.00
B: speed
210.00
230.00
250.00
270.00
290.00

Figure 7 Response surface plot for bulk density as a function of interactive factors

shows that bulk density reduced with increased moisture content and feed rate. At a feed rate of 120 kg/hr with increased moisture content, there was a faster reduction in bulk density than at a feed rate of 80 kg/hr. The interaction between shaft speed and feed rate on bulk density depicts that at a feed rate of 120 kg/hr, with increased shaft speed, there was an increase in bulk density. However, at feed rate of 80 kg/hr, there was a decrease in bulk density. The positive effect of feed rate of 120 kg/hr as speed increases on pellets bulk density may be due to the more quantity of raw materials on the die zone which increase the compaction of materials granules.

4. CONCLUSIONS

Based on the results presented in this work, the following conclusions can be made:

1. The durability, hardness and bulk density of the pellets were significantly ($p < 0.05$) affected by the process factors (moisture content, die diameter, shaft speed, feeding rate) and by some of the interactions between them.
2. Durability of the pellet was not significantly affected by the moisture content, machine speed and feed rate. However, pellet durability decreased with increased die diameter.
3. Pellet hardness decreased with increased feed rate and increased with increased die diameter.
4. The pellet bulk density reduced with increase moisture content.
5. Interactions of the process conditions showed that good quality pellets are best produced at 0.445 wb, high machine speed 290 rpm, however, the die diameter and feed rate can be adjusted based on the mechanical property best needed.

5. ACKNOWLEDGEMENT

This material is based upon work that is supported by the Center for Excellence in Agricultural Development and Sustainable Environment (CEADESE). Abeokuta, Nigeria.

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Effects of pre-drying treatments on the **enzymatic activity, drying efficiency and textural properties of dried pomegranate arils**

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ABSTRACT

Drying of pomegranate arils reduces postharvest losses and waste of the fruit. However, the high heat associated with drying decreases the quality attributes, result in browning appearance and hardening of the dried product. The objective of this study was to determine the effects of chemical (citric acid and ascorbic acid) and blanching treatments on the enzymatic activity, drying efficiency and textural properties of dried pomegranate arils. The arils were blanched at 70, 85 and 100 °C for 10, 20 and 30 s, respectively. For chemical treatment, arils were dipped separately in ascorbic acid (0.5, 1.0 and 1.5 %) and citric acid (0.2, 0.4 and 0.6%) for 15 min. Blanching of arils at 100 °C for 30 s reduced drying time by 20 % compared to untreated arils. Furthermore, control arils differed in hardness (132.68 ± 3.69 N) compared to the blanching treatment (92.78 ± 3.26 N) at a similar moisture content. Generally, none of the treatments inhibited polyphenol oxidase enzyme activity significantly compared to the control. The blanching treatment (100 °C, 30 s) has a potential to be used as a pre-drying treatment for the drying of pomegranate arils since it reduced drying time and hardness of arils.

Keywords: Pomegranate arils, pre-drying treatments, blanching, polyphenol oxidase, South Africa.

1. INTRODUCTION

The South African industry is one of the main exporters in the southern hemisphere, competing with countries like Chile, Argentina and Peru. However, postharvest losses pose a major threat to fruit supply in the growing South African pomegranate industry. Only 51% of total fruit at pack house level suitable for export as class one and two fruit. The remaining fruit, which could be cracked, blemished or sunburned, are often regarded as waste due to lack of diversity and technological know-how in the industry (Goosen, 2016). These results in loss of revenue for producers and limits growth of the industry.

Drying is one of the ways to utilise fruit regarded as waste. Studies on dried pomegranate arils have been reported by many authors (Pruthi and Saxena, 1984; Singh and Dayal, 2015; Horuz and Maskan, 2015). While the advantages of drying are numerous, the effect of drying on fruit quality can be detrimental. For example, Thakur et al. (2010) reported that discolouration of pomegranate arils due to browning resulted in poor quality products. Pericarp browning of fresh litchi fruit was reported to be caused by degradation of anthocyanins by polyphenol oxidase (PPO) and peroxidase (POD) enzymes (Zhang et al., 2001). Apart from its detrimental effect on fruit colour, drying also changes the textural properties of food, which has negative effect on the sensory quality of the product (Kingsly et al., 2006). Pre-treatments of fresh produce is one of the ways to minimise loss of colour and hardening of dried fruit product. Pre-treatments inactivate browning enzymes and overcome the waxy external layer of fruit, allowing water mass transfer for faster drying (Adiletta et al., 2015; Cinquanta et al., 2010).

The aim of this study was to investigate the effect of physical and chemical pre-treatments on the drying efficiency, enzymatic activity and texture of pomegranate arils dried in a hot air oven. These experiments were carried out with the purpose of establishing the potential of dried arils as value added product for the South African pomegranate industry.

2. MATERIALS AND METHODS

2.1 Fruit source

Pomegranate ‘Wonderful’ fruit were sourced from Sonlia Packhouse during commercial harvest in the Western Cape, South Africa. Fruit were transported to the Postharvest Technology Laboratory at Stellenbosch University and stored at 5 °C until analysis. Fruit were equilibrated at room temperature and hand-peeled for aril extraction.

2.2 Pre-treatments

Citric acid (0.2%, 0.4% and 0.6%) and ascorbic acid (0.5%, 1.0% and 1.5%) were used as chemical pre-treatments. Arils were dipped in 1 L of each chemical solution for 15 min (Sarpong et al., 2018). The blanching pre-treatment was carried out according to Canet et al. (2005), with slight modifications. Briefly, pomegranate arils were blanched in a water bath at 70, 85 and 100 °C, each temperature 10, 20 and 30 s followed by dipping blanched samples in ice water for 20s. Each treatment was carried out in triplicate.

2.3 Enzymatic activity

Enzymatic activity of PPO was determined according to the method described by Meighani et al. (2014) with slight modifications. Pre-treated pomegranate arils (10 g) were ground with 10 mL extraction buffer (100 mM L^{-1} potassium phosphate buffer at pH 7.0, 0.5 mM L^{-1} ethylenediaminetetraacetic acid, 60 g L^{-1} polyvinyl polypyrrolidone). The homogenate was vortexed, sonicated for 20 min at 5 °C and incubated at 4 °C for 2 h in the dark. Thereafter, the supernatant was obtained by centrifugation at 10 000 rpm for 20 min. The supernatants were stored at 4 °C until assayed for PPO activity. Polyphenol oxidase activity was measured as the initial rate of increase at 420 nm according to González et al. (1999). Absorbance was measured in triplicate for each treatment. The reaction mixture consisted of 2.5 mL potassium phosphate buffer (pH 6.0), 0.3 mL pyrocatechol (0.5 M) and 0.2 mL prepared enzyme solution. Enzyme activity was expressed as change in absorbance at 1 min intervals for 4 min using the following equation:

Activity U/ mL = $\frac{(\text{Abs at 4 min} - \text{Abs at 1 min}) \times \text{total reaction vol}}{\text{time interval} \times 0.2}$ (1)

where Abs = Absorbance, total reaction vol = 3 ml, time interval = 4 min. Final results were expressed as U/ g.

2.4 Drying

Drying was done using an oven dryer (072160, Prolab Instruments, Sep Sci., South Africa) at an air temperature and velocity of 60 °C and 1 m/s, respectively. In triplicates, fruit samples were dried in glass petri dishes and weighted at an hourly interval until moisture content of between 10-12 % was obtained. Weight change was recorded using a digital balance (ML3002, Mettler Toledo, Switzerland).

2.5 Response variables

2.5.1 Determination of effective moisture diffusivity

Moisture content was calculated according to Vásquez-Parra et al. (2013) assuming that water loss was the only factor influencing mass loss, using the following equation:

$$X_t = \frac{M_0 - M_t}{M_0} \times 100 \quad (2)$$

where X_t is the moisture content at time t, M_0 is the initial weight of the sample (g), and M_t is the weight of the sample (g) at time t.

The moisture ratio (MR) of pomegranate arils were calculated using Equation (3).

$$MR = \frac{M_t}{M_0} \quad (3)$$

where M_t is the moisture content at time, t, and M_0 is the initial moisture content.

The effective moisture diffusivity (D*eff*) was determined according to (Sarpong et al., 2018) using Equation (4). The slope of the natural logarithm of moisture ratio (lnMR) against drying time (s) was used to calculate effective moisture diffusivity.

$$MR = \frac{M_t}{M_o} = \frac{8}{\pi^2} \sum_{n-1}^{\infty} \frac{1}{(2n-1)^2} exp \left[-\frac{(2n-1)^2 \pi^2 D_{eff} t}{4L^2} \right] \quad (4)$$

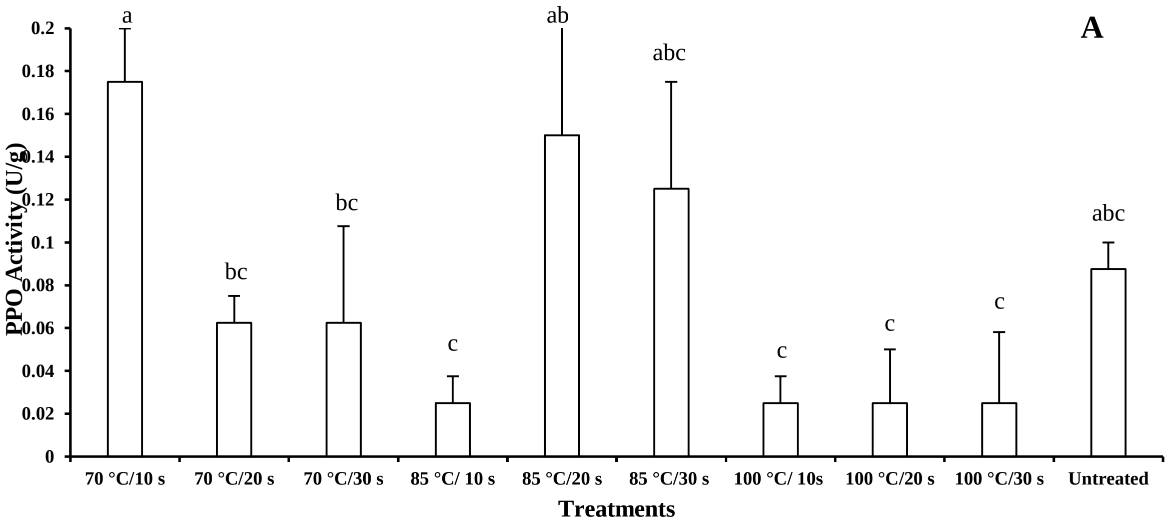
where t is the drying time (s) and L is the half thickness of the pomegranate aril (m).

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L^2} \quad (5)$$

2.5.2 Moisture dependent texture changes

The moisture dependent compression test was carried out with a 35 mm diameter cylindrical probe using the texture profile analyser (TA-TX plus, Stable MicroSystem Ltd, UK). Settings used for the test were as follows: pre-test speed 1.5 mm/s, probe test speed 1 mm/s and post-test speed 10 mm/s (Fawole and Opara, 2013) to a return distance of 10 mm and compression strain of 80 %. Fifty arils were sampled per treatment at each moisture content. Total compression force or hardness (N) and toughness (N.mm) of aril samples were deduced from the force-displacement curve.

3. RESULTS AND DISCUSSION



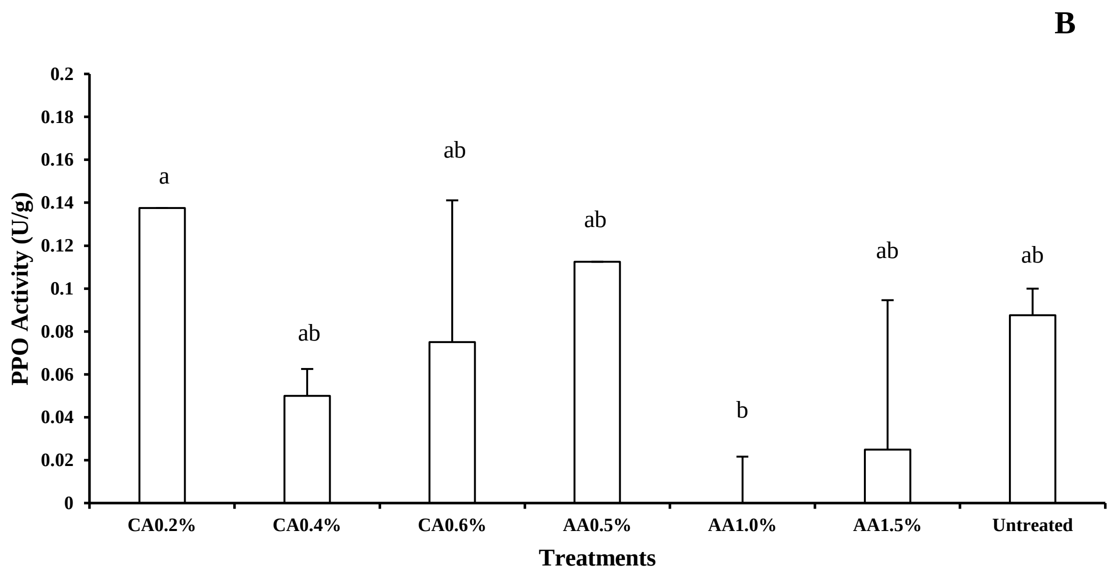


Figure 1. Polyphenol oxidase (PPO) activity of a) blanched and b) chemically treated pomegranate (cv. Wonderful) arils. Data represents means ± standard error (SE). Different letter(s) on the bars indicate statistical differences according to Fischer's LSD test ($p<0.05$).

3.1 Enzymatic activity

Figures 1a and 1b depict the effect of blanching and chemical pre-treatments on PPO activity, respectively. Amongst the investigated blanching conditions, blanching at 100 °C, regardless of exposure time, proved effective in inhibiting PPO activity, all having more than 2-fold reduction compared to the control sample. The same could be said for blanching at 85°C at 10 s, where significant reduction in PPO activity was observed (Figure 1a).

Although, according to Arogba et al. (1998), blanching temperature of 70 °C was reported to inactivate PPO enzyme, blanching at 70 °C was not effective for the investigated pomegranate arils. This result is in agreement with Jaiswal et al. (2010) who reported that boiling of arils reduced PPO activity by 75 % compared to fresh arils.
Similarly, none of the citric acid (CA) and ascorbic acid (AA) dipping treatments differed significantly from the control. Ascorbic acid dipping of 1.0 % (0.00 ± 0.02 U/g FW) inhibited PPO activity compared to CA at 0.2 % (0.14 ± 0.07 U/g FW). The results concur with those found by Jiang et al. (2004) who found that PPO activity was stimulated by CA treatment at low concentrations. Sarpong et al. (2018) also reported lower PPO values of 5.12 and 4.51 % for CA (1%) and AA (1%), respectively. Given that increase in anti-browning agent concentration may suppress PPO enzyme activity, it can be hypothesize that content of endogenous organic acids, such as ascorbic acid and malic acid, in pomegranate arils could be implicated in the insignificant differences between the control and treated arils. This hypothesis can be supported by Arogba et al.(1998), who suggests that organic acids can act as competitive inhibitors of catechol as a substrate in the browning reaction.

3.2 Drying

Drying of pomegranate aril samples exhibited characteristic moisture desorption behaviour with high moisture removal at initial drying time followed by slower moisture removal towards the end of drying. Specifically, blanching treatments (Figure 1a) of 100 °C/30 s resulted in a moisture ratio of 0.22 within 240 min of drying followed by blanching at 85 °C/30 s (0.24). However, lower blanching temperatures and blanching times (85 °C/20 s and 70 °C/10 – 30 s) only reached this moisture ratio after 300 min of drying. These lower temperature and time blanching treatments did not differ significantly from the control. It is reported that water transfer across fruit skin is dependent on various factors, one of them being the degree to which cells and cuticular membranes are disrupted by thermal heating during the process of drying (Price et al., 2000). Wang et al. (2017) reported smooth cell walls rich in plastoglobuli and integrated plastids in control samples whereas, hot water blanched samples, at 80 or 90 °C, were characterised by disrupted plastids with grana separated from cell walls. As expected, none of the chemical pre-treatments differed significantly from the untreated control (Figure 2b). Sarpong et al., (2018) reported similar results where no difference was found for drying curves following treatment with varied anti-browning concentrations. The results obtained might be due to the long immersion time (15 min) to which the arils were exposed.

Table 1. Moisture effective diffusion (D*eff*) of dried pomegranate arils under different blanching pre-treatments

Treatments	Moisture effective diffusivity (m^2/s)
UNTREATED	2.94×10^{-8}
70°C/10s	1.72×10^{-8}
70°C/20s	1.42×10^{-8}
70°C/30s	2.23×10^{-8}
85°C/10s	2.13×10^{-8}
85°C/20s	2.23×10^{-8}
85°C/30s	2.53×10^{-8}
100°C/10s	1.72×10^{-8}
100°C/20s	1.62×10^{-8}
100°C/30s	1.42×10^{-8}

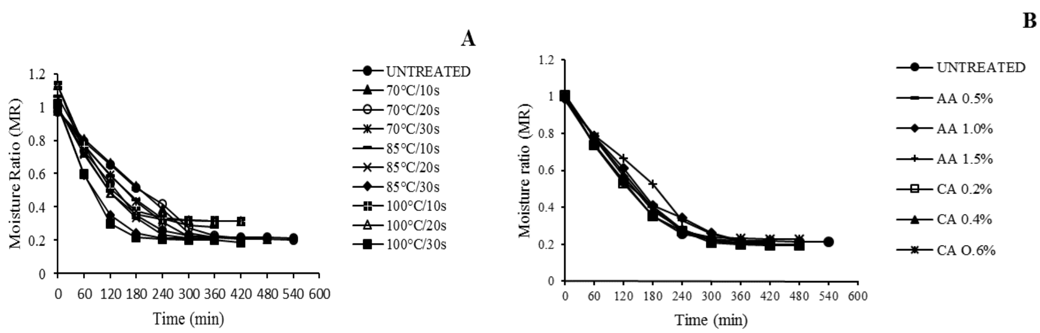


Figure 2. Moisture ratio (MR) of blanched (a) and chemically (b) pre-treated pomegranate arils.

3.3 Effective moisture diffusivity

Results of effective moisture diffusivity for blanched samples are summarised in Table 1. Treatments 100°C/30s and 70°C/20 s had the highest effective moisture diffusivities of 1.42×10^{-8} m^2/s each compared to the untreated control (2.94×10^{-8} m^2/s). Additionally, all of the blanching treatments increased moisture diffusivity, indicating that blanching treatments have a significant effect on drying time. On the contrary, chemical treatments had little effect on the moisture diffusivity (Table 2). The effective diffusion coefficients for chemical pre-treatments ranged between $3.34 – 4.15 \times 10^{-8}$ m^2/s. These values were below the range ($6.61 – 7.42 \times 10^{-11}$) reported by Vásquez-Parra et al. (2013) for dried gooseberries using various chemical and thermal pre-drying treatments.

Table 2. Moisture effective diffusion (D*eff*) of dried pomegranate arils under different chemical pre-treatments

Treatments	Moisture effective diffusivity (m^2/s)
UNTREATED	2.94×10^{-8}
AA 0.5%	4.05×10^{-8}
AA 1.0%	3.95×10^{-8}
AA 1.5%	4.15×10^{-8}
CA 0.2%	3.65×10^{-8}
CA 0.4%	3.75×10^{-8}
CA 0.6%	3.34×10^{-8}

3.4 Moisture dependent textural properties

This study showed significant influence of pre-treatments on textural properties of pomegranate arils (Tables 3 and 4). After approximately 6 h of drying (MR = 0.22), untreated arils remained significantly harder and tougher compared to blanching and chemically pre-treated arils. Blanching at 85 °C/30s appeared to influence the hardness and toughness of the samples more significantly than the rest of the blanching pre-treatments. This might be due to the fact that this treatment reduced drying time the most.

Table 3. Hardness (N) and Toughness (N/mm) of blanched pomegranate arils at moisture ratio of 0.22

Moisture ratio (MR)	Treatment	Hardness (N)	Toughness (N/mm)
0.22	UNTREATED	132.68 ± 3.69a	128.40 ± 6.74a
	70°C/10s	96.57 ± 2.28cd	79.11 ± 2.45bc
	70°C/20s	102.86 ± 3.14c	86.37 ± 3.10b
	70°C/30s	98.62 ± 2.16cd	76.54 ± 1.72cd
	85°C/10s	98.31 ± 3.16cd	70.29 ± 2.15de
	85°C/20s	101.50 ± 4.00c	71.40 ± 2.90cd
	85°C/30s	124.38 ± 2.64b	87.27 ± 1.81b
	100°C/10s	79.10 ± 2.51e	56.85 ± 1.91f
	100°C/20s	100.45 ± 2.22cd	69.27 ± 1.46de
	100°C/30s	92.78 ± 3.26d	62.58 ± 2.26ef

Table 4. Hardness (N) and Toughness (N/mm) of chemically pre-treated pomegranate arils at moisture ratio of 0.22

Moisture ratio (MR)	Treatment	Hardness (N)	Toughness (N/mm)
0.22	UNTREATED	132.68 ± 3.69a	128.40 ± 6.74a
	AA 0.5%	83.19 ± 2.36e	58.56 ± 1.44e
	AA 1.0%	87.88 ± 2.60e	60.40 ± 1.82e
	AA 1.5%	107.23 ± 2.56c	84.04 ± 1.97c
	CA 0.2%	96.01 ± 2.35d	73.91 ± 1.93d
	CA 0.4%	62.74 ± 1.80f	63.52 ± 2.42e
	CA 0.6%	124.64 ± 3.68b	104.59 ± 3.26b

4. CONCLUSION

This study revealed that blanching pre-treatments at a high temperature (70 – 100°C) and long blanching time could be useful in reducing the drying time of pomegranate arils. Although none of the treatments significantly reduced PPO activity, the textural properties of hardness and toughness were significantly affected by all treatments at a moisture ratio of 0.22. Blanching pre-treatment condition (100°C/30s) has a potential commercial application to control browning, reduce drying time and improve textural properties of dried pomegranate arils.

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Comparative evaluation of novel low-cost moisture meters suitable for grain moisture measurement

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ABSTRACT

Monitoring grain quality is an important postharvest activity which starts at harvest, continuing during storage and up to the point of sale. High moisture in stored maize can be detrimental to food safety because of the likelihood of aflatoxin contamination and other forms of deterioration. Moisture meters are devices which provide real-time access to measuring moisture levels thereby allowing farmers to meet grain quality requirements. A newly developed low-cost moisture meter known as the Post-Harvest Loss (PHL) moisture meter is a device with potentials for massive deployment among smallholder farmers. This study was therefore set up to compare the efficiencies of some existing moisture meters compared with this newly developed device. Two commercially available moisture meters — Dickey john GAC 2100 and John Deere meters were compared with the PHL moisture meter and oven-dried method (ASABE standards) used as control. Maize grains from a bagged storage experiment were used as samples over a 12-month period. Results showed that the moisture meters had a positive difference of <3% MCwb relative to oven-dried method. Average measurements showed variances of 2.34, 1.08 and 0.56% MCwb for John Deere, PHL and GAC 2100 meters respectively, when compared with the oven-dried method. Thus, it was concluded that the low cost PHL moisture meter may serve as an effective alternative to the more expensive types and may be relatively easy to adopt for laboratory and field use among smallholder farmers in sub-Saharan Africa.

Keywords: Moisture content, maize, moisture meter, postharvest loss, grain quality

1. INTRODUCTION

The quality of grain is influenced by its moisture content (MC) (Rai *et al.,* 2005). It is one of the important parameters considered when deciding price and quality at the stage of harvest, storage, processing and marketing. High moisture can lead to quality reduction and even crop loss during storage (Armitage *et al.,* 2008). When storage environments are not properly maintained, quality and economic losses can occur from such agents as mold growth and insect damage, which are usually the two most troublesome problems in modern grain storage structures. Appropriately low grain moisture contents and low grain temperatures are the primary weapons for preventing mold and insect infestations (Casada and Armstrong, 2008). There are two basic methods of determining the MC of biomaterials –the primary/direct and secondary/indirect methods (Obi *et al.*, 2016). A primary moisture measurement method involves determining the mass of an undried and dried sample to determine the amount of water in the sample (Armstrong *et al.,* 2017). In secondary methods, the MC is determined indirectly from the empirical relationship between physical and chemical features and the actual MC obtained from primary methods such as standard oven drying methods (Chen, 2003). Some common instruments used in secondary methods such as moisture meters and probes rely on the electrical characteristics of the grain, such as capacitance and conductance (Armstrong *et al.*, 2017) and are calibrated against the oven-based moisture determinations.

Heating whole grain in a hot air oven is the most widely used method for moisture content determination (ASAE, 2002), however the long drying time necessitated the development of moisture meters and probes. The need for a low-cost moisture meter in developing countries has been advocated for several years to help mitigate postharvest losses of grain (World Bank, 2011; Maier, 2015). Fast as well as field usable portable grain moisture meters and probes are a necessity to meet the requirements of farmers, grain storage personnel and agricultural products marketing corporations (Rai *et al.*, 2005).

Commercially available moisture meters include two low cost meters by developed country standards; the Post-Harvest Loss (PHL) meter which was developed under a USAID project to reduce post-harvest loss (~US$100) and John Deere portable device (~US$260, 2018 price). The GAC 2100 bench-top moisture meter is an approved moisture tester by the Grain Inspection, Packers and Stockyards Administration (GIPSA) and has been a highly regarded and used electronic meter (~US$3600, 2018 price).

The objective of this research was to demonstrate the accuracy of three moisture meters compared to the oven-dried reference method. The meters are — Post-Harvest Loss (PHL) meter developed by the USDA-ARS Center for Grain and Animal Health Research, Manhattan KS, John Deere Moisture Chek PLUS, model SW08120 (AgraTronix Streetsboro, Ohio) and Grain Analysis Computer GAC 2100 Agri (DICKEY-john Corp., Auburn, Ill.). Both laboratory and field tests of these four moisture measurements were carried out to validate their performance and to provide basic information on moisture levels of maize over a 12-month storage period.

2. MATERIALS AND METHODS

2.1 Maize

Maize used in this study was sourced from a single local farm in order to ensure uniformity of maize used for the study. Moisture content measurements of maize samples were collected during a study of insect infestation of bagged grains in a storehouse located in

Arisekola market, Bodija, Ibadan (7°25’59 N, 3°54’43 E) from February 2017 – January 2018. Batches of 50 kg of maize were placed individually in bags according to the various treatments as follows: (1) untreated polypropylene (PP) bags,(2) Insecto diatomaceous earth–treated PP bags, (3) PICS bags, (4) PP bags with a single hermetic liner, (5) ZeroFly storage bags, (6) Insecto diatomaceous earth-treated ZeroFly storage bags, (7) ZeroFly storage bags with two PICS bag hermetic inner liners and (8) ZeroFly storage bags with a single hermetic liner. Each bag had three sub-replicates and were measured for each treatment. Monthly moisture measurements were taken for non-hermetic treatments while moisture measurements were taken every four months for the hermetic treatments.

2.2 Moisture content measurement and data collection

2.2.1 Post-Harvest Loss (PHL) meter

The PHL meter was used by inserting the probe deep into each storage bag of maize in the storehouse, left initially to stabilize over a 6-minutes period and then the temperature (°C) and relative humidity (%) of air surrounding the grain determined was used to calculate and display the moisture content of the grain. Three measurements were taken from each bag — at the center, and opposite sides of the bag and the average moisture content, weight basis (MCwb) calculated for each bag. This procedure was performed in the storehouse.

In addition to the field moisture data, a 1.2m open-ended grain probe (Seedburo Equipment, Chicago, IL) was used to sample maize from bags. Composite samples were taken from the center and opposite sides near the inner surface of each bag and placed inside labelled Ziploc bags. Samples collected were then transported to the laboratory for data collection. About 700 g samples collected from each bag were mixed thoroughly in a tray to ensure homogeneity for moisture readings with GAC 2100, John Deere moisture meters and Oven-dried method.

2.2.2 GAC 2100 moisture meter

Maize sample was poured into the top unit of the moisture meter; the load key was depressed and the sample automatically loads the grain into the test cell and a strike-off arm levels and removes the excess. After about 15 seconds, the moisture reading and grain temperature was displayed on its LCD. Three sample measurements were taken and the average MCwb was calculated for each bag. Moisture reading for the first month (February 2017) was however not available at the beginning of the study.

2.2.3 John Deere moisture meter

Sampled grain was scooped with a hollow plastic spoon into the top chamber of the meter and the cap screwed on to compress the grains around the electrodes. A uniform pressure was maintained on the test sample by a plunger in the cap which contains a heavy spring, allowing the plunger shaft to protrude through the cap as pressure on the grain increases. The plunger shaft was set flush with the surface of the cap each time a sample was tested. The unit was powered by two 9V batteries to run the backlight display and the microprocessor which then reports the water content and temperature of grains digitally.

Three sample measurements were taken and the average MCwb was calculated for each bag.

2.2.4 Oven–dried method

100 g samples (replicated two times) were oven-dried at 103°C for 72 hours (ASABE, 2008) using a Memmert UF 55 Model 30-750 oven (Memmert GmbH + Co. KG, Schwabach). After heating, the samples were allowed to cool inside a dessicator and the MCwb was calculated for each bag. Two sample measurements were recorded and the average MC was calculated for each bag.

2.3 Statistical analysis

Data were summarized using the SPSS version 20 software to evaluate means of each response variables.

3. RESULTS AND DISCUSSION

3.1 Grain moisture content

In the non-hermetic bags where monthly moisture measurements were taken, moisture levels recorded by the four methods in the bagged maize were higher at the end of the study compared with moisture levels at the beginning (Fig. 1). In the hermetic bags, slight increases in moisture readings were observed in months when measurements were taken (Fig. 2). MCwb readings using the oven-dried method were uniformly lower than all the 3 moisture meters used (Figs. 1 and 2). Among the moisture meters, GAC 2100 meter readings were consistently lower than the PHL and John Deere meters. There were variations in the monthly measurements of moisture in the triplicate bags during storage period. Moisture readings progressively increased during the rainy season (April to October) but fell during the dry season (November to January). High humidity observed during the rainy season which allows moisture gain from the surrounding air and low humidity during the dry season accounted for the initial gain and later, loss of moisture from the grains during the study. This appears to show that bagged grains responds readily to monthly variation in climatic conditions (Armstrong *et al*., 2017). Combined moisture measurement for all bags (hermetic and non-hermetic) showed that the John Deere, PHL and GAC meter readings had mean positive differences of 2.34 ± 0.34%, 1.64 ± 0.27% and 1.08 ± 0.31% MCwb respectively, relative to the oven-dried method. Comparing the moisture meters, John Deere meter had a mean positive variance of 1.26 ± 0.38% MCwb relative to GAC 2100 and PHL meter had a mean positive variance of 0.56 ± 0.25% MCwb. This result was in agreement with Armstrong et al., 2017 who showed that PHL meter readings were lower than John Deere moisture meter stating average positive differences of 0.45% and 2.12% MCwb for PHL and John Deere meters respectively, relative to the GAC 2100 meter. Overall, moisture levels in the bagged maize over the 12–month storage period were within safe levels for maize storage; an average of 12.82% MCwb was recorded in all the bags. The highest moisture level recorded for any bag was 15.5% using John Deere meter.

4. CONCLUSION

The use of robust moisture meters is important for farmers and grain managers to constantly monitor moisture levels of stock. The PHL meter, John Deere meter and GAC 2100 meter provide simple and rapid prediction of moisture readings of stored grains in the field and laboratory, thus enabling farmers to make quick decisions on the maintenance of quality of their grains.

5. ACKNOWLEDGEMENT

We thank the USDA/USAID funded Nigeria Agriculture Capacity Strengthening Program for the moisture meters used in this study. Special thanks to the Food and Nutrition Laboratory, IITA Ibadan for providing bench space to conduct the oven dried test. This study was funded by the Swiss Agency for Development and Cooperation. Mention of proprietary product does not constitute a guarantee of the product by the authors, institutions and sponsor, and does not imply its approval to the exclusion of other products that may also be suitable.

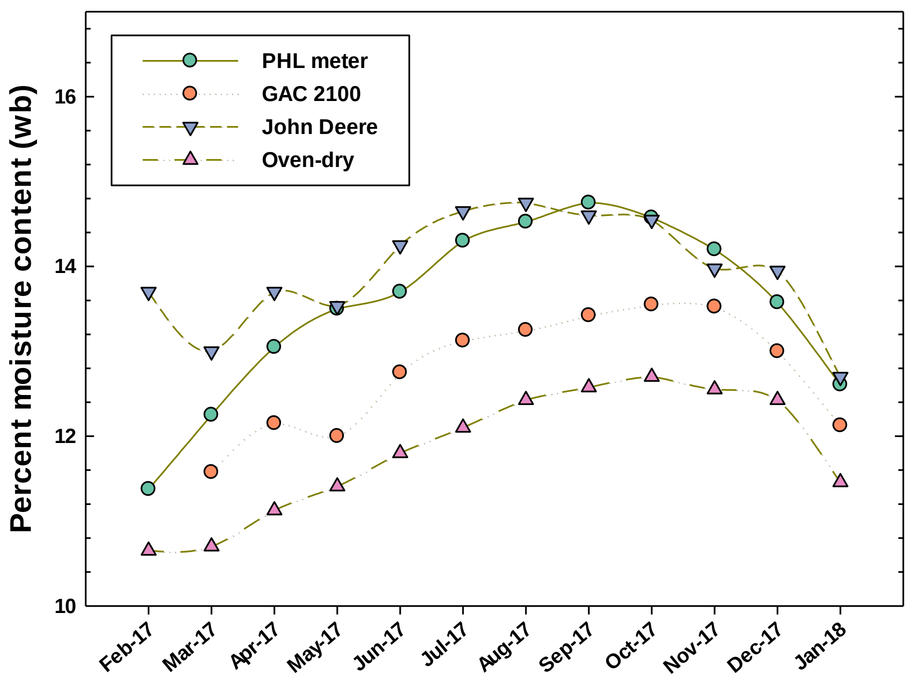

Fig 1: Monthly moisture measurement in the non-hermetic bagged maize from February 2017 to January 2018.

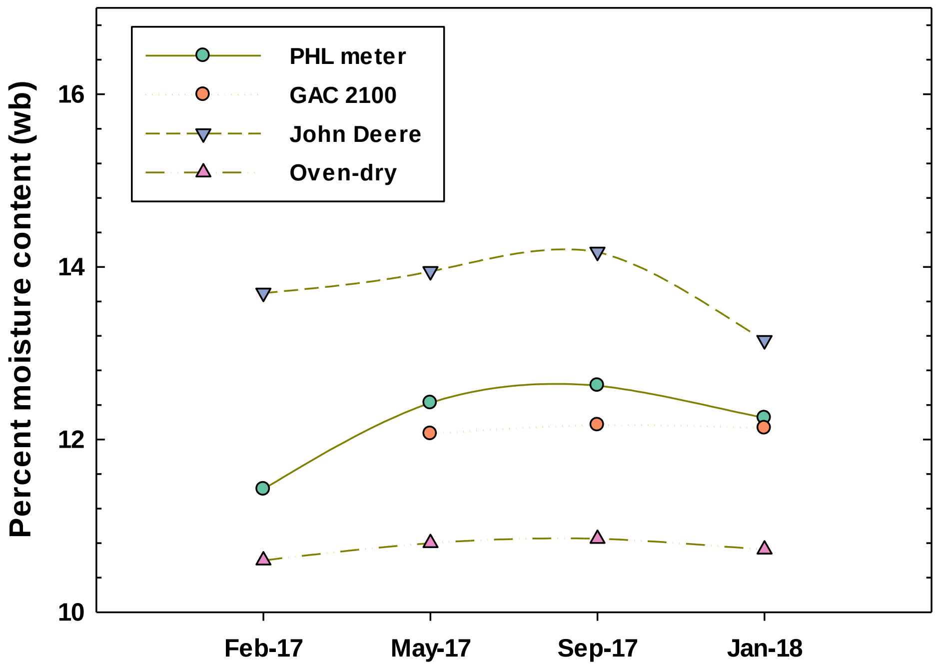

Fig 2: Quarterly moisture measurement in the hermetic bagged maize from February 2017 to January 2018.

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Specific Mechanical Energy Consumption of Extrusion of Pineapple Pomace Based Fish Feed

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ABSTRACT

Extrusion cooking process can be used in the production of environmentally friendly waste materials. Therefore, this study was designed to determine the specific mechanical energy (SME) consumption of a single screw extruder for fish feed made of pineapple pomace at a varied level of moisture of raw materials mixtures and die holes. Functional ingredient which supports the extrusion process was applied to pineapple pomace at varied levels. SME was determined relative to the moisture content of the pineapple pomace based raw material and die holes. SME values of 0.08 to 0.93Wh/kg were significantly affected by pineapple pomace inclusion rate. The SME of the extrusion process decreased with addition of the pineapple pomace, along with an increase in moisture content from 16 to 22%, and the open surface die from 50 to 100%. Research has proven that it is possible to obtain good fish extrudates with high process efficiency and low mechanical energy consumption.

Keywords: Pineapple pomace, single screw extruder, moisture, Energy

1. INTRODUCTION

The extrusion process is an efficient process that uniquely combines cooking, mixing, shearing, heating, pumping, molding and sizing(Chen *et al.*, 2010).It has been widely used in the production of cereal-based snack-like products, and it is recommended to be a shorter and more flexible process than others (Harper, 1992). The cooking process resulted from a complete reformed product that minimizes the degradation of food nutrients by heat while increasing digestibility through gelatinization of starch, denaturation of protein and deactivation of undesirable compounds such as enzymes and non-digestible proteins (Alonso *et al*., 2000; Shimelis and Rakshit, 2007).During extrusion, food materials are thermo-mechanically cooked in a screw-barrel arrangement by a combination of moisture, pressure, temperature and die holes constraints to be mechanically sheared and formed (Rodriguez-Miranda *et al*., 2011) and they undergo many chemical and structural transformations. The quality of the final products depends on the process conditions, such

as the type of extruder, the feed moisture, temperature profile, the screw speed and the feed rate (Thymi, *et al*., 2005).
Specific mechanical energy (SME) represents the amount of mechanical energy transferred to the starting material during extrusion, and it can be used to indicate extrusion conditions. SME is one of the major system parameters affecting the relationship between processing variables and properties of expanded products during extrusion cooking process (Kumar, *et al.*, 2007). SME was found to be dependent on feed moisture, feed rate, screw speed and barrel temperature (Onwulata, *et al*., 1994). It was observed that increase in moisture content of ingredients mixtures increase efficiency and specific mechanical energy consumption of wheat foamed packaging material in single-screw extrusion cooking (Maciej *et al.,* 2015). However, SME has the potential to predict the properties of extruded products when there is no additional thermal energy input.

Agro-waste has become an attractive ingredient in the extrusion industry in recent year. The use of less expensive ingredients in fish feed formulations is highly recommended nowadays (Davis and Arnold, 2000; Forster and Dominy, 2006). The beneficial effects of dietary fruit pomace have been demonstrated by several authors (Costa *et al*., 2007; Rogerio *et al*., 2007; Lamidi *et al.,* 2008 Heuzé *et al.*, 2013). Pineapple pomace is rich in nutrients, functional and phytochemical compounds (Correia *et al*., 2006). In view of this, pineapple pomace has become a focus of interest as a source of functional feed ingredient. One of the established technologies of processing pineapple pomace in animal feed is the extrusion process.

The extrusion cooking is a widely studied process, however, the addition of pineapple pomace into fish feed composition on the extrudates, has not been extensively examined. The effects of ingredient properties and processing conditions on final product quality are also reflected by their influence on process responses or extruder system parameters such as motor torque, die pressure, product temperature and SME. As they are a result of different combinations of extrusion conditions such as feed moisture, screw speed, and barrel temperature, system parameters can be used to describe or compare extrusion process under different operating conditions (Moraru and Kokini, 2003).As a result, the innovative aspect of the present study was the investigation of determine the SME consumption of a single screw extruder for fish feed made of pineapple pomace at a varied level of moisture of ingredients mixtures and open surface die.

2. MATERIALS AND METHODS

Pomace flour was used to replace wheat bran at various levels (5, 10, 15 and 20%) to produce a formulated, balance diet fish feed and a varied level of moistening were used to evaluate throughput and specific mechanical energy of the extrusion cooking process. In the extrusion-cooking process a single-screw extruder (Fexod ES 990, Nigeria) of compression ratio of 3:1, screw Length-to-diameter (L/D) ratio of 6:1 and a barrel length of 317.5 mm was used. However, the practical ranges of the barrel temperature, feeding rate screw speed, cutter speed and feed water content were taken into account in selecting the number and range of process variables in the experimental design (Oduntan and Bamgboye, 2015). A single screw extruder which was powered by a 7.5 hp motor with the screw speed monitored with the use of variable transformer (Milan Italy) and photo/contact tachometer (Taiwan) to achieve the speed range of 0 to 409 rpm. The torque (T) was display on the extruder control panel; each sample was recorded in Nm

The screw speed was varied between 309-409 rpm for all treatments. The die head was equipped with a probe to monitor the temperature at the center of the product flow. The die had circular holes of (5 mm) with a length of 10 mm which resulted in a die L/D of 2.0. Open surface of the die was modified by closing some of the 8 holes on the die. The die holes were opened at three different levels 4, 6 and 8 holes (50%, 75% and 100%).The extrudates were cut at the die exit with three hard knife blades rotating at 1300 rpm, 1400 rpm and 1500 rpm. During the extrusion-cooking the engine load and process throughput were recorded. The recorded data allowed calculation of specific mechanical energy consumption of the extrusion-cooking process.

The extrusion throughput was calculated using equation 1 (Oduntan *et al.*, 2014)

$$MFR = M_p/t \qquad \ldots \quad \ldots\ldots (1)$$

Where:

M_p– average mass of the extrudates collected after extrusion (kg), t– extrusion time (h)

Specific mechanical energy (Wh/kg), the amount of mechanical energy per unit weight of extrudates was computed for each treatment by breaking up the net power input into the screw at the flow rate of the extrudates using equation 2 (Ryu and Ng, 2001).

$$SME = \frac{\left\{\left[\frac{(T-T_0)}{100}\right]\left(\frac{N}{N_r}\right)P_r\right\}}{m}(\text{Wh/kg}) \qquad \ldots\ldots(2)$$

Where:

N -screw speed, Nr - varied screw speed, T - percent torque, T_0 - no-load torque (5%), P_r - rated motor power (7.5 kW), m -mass flow rate (kg/hr)

I-optimal design was used to reveal the effect of process conditions on the extruder performance. Feeding rate, screw speed, temperature, moisture content, pomace inclusion ratio, cutting speed and open surface die were used as independent variables for the production of extrudates. The design required 46 independent experiments. Extruder process efficiency was measured in triplicate. The results which were obtained during tests were analyzed with the use of Statistical 11.0 software. Extruder specific mechanical energy was measured in triplicate. Moreover, polynomial regression and determination coefficients were established.

3. RESULTS AND DISCUSSION

As shown in Figure 1, that at lowest pineapple pomace incorporation (5%) to the feed composition, the specified mechanical energy increases with the increase in the die opening percentage and moisture content. It was observed that specific mechanical energy increased until it reaches 75% of the opening speed before it starts to fall (0.37 kWh/kg). It was noticed that a low moisture content at 75% of the die opening resulted in high specific mechanical energy. This phenomenon can be caused by a strong gelatinization of starch with a small percentage of opening and fast exist of extrudates at the maximum opening number of the die holes (100%). The specified mechanical energy builds up with the rise in feed composition moisture content, with the minimum opening rate of the die. Kannadhason *et al*. (2000) also reported similar results that increasing the moisture content in the composition led to an increase in the specified value of the mechanical energy. The specific mechanical energy initially increased, but decreased at the higher percentage of die opening. It was established from figure 2 that at 20% pineapple pomace inclusion, optimum value of specific mechanical energy were established between the moisture content of the feed composition and the selected percentage of the open surface die. At 20% inclusion of pomace, specific mechanical energy decrease with raise in moisture content from 0.71 to 0.92 kWh/kg. This indicated that high inclusion of pomace reduced the starch content in the feed mash and the rate of material flow in the barrel was improved with increase in moisture of the feed mash. This is similar to the high value of increased specific mechanical energy with increase potato based feed (Della Valle *et al.*, 1995). This result also indicated that the effect of melt viscosity during extrusion thus witnessing decrease in SME (Alam and Kumar *et al.*, 2010; Bhattacharya, 1997).

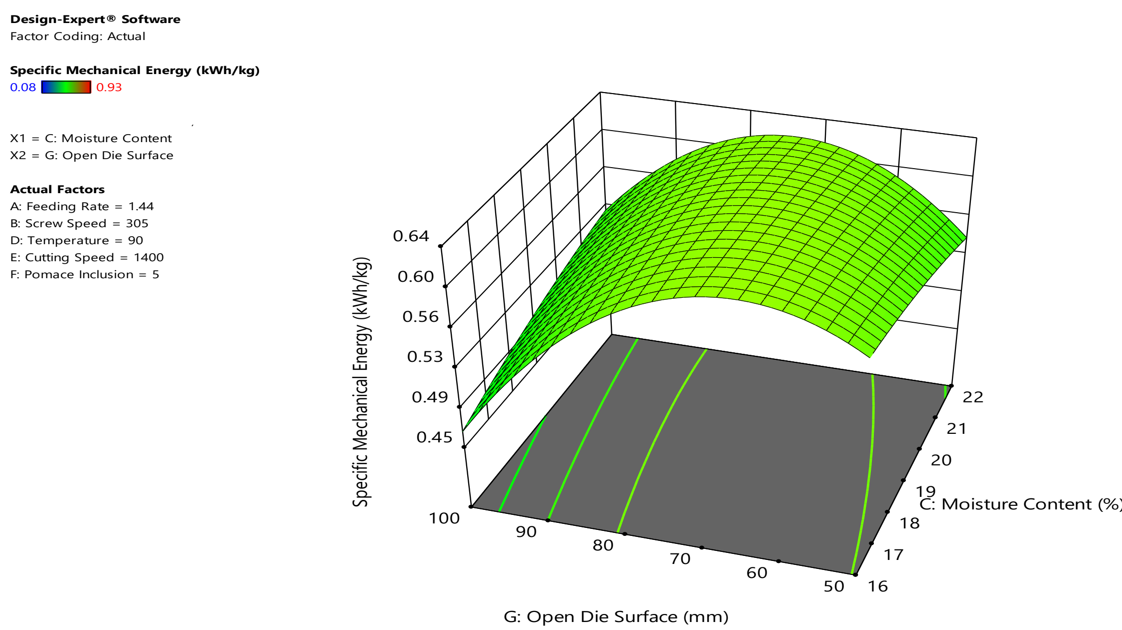

Fig. 1: Effect of open surface die and moisture content on specific mechanical energy at 5% pomace inclusion rate.

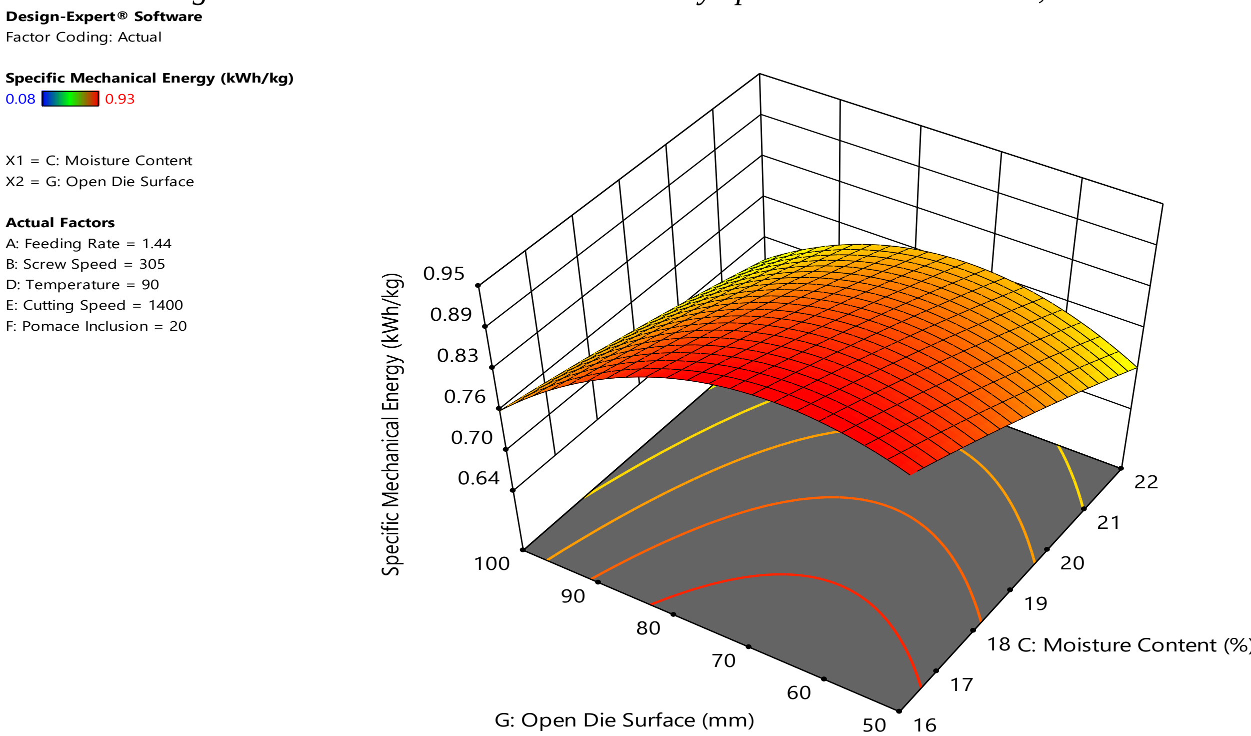

Fig. 2: Effect of open surface die and Moisture content on Specific Mechanical Energy at 20% pomace inclusion rate

The specified mechanical energy ranged from 0.08 to 0.93 kWh / kg with a maximum to the minimum of 12.42. The F model with a value of 34.26 implies a significant model. "No robust F-value" of 20.67 means that the lack of Fit is significant. The "Prob> F" values above 0.05 indicate that the model conditions are significant. Predictive models for the indicated mechanical energy rate using coded variables:

$Y_{SME} = +0.39-0.036x_1-0.32x_2+0.00036x_3-0.017x_4-0.010x_5+0.045x_6-0.017x_7+0.019x_1x_2+0.03x_1x_3+0.056x_1x_4-0.047x_1x_5-0.025x_1x_6-0.014x_1x_7+0.038x_2x_3-0.011x_2x_4-0.0035x_2x_5-0.071x_2x_6+0.025x_2x_7+0.078x_3x_4-0.050x_3x_5-0.039x_3x_6+0.028x_3x_7-0.035x_4x_5-0.061x_4x_6-0.0$
$048x_4x_7+0.036x_5x_6+0.0068x_5x_7-0.004x_6x_7+0.11x_1^2-0.0085x_2^2-0.0057x_3^2+0.034x_4^2-0.024x_5^2+0.042x_6^2-0.086x_7^2$ --- --- ---(3)

The coefficient of cutting speed (x_5), the pomace inclusions ratio (x_6) and the open surface die (x_7) were positive, and the feeding rate (x_1), screw speed (x_2), moisture content (x_3) and temperature (x_4) were negative as indicated in Fig. 3. As a result, an increase in the pomace inclusion ratio and the open surface die would lead to increased mechanical energy (Fig. 3). The relationship between moisture content and temperature are significant model conditions. In this case, the analysis of variance showed that the specific mechanical energy is largely dependent on the linear conditions of screw speed, open surface die, and pomace inclusion ($p < 0.05$), quadratic terms of moisture content of the raw materials and open surface die ($p < 0.05$) with a probability of 0.24%.

4. CONCLUSIONS

As a result of increasing moisture of raw materials specific mechanical energy consumption of the extrusion-cooking process of pineapple pomace fish feed increased. The increase of open die surfaces with the introduction of pineapple pomace at any rate influenced the decrease of specific mechanical energy consumption. The extrusion cooking of pineapple pomace fish feed is related with rather low energy input. The research showed the possibility of obtaining environmentally friendly pineapple pomace-based fish feed with low SME of the process.

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Reducing the Energy Usage of Refrigerated Container for Apple Fruit

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ABSTRACT

This paper investigates the energy usage of a refrigerated container (reefer) for apple fruit, with the objective of reducing energy consumption during shipping. A fully loaded reefer was modeled using a computational fluid dynamic (CFD) method. The model explicitly incorporated the controller dynamics of the cooling unit. The model was validated and used to predict the airflow, temperature distribution, refrigeration heat loads, energy usages and serves as a tool to evaluate temperature control strategies. The transient performance of the reefer while operating under various climate control configuration was investigated. Three different control strategies: (1) increased the temperature range of the controller, (2) turning the evaporator fan 'off 'during the 'off' stages of the compressor and (3) increased the temperature range of the controller and turning the evaporator fans 'off' during the 'off' period of the compressor, were investigated. The alternatives were assessed with the objective of reducing energy consumption while ensuring satisfactory internal temperature conditions. The CFD model provides the visual and numerical values of the spatiotemporal temperature distribution inside the reefer under the different control configuration for analysis. The result demonstrated a 30% reduction in the total electricity usage by adjusting the maximum and minimum temperature range of the controller, from 1± 0.2°C to 1± 0.5°C. Turning the evaporator fan off with the off periods of the compressor resulted in a 20% reduction in energy usage compared to continuously running of the evaporator fan. Application of the third alternative, that is, increasing the temperature range and turning the evaporator fan off following the compressor may result in a pronounced unevenness in the temperature distribution inside the reefer with hot spots in the stack.

Keywords: Food; Energy-saving, Sustainability; Postharvest; Loss-reduction; control.

1. INTRODUCTION

Refrigerated container (reefer) is an insulated rectangular box with a loading door in one end and a refrigeration unit in the other. The refrigeration unit provides the required cooling effect and keeps the air in circulation to regulate the climate: temperature, humidity and gas composition inside the container. The main factors that contribute to the refrigeration load inside the reefer are heat from the ambient air and direct sunlight, heat from the motors of evaporator fans, heat from the produce respiration and heat from defrosting the evaporator coil. An attempt to reduce the heat load into the reefer system should deliberate on reducing these heat loads. From a process control point of view, reducing the contributions from the evaporator fan is important for saving energy. For instance, reducing the working hours of the evaporator fans can save a significant amount of energy (Ambaw et al., 2016; van den Boogaard and de Kramer, 2006). Increasing the energy efficiency of reefer containers through packaging box design and package arrangement has been studied previously (Getahun et al., 2017 a; b; Defraeye et al., 2014). Adaptive model predictive control (MPC) strategies have been proposed by several researchers (van den Boogaard and de Kramer, 2006), which primarily focus on product quality control of chilled foods.

Previous studies employed elaborated refrigeration control algorithms with emphasis on the control of the setpoint temperature. However, the spatiotemporal produce temperature dynamics inside the reefer has not been properly examined. Therefore, there is a strong interest for a method that enables to perform a detailed evaluation of the internal temperature dynamics to assess alternative control strategy. The location of high and low-temperature regions inside the reefer should be identified and consequences evaluated accordingly. In this paper, a model will be presented that can predict the spatiotemporal temperature dynamics inside a fully loaded reefer container. The model is used to evaluate the temperature dynamics and energy efficiencies of selected climate control strategies. More particularly, the model will assess the effect of refrigeration on/off cycling on the temperature history inside the reefer and the energy usages.

2. MATERIALS AND METHODS

2.1 Reefer

Apple fruit was packed in corrugated fibreboard carton (CFC) box. This box has an outer (L × H × W) dimensions of 0.49 m × 0.26 m × 0.29 m and is 3 mm thick (Fig. 1 (a) and (b)). The 40-foot Starcool reefer (Starcool SCI-40, Maersk reefer) was used in this study. The internal dimensions of the unit are length, 11.5 m; width, 2.3 m, and height, 2.4 m. The reefer was loaded with 20 pallets of fruit (64 boxes per pallet, each holding 12 kg apple fruit) and operating at a constant air circulation rate of 8100 m3 h-1. The cooling unit of the reefer is a one-piece unit fitted in the front of the container. The cooling coil uses refrigerant 134a (R134a). The unit can maintain supply air temperature to within +/- 0.25 °C of the set point by positioning the suction modulation valve (SMV) which control the flow of refrigerant gas into the compressor, cycling of the compressor, and cycling of the heaters.

2.2 Measurements

Airflow field and fruit pulp temperatures were monitored during a cooling down period of 72 h (Getahun et al., 2017). Additionally, the power usage of the evaporator fan, condenser, and compressor motors were measured. Power Track instruments (Advanced Monitoring Solutions, Durbanville, South Africa) with ± 0.05 % reactive power uncertainty (class one accuracy) were used to monitor the total and component power consumptions, simultaneously.

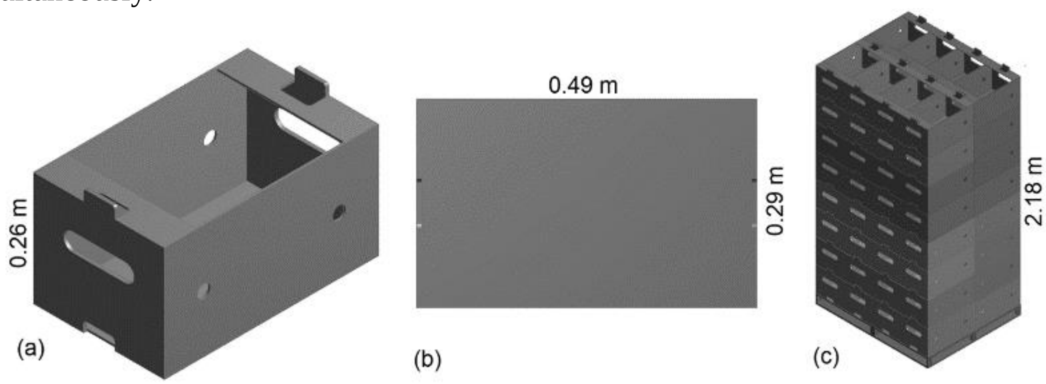

Fig. 1 Schematics showing the dimensions of the CFC used in the study. Isometric view of the box (a), bottom view (b) and palletized stack of the box (c).

2.3 Model formulation

Fig. 2 depicts the model geometry of the reefer. The detailed structure of the T-bar floor (Fig. 2 (b) and (c)) is incorporated. The computational domain contains: the free air domain (the region above and below the evaporator section, the region in between the T-bars, the region above and sides of the stack which is bounded by the room walls, door, ceiling and floor), the porous domain representing the palletized stacked fruit and an additional fluid domain representing the evaporator section.

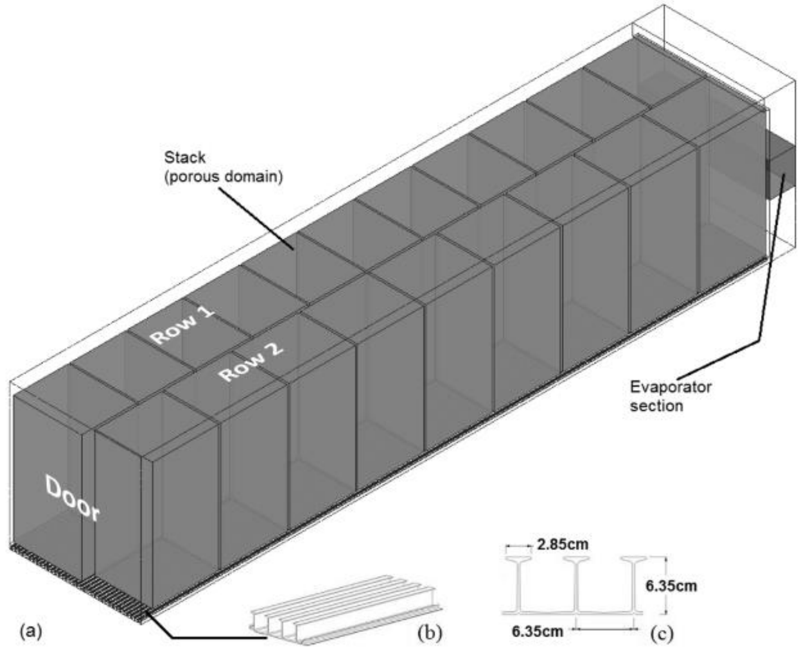

Fig. 2 Schematics of the reefer model.

2.4 Simulations

The CFD model was first validated by comparing it with temperature and energy usage data. The tests covered the period of cooling from an ambient 9.5 °C to the transport temperature, which was about -0.5 °C. Using the validated model, alternative control strategies: (1) increased the temperature range of the controller (Alt1), (2) turning the evaporator fan 'off 'during the 'off' stages of the compressor (Alt2) and (3) increasing the temperature range of the controller and turning the evaporator fans 'off' during the 'off' period of the compressor (Alt3), were investigated.

3. RESULTS AND DISCUSSION

3.1 Energy usage

The measured electricity usages of the different components of the cooling unit of the reefer are shown in Fig. 3. The total energy usage of the reefer during the test (Experiment) is compared with the corresponding CFD model (Model) in Fig. 4. The model correctly captured the measured total energy usage. Fig. 4 also includes the simulated energy usages of the three energy-saving alternatives. The result demonstrated a 30% reduction in the total electricity usage, compared to the test, by adjusting the maximum and minimum temperature range of the controller from 1± 0.2 °C to 1± 0.5°C. Turning the evaporator fan off with the off periods of the compressor resulted in a 20% reduction in energy usage compared to the test. During the test, normal reefer operation, the evaporator fans were continuously running. Application of the third alternative, that is, increasing the temperature range and turning the evaporator fan off following the compressor may result in a significant unevenness in the temperature distribution (see Fig. 5) inside the reefer with hot spots in the stack.

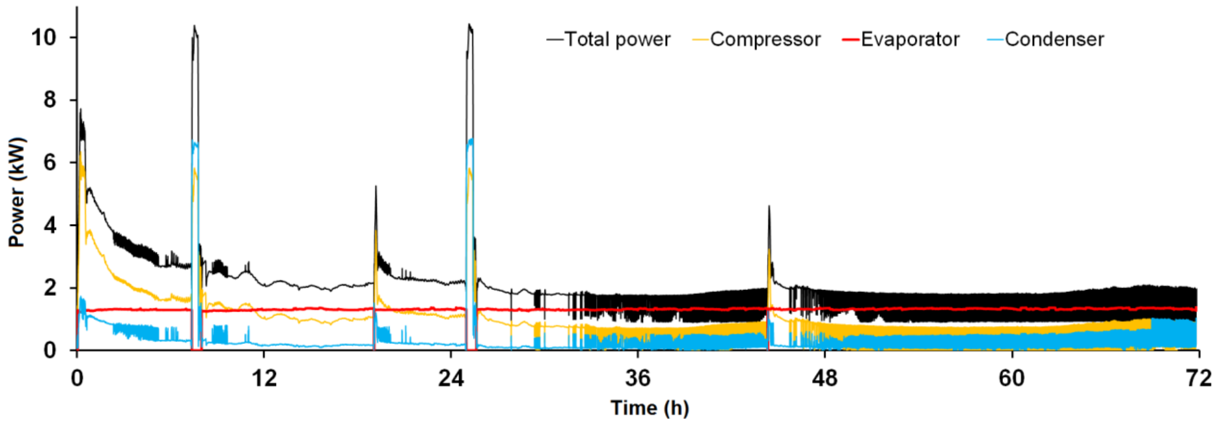

Fig. 3 Measured power consumptions of the different components of the refrigeration unit of the reefer during the cooling down period of 72 h.

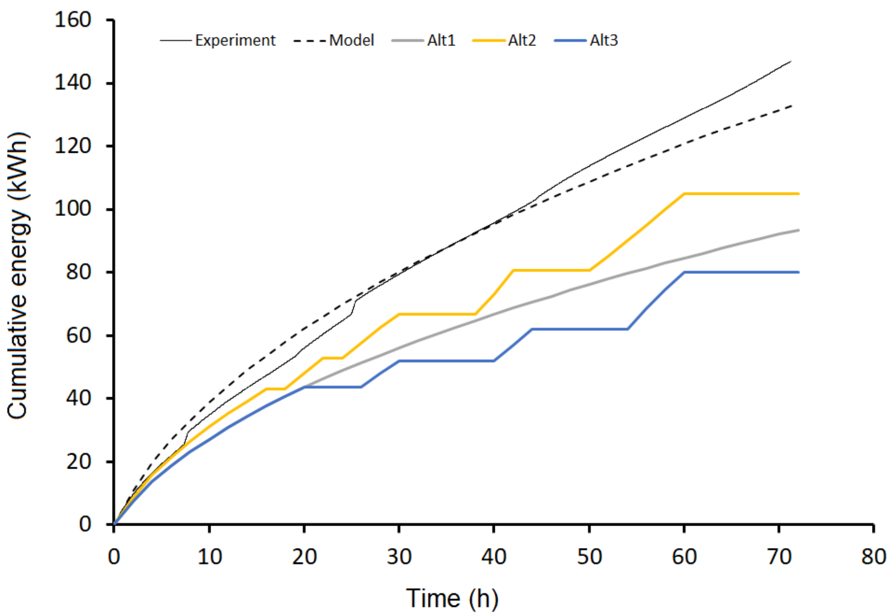

Fig. 4 Cumulative energy consumptions of reefer during the cooling down period of 72 h under different temperature control strategies. Alt1 is energy saving alternative by increasing the temperature range of the controller from 1± 0.2 °C to 1± 0.5°C, (Alt2) is energy saving by turning the evaporator fan 'off 'during the 'off' stages of the compressor and (Alt3) is energy saving by increasing the temperature range of the controller from 1± 0.2 °C to 1± 0.5°C and turning the evaporator fans 'off' during the 'off' period of the compressor.

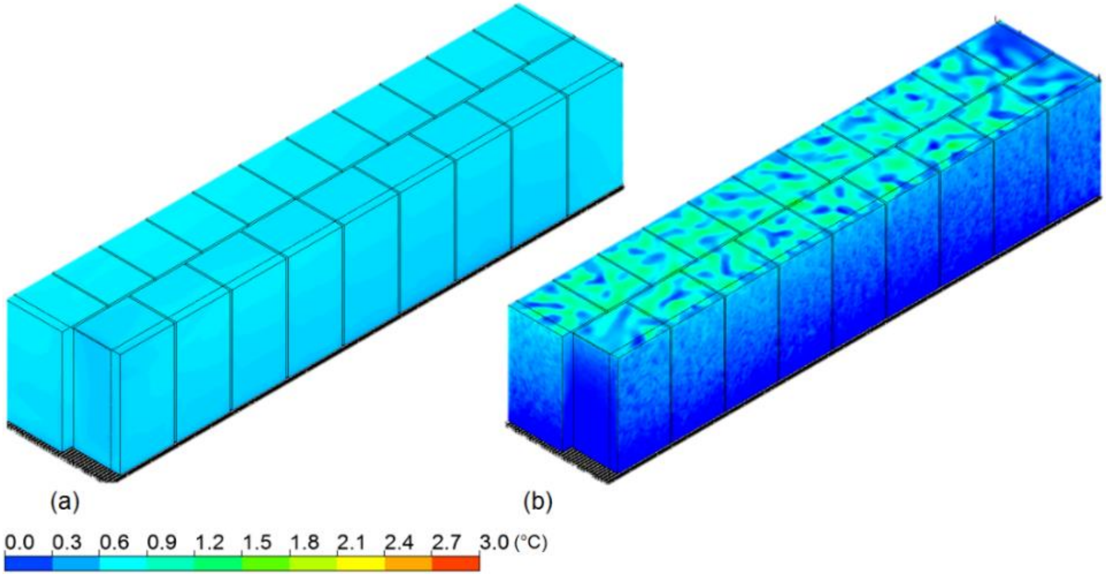

Fig. 5 Instantaneous temperature contours inside the reefer after the cooling unit is off for a period of 2-h. (a) when the evaporator fan is operating and (b) when the evaporator fan is turned off.

4. CONCLUSIONS

Porous medium CFD model of reefer was developed and validated using temperature and energy measurement data. The model explicitly incorporated the controller dynamics of the cooling unit and used to investigate three different energy-saving alternatives. The result demonstrated a 30% reduction in the total electricity usage by adjusting the maximum and minimum temperature range of the controller, from 1± 0.2°C to 1± 0.5°C. During the cooling off and fan off period, due to the dominant effect of natural convection, the hot and light air flows upward towards the ceiling of the reefer. Due to this, the top region of the stack would be the hottest region. Hence, attempt to reduce energy usage by reducing the running hours of the evaporator fans should consider this phenomenon. Further analysis of the reefer internal temperature distribution in consideration of the ambient temperature condition is required to recommend a generalized and control algorithm.

5. ACKNOWLEDGEMENTS

This study is based upon the research supported by the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation. The authors are grateful to Postharvest Innovation Programme (PHI) and HortgroScience for the financial support, and to Mr. Henk Griessel and Mr. Con Louw for their support in organising logistics for the apple packed reefer experiment.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

X-ray Micro Tomography and Lattice-Boltzmann Analysis of the Moisture and Gas Transport in the Peel of Pomegranate Fruit

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ABSTRACT

The microstructure of pomegranate fruit has a crucial influence on the moisture and gas exchange phenomena during postharvest storage and handling processes. However, its detailed structure is still unclear. In this work, X-ray microtomographic (μ-CT) based analysis of pomegranate fruit peel is presented. The μ-CT help to visualize and quantify the porosity and the internal structural arrangement of the peel tissue via the development of 2D and 3D images. Subsequently, Lattice-Boltzmann based numerical model was developed to analyze the transport of water through the porous structure of the pomegranate fruit. This modeling approach used a direct voxel-based 2-phase fluid flow model. This approach helped to avoid the requirement of the mesh file corresponding to the 3-D images obtained from the μ-CT. The meshless feature of the proposed approach makes it a more powerful method, especially for 3-D images generated from X-ray microtomography in which using meshes introduces significant numerical errors into the solution or improving the mesh quality is a complex and time-consuming process. The study was conducted on 'Wonderful', the most important pomegranate cultivar produced and exported from the Western Cape, South Africa. The 3-D imaging of the intercellular spaces revealed that these spaces were not completely interconnected and were disrupted in some parts. The absolute permeability of pomegranate peel tissue ranges from 42 millidarcies (mD) at the bottom to 500 mD at the top of the fruit. Correspondingly, the effective void fraction ranges from 11% at the bottom to 24% at the top of the fruit. The peal sample from the middle of the fruit was always intermediate with the permeability of 212 mD and void fraction of 14%. The result of this study will further be used for numerical modeling of transport processes in pomegranate fruit.

Keywords. Postharvest, Intercellular air spaces, Transport phenomena, Porosity, Permeability, Tortuosity,

1. INTRODUCTION

Pomegranate fruit, being a non-climacteric, is characterized by a very low respiration rate (Caleb et al., 2012). However, pomegranate is a perishable commodity due to moisture loss (Barman et al. 2011). The peel of pomegranate fruit has numerous openings that allow free movement of water vapor, making the fruit highly susceptible to water loss (Fawole and Opara 2013). Gases diffuse is faster in the air than in a liquid or solid, the gas-filled intercellular spaces in the peel of the fruit are thought to be the diffusion pathways for supplying adequate O_2 for respiration and CO_2 for photosynthesis. In addition, the supply of oxygen from the atmosphere into the fruit internal environment, purging of carbon dioxide and fermentative metabolites in the opposite direction, are affected by the microstructure of the fruit peel. Modified atmosphere packaging and application of wax on the fruit surface for the extension of storage life depend on the modification of O_2, CO_2, moisture and/or C_2H_4 concentrations in the atmosphere surrounding the commodity. Quantitative description of the fruit microstructure is important to study the gas transport and water loss behavior of the fruit. Studies have used models of gas diffusion at tissue level to predict the gas exchange properties of apple fruit tissues. The study developed a 3-D microscale model obtained from synchrotron radiation tomography (Ho et al., 2011). This approach has an inherent drawback due to the mesh generation step required to prepare the 3D microscale image for the subsequent computational step. Meshfree methods in computational mechanics have been proposed to overcome the drawback. This technique does not require the generation of the mesh of the complicated three-dimensional domain obtained from the synchrotron radiation tomography and is appealing.

Hence, the first objective of this study was to obtain 3-D spatial information of the gas-filled intercellular spaces of the peel of pomegranate fruit. For the detection of gas-filled spaces within the tissue, μCT was applied. The second objective of this study was to perform microstructure level virtual flow and diffusion experiments directly on CT scans of the pomegranate fruit peels.

3. MATERIALS AND METHODS

3.1 Sample preparation

Pomegranate fruit (Punica granatum L. cv. Wonderful) obtained from the local market (Western Cape, Stellenbosch, South Africa, in Jan 2017), were used in this study. The pomegranate fruits were visually free of any external defects. Prior to scanning by means of X-ray CT, pomegranates were equilibrated to 5 °C and RH of 90%. Cuboid shape specimen of 2 mm × 2 mm × 5 mm was carefully dissected out from the shoulder (the bulge around the calyx at the top of the fruit); cheek (the sides of the fruit); bottom (opposite the calyx). A specimen was immediately wrapped up in parafilm to prevent water loss and then fixed to a specimen holder. Three fruits were used for the experiment.

3.2 X-ray computed tomography (CT) scanner

The scanning of pomegranate peel tissue samples was performed using Phoenix V|Tome|X L240 (General Electric Sensing and Inspection Technologies / Phoenix X-ray, Wunstorff, Germany), equipped with a nano-focus tube at the Stellenbosch University CT Scanner facility (du Plessis et al 2016a). The system was integrated with Phoenix Datos acquisition and reconstruction software (General Electric Sensing and Inspection Technologies/Phoenix X-ray, Wunstorff, Germany). Optimal CT scans (tomograms) were obtained with an isotropic voxel size of 3 µm voxel, using optimized parameters according to the guidelines in du Plessis et al., (2017). X-ray settings included 60 kV and 240 µA, with fastscan option activated, resulting in total scan times of roughly 1 hr per sample, excluding sample setup and subsequent data reconstruction.

3.3 Image analysis

The analysis and visualization of the 3D image were performed using VGStudio Max 3.0 software (Volume Graphics GmbH, Heidelberg, Germany). Data processing, in this case, required an initial de-noising using Adaptive Gauss filter, followed by cropping the volume to remove edge artifacts. This was followed by an advanced surface determination to precisely define the edge between material and void. This process involves a global threshold, locally optimized at every point to minimize human bias and limit the effect of brightness changes across the images.

6.4 Modeling the transport phenomena

i. Hydraulic permeability

Fluid flow simulations were performed using the Lattice-Boltzmann method with the BGK collision model (Succi, 2001) on VGStudioMax software. The model assumes Stokes flow, described by Eq. (1), to model the fluid flow.

$$0 = -\nabla p + \mu \nabla^2 V \tag{1}$$

where V is the flow velocity, p is pressure, µ is dynamic viscosity, ∇ is the gradient operator. Water was assumed as the flowing fluid and fluid thermal properties at standard condition were used. To calculate the permeability of the peel samples, a pressure gradient of 1 Pa (equivalent to 100 Pa m-1) was applied across the two opposite boundaries of the tissue domain (the top and the bottom) while sealing the lateral boundaries. Once the flow velocity, V, is obtained from Eq. (1), the absolute permeability k of the material is calculated from Darcy's law (Eqn. (2)).

$$\langle V \rangle = \frac{-k}{\mu}\frac{dp}{dx} \tag{2}$$

where *dp* is the pressure difference between inlet and outlet, *dx* is the length of the sample (thus, dp/dx is the volume-averaged pressure gradient), µ is the dynamic viscosity of the fluid, and $\langle V \rangle$ is the component of the average flow velocity in the direction of the pressure gradient obtained from solving Eq. (1).

ii. Gas diffusivities

The diffusion coefficients of CO_2 and O_2 in the intercellular pore-space and in the cells were approximated from data (Cussler, 1997) for air and water, respectively (Table 1). Then, the effective diffusivity of the two gases in the 3D- microstructure were modeled based on Fick's 1st law and solved using a mesh-free finite-element method.

Table 2 Diffusivity values of CO_2 and O_2 used in the gas transport model

	Air ($m^2 s^{-1}$)	Water ($m^2 s^{-1}$)
CO_2	1.6×10^{-5}	1.92×10^{-9}
O_2	1.76×10^{-5}	2.10 10^{-9}

5. RESULTS AND DISCUSSIONS

5.1 Analysis of the pore network of the peel of pomegranate fruit

The viscous transport of water through the 3D microstructure was modeled using a direct voxel-based 2-phase material model. A typical simulation of the seepage of water through the 3D microstructure is shown in Fig. 1(a). The absolute permeability measures the ability to transmit fluids (water) through the peel, which is measured in units of millidarcies (mD ≈ 1 × 10-15 m2). The absolute permeability of pomegranate peel tissue ranges from 42 mD at the bottom to 500 mD at the top of the fruit (Fig. 1(b)). Correspondingly, the effective void fraction ranges from 11% at the bottom to 24% at the top of the fruit. The peal sample from the middle of the fruit was always intermediate with the permeability of 212 mD and void fraction of 14%. The hydraulic tortuosity (τ) is a unitless quantity describing the average elongation of fluid streamlines in a porous medium as compared to free flow. It is the factor by which the length of a typical fluid streamline through the medium deviates from the length of a straight line. It is calculated according to Duda et al. (2011).

$$\tau = \frac{\langle V \rangle}{\langle V_n \rangle} \tag{2}$$

where, $\langle V \rangle$ is the volume-averaged magnitude of the velocity and $\langle V_n \rangle$ is the volume-averaged velocity component parallel to the applied pressure differential. The hydraulic tortuosity is inversely related to both the permeability and void fraction. The peel from the bottom of the fruit is always with higher value of tortuosity (= 2.1) while peels from the middle and top of the fruit were with tortuosity of 1.9 and 1.8, respectively.

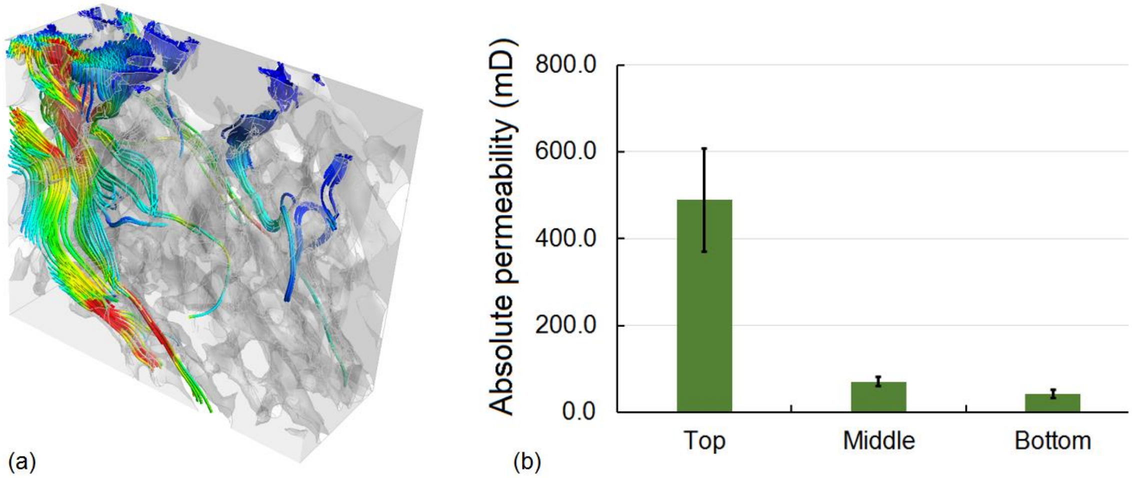

Fig. 3 The viscous transport of water through the 3D microstructure. Flow path through the 3D microstructure (a) and absolute permeability of pomegranate peel tissue (b).

4.2 The effective diffusivity of CO_2 and O_2 in the pore network of the peel of pomegranate fruit

Fig. 2 depicts the distributions of O2 (left column) and CO2 (right column) concentrations in the intercellular void space (top row) and the cells (bottom row) of the pomegranate peel sample. A fixed gas concentration of 1mol m-3 and 0 mol m-3 were used as the top and bottom side boundaries, respectively. The lateral sides of the sample were assumed impermeable. The gas concentrations are spatially non-uniform. The observed non-uniformity is due to the distribution of the void space along the three spatial directions. The O2 concentration is higher both in the pore space (gas phase) and in the cells (liquid phase) than the CO2. This is because O2 diffusivities in the air and in water are higher than the CO2 diffusivities. Accordingly, the effective diffusion coefficients were found to be (3.74±0.25) ×10-7 m2 s-1 and (3.43±0.31) ×10-7 m2 s-1 for O2 and CO2, respectively. The voxel-based approach employed in our study is a diffusion-only model and it does not consider O2 consumption and CO2 production due to the respiration. Considering the non-climacteric nature of pomegranate fruit, respiration can be assumed negligible. However, for a more realistic model, incorporating the respiration kinetic is required.

6. CONCLUSION AND RECOMMENDATIONSS

The 3-D spatial information of the gas-filled intercellular spaces of the peels of pomegranates was obtained for small size samples. Then, the microstructure level flow and gas diffusion parameters were obtained using a direct voxel-based and mesh free finite element approach. The voxel-based, mesh-free approach is a diffusion-only model and it does not consider O2 consumption and CO2 production due to the respiration. Considering the non-climacteric nature of pomegranate fruit, the approach is assumed realistic. For a more realistic model, incorporating the respiration kinetic is required.

The method presented saved the time one would spend on mesh generation. This can translate into substantial cost and time savings in modeling and simulation. Currently, it is only possible to do this on small samples. Considering the continual advancement of X-ray microtomography technology and the accompanying image processing algorithms, it will soon allow for scanning the whole fruit with enough resolution to perform fruit level flow and gas transport analysis.

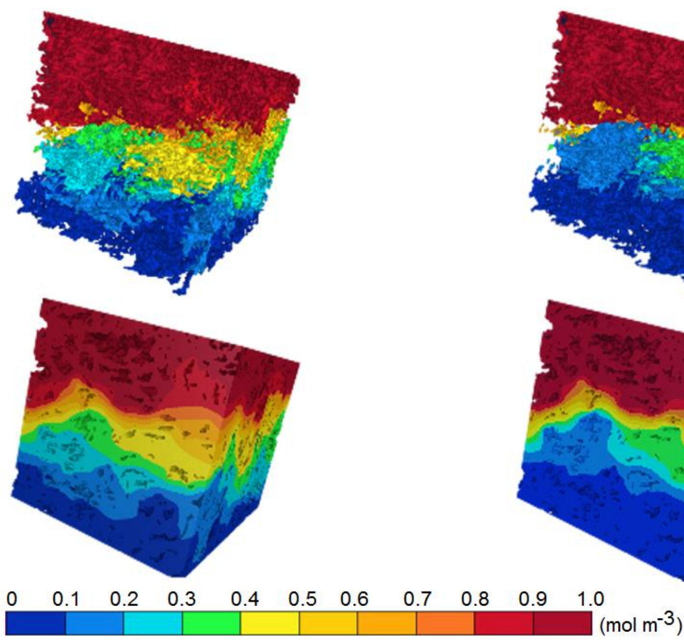

Fig. 4 Simulated O_2 (left column) and CO_2 (right column) distribution in the void space (top raw) and solid part (bottom row) of the peel of pomegranate fruit. At the top and bottom side, an O_2 and CO_2 concentration of 1 mol m^{-3} and 0 mol m^{-3} were applied, respectively. The lateral sides of the sample were assumed to be impermeable. Simulation was carried out using a direct voxel-based, mesh-free finite-element method.

7. ACKNOWLEDGEMENT

This work is based upon research supported by South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation. We would like to thank Mr Stephan Le Roux for technical support.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Empirical Analysis of Traditional Akara Frying Process

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ABSTRACT

Akara results from frying of fermented batter which after frying gives a dome –like shape, it has a brown crust and burnt material at the edges. Information on the existence of a mechanical device with capability for frying akara and carrying out turning operations appears to be very scarce. An empirical analysis of the traditional akara frying process was carried out in order to solve the above problem. The effect of different batter concentration (11g/ml, 13g/ml and 17g/ml) and spoon diameter-depth ratio (3.4.4.0,4.2) on the physical characteristics, frying time and frying rate of akara was investigated. The physical characteristics which include crust thickness, level of shrinkage, oil consumption, akara weight, density, surface area and extent of burnt material formation. Data obtained were subjected to statistical analysis using Excel and SPSS. The results showed that crust thickness, level of shrinkage, oil consumption, and burnt material increased with increase in concentration, frying time, weight, density and surface area also increased with increase in concentration. The result also indicates that crust thickness, level of shrinkage, oil consumption, weight, density, surface area, burnt material, frying time, decreases with increase in spoon diameter-depth ratio. Statistical analysis of variance (ANOVA) showed that all the processing variation and their interaction had significant effects on the physical characteristics of akara at 1% of significance. The model yielded coefficients that enabled the akara physical characteristics to be predicted with high coefficient of determination.

Keywords: Empirical, analysis, traditional, Akara, physical properties, frying process.

1. INTRODUCTION

Akara (fried bean cake) is a popular food in Nigeria and other West African Countries (Ngoddy *et al*., 1986; Henshaw and Lawal, 1993; Ekariko, 2005), and form part of diet for most ethnic groups in Nigeria. Nigerians usually eat it as breakfast with ogi, or lunch with gari or even dinner with eko. Akara is a traditional African food made by deep frying cowpea paste that has been whipped and seasoning with salt, pepper, onions and other optional ingredients. The outer crust of akara is crisp and the interior is spongy like bread.

It is considered to be the most commonly consumed cowpea based food in West Africa (Henshaw & Lawal, 1993;Asare *et al*., 2013). Akara is made mainly from cowpea and other sources like maize ―Monsa‖.It can be fried with vegetable oil, palm oil, and other edible oils. It is a staple food which mostly consumed in Nigeria and other West African countries including Ghana, Togo, Benin, Mali and Gambia. Akara is prepared mainly for sale and consumption for breakfast and snacks. Akara is a popular recipe in Nigeria but its production depends on the different effects on the physical characteristics of Akara such as its sphericity, thickness, diameters in terms oflength, volume and volumetric index as well a**s its weight (Steinkraus, 1994).**Akara is a deep-fat fried ball prepared from whipped cowpea paste, flavoured with pepper, onion and salt (McWatters, 1983; Olapade *et al*., 2004). Whipping of the paste is usually done prior to the addition of other ingredients to incorporate air and enhance the formation of stable foam (Ngoddy, *et al*., 1986; Hung and McWatters 1990). The paste obtained through milling dehulled and cleaned cowpea seeds can be processed into moin moin and akara by steaming or deep-fat frying of the paste respectively (McWatters, 1983). Akara is the most common cowpea-based product in West Africa (Reber, 1983), which makes it contribution to diet particularly significant. Blending and whipping are important steps in processing of cowpea into akara. Blending clearly aids in reducing the particle size of paste to a more acceptable level and thus aiding in better distribution of moisture. Whipping incorporates air into paste, thus making it foam and giving it good dispensing properties and frying qualities (Mbofung *et al*., 2002). Cowpea is a good source of protein in the tropics with the seed containing appreciable amounts of lysine and tryptophan but is deficient in methionine and cystiene when compared to animal protein. The crop therefore plays a critical role in the lives of millions of people in Africa and other parts of the developing world, where it is a major source of dietary protein that nutritionally complements staple low-protein cereal and tuber crops. It is also a valuable and dependable commodity that produces income for farmers and traders (Singh *et al*., 2002; Langyintuo *et al*., 2003).A lot of researches has been conducted on other products such as turkey, chicken, and doughnut but not much has been carried out on Akara processing and production, hence the study aimed at studying the empirical analysis of traditional akara frying process.

2. MATERIALS AND METHODS

2.1 Preparation of Akara

Cowpea was sourced locally at Bodija market in Ibadan, Oyo State. 650 g weight of cowpea was soaked inside a container for five minutes, then the soaked cowpea was dehulled traditionally using hands by rubbing it between two palms. It was then cleaned by separating the coat from the grains. 320 g weight of onions and peppers were mixed with cleaned cowpea and the mixture was then milled. After milling, the viscosity of batter was taken at 11g/ml, 13g/ml and 17g/ml by adding different quantity of water. 1250 ml volume of oil was poured inside a frying pan and placed on fire. The frying was conducted at three different spoon diameters–depths. The frying time were obtained by the addition of time of first turning of akara ball with the time of second turning. The oil temperature before frying was noted as well as oil consumed by akara ball was determined. The experiment was repeated five times.

Figure 1: Frying of akara ball   Figure 2: Akara ball inside the net after frying for cooling

2.2 Determination of physical characteristics

2.2.1 Viscosity

Three different sizes of spoon were used with three levels of viscosity at 11g/ml, 13g/ml, and 17g/ml of butter viscosity respectively.

Viscosity or concentration were expressed as

$$c = \frac{m}{v} \tag{1}$$

Where, m = mass of batter (g)
v = volume of batter (ml)
c = viscosity or concentration (g/ml) of batter

2.2.2 Frying time (F_t)

The time of frying with size was calculated by adding the time of first turning with the time of second turning

$$\mathbf{F_t = F_{t1} + F_{t2}} \tag{2}$$

Where, F_t= Frying time (seconds)
Ft_1 = Time of first turning (seconds)
Ft_2 = Time of second turning (seconds)

2.2.3 Diameter-depth ratio

This is the ratio of the diameter of spoon (in mm) to the depth of spoon (in mm)

$$D_d = \frac{S_D}{S_d} \tag{3}$$

Where, D_d = diameter – depth ratio
S_D = diameter of spoon (mm)
S_d = depth of spoon (mm)

2.2.4 Crust thickness

The crust thickness of akara ball was obtained by the use of vernier caliper. It is measured in mm

2.2.5 Level of shrinkage

The levels of shrinkage were calculated using the expression.

$$s_n = P_v - M_w \quad (4)$$

where, s_n = Level of shrinkage (mm)

P_v = volume of spoon (ml)

M_w = weight of akara(g)

Weight of akara ball

Each weight of akara ball was obtained by weighing each akara ball on an electric weighing balance.

2.2.6 Density of akara ball

The density of akara ball were expressed as

$$D = \frac{M_w}{V_p} \quad (5)$$

Where, D = density of akara ball (g/ml)

M_w = Weight of akara ball (g)

V_p = Volume of akara ball (ml)

2.2.7 Surface area of akara (cm^2)

The surface area of each akara ball was obtained using the method of coating. This method of cooking was wrapping of akara ball with foil paper and cut off the excess paper. Then, the foil paper was removed from akara ball and spread on a graph sheet. The shape of the foil paper on the graph sheet was traced and the surface area of akarawas obtained by counting the numbers of square occupied by foil paper.

2.2.8 The extent of burnt material formation

The extent of burnt material formation was obtained by the use of vernier caliper. It is measured in mm.

2.2.9 Oil Consumption (ml)

The volume of oil consumed by akara ball were obtained by measuring the initial volume of oil before frying and final volume of oil after frying

$$O_c = V_i - V_f \quad (6)$$

Where, O_c = Oil consumption (ml)

V_i = Initial volume of oil before frying (ml)

V_f = final volume of oil after frying (ml)

Note – Neglect the volume of oil evaporated or sublimed by heat.

2.3 Data Analysis

The results obtained were analysed and evaluated using Turkey and Duncan Multiple Analysis of Variance, as well as multiple regression models.Data analysis were used to determine the variation of physical characteristics of akara ball and frying parameters such as frying time, frying rate, density, oil consumption, level of shrinkage, crust thickness, weight, extent of burnt material and surface area at three different levels of batter viscosity and three spoon diameter-depth respectively.

3. RESULTS AND DISCUSSION

The result of frying parameters and physical characteristics determined for each batter concentration at different spoon sizes are presented in Tables 1, 2, and 3 respectively.
From Table 1, it can be seen that the shortest frying time for concentration of 11 g/ml was obtained at spoon size A having pan diameter-depth ratio of 4:2 and the longest frying time was obtained at spoon size C having light spoon diameter-depth ratio of 3.4. Similar observations were obtained for the frying time when batter concentrations were 13 g/ml and 17 g/ml respectively (Table 2 and 3).

Table 1: Akara physical characteristics, frying time and frying rate for different spoon size at batter concentration of 11g/ml.

S/N	Measured Parameters	Spoon size A	Spoon size B	Spoon size C
1	Spoon depth (mm)	13	15	20
2	Spoon diameter (mm)	55	60	68
3	Spoon diameter depth ratio	4.2	4.0	3.4
4	Crust thickness (mm)	1.9	2.0	2.1
5	Extent of burnt material formation(mm)	1.8	1.6	1.7
6	Level of shrinkage	4.6	4.8	5.0
7	Oil consumption (ml)	6.9	7.6	8.0
8	Oil temperature (^{0}C)	205	198	204
9	Time of 1st turning (sec)	240	245	253
10	Time from 1st turning to 2nd turning (sec)	231	241	238
11	Frying time (sec)	471	486	491
12	Spoon volume (ml)	35	40	42
13	Variation of akara weight (kg)	0.056	0.051	0.065
14	Density (kg/ml)	0.00054	0.00057	0.00061
15	Frying rate (no/hr)	180	156	120
16	Surface area (cm^2)	36	43	45

Table 2: Akara physical characteristics, frying time and frying rate for different spoon size at batter concentration of 13g/ml

S/N	Measured Parameters	Spoon size A	Spoon size B	Spoon size C
1	Spoon depth (mm)	13	15	20
2	Spoon diameter (mm)	55	60	68
3	Spoon diameter depth ratio	4.2	4.0	3.4
4	Crust thickness (mm)	1.8	2.1	2.3
5	Extent of burnt material formation (mm)	1.7	1.5	1.8
6	Level of shrinkage	4.4	4.6	4.9
7	Oil consumption (ml)	6.5	7.3	8.1
8	Oil temperature (^{0}C)	202	200	204
9	Time of 1st turning (sec)	241	243	249
10	Time from 1st turning to 2nd turning (sec)	232	246	261
11	Frying time (sec)	473	489	510
12	Spoon volume (ml)	35	40	42
13	Variation of akara weight (kg)	0.054	0.053	0.068
14	Density (kg/ml)	0.00055	0.00058	0.00064
15	Frying rate (no/hr)	178	161	130
16	Surface area (cm^2)	34	40	42

3.1 Observable phenomena that occur during frying of akara

The first observed phenomenon after pouring the batter into the frying pan is rapid evaporation of water from the surface of the batter because of the high temperature of the frying oil and there was little reduction in temperature. There was a puffing (bubble like) at the top of akara because of loss of moisture. After that, due to the loss of moisture from the batter by hot oil and oil uptake by batter due to high temperature, crust was started to develop at the edges of akara. After the first turning of akara (1st turning) akara was swelled up and then gradually shrunk down due to loss of moisture and gradual increase in frying temperature. Burnt material started to develop at the ring of akara which indicates that akara is ready. Sequences of events that take place during the frying of mass: (a) Rapid evaporation of water from the batter by hot oil and oil uptake by batter due to high temperature (b) Formation of crust (c) Swelling (d) Shrinkage (e) Burnt material formation.

Table 3: Akara physical characteristics, frying time and frying rate for different spoon size at batter concentration of 17g/ml

S/N	Measured Parameters	Spoon size A	Spoon size B	Spoon size C
1	Spoon depth (mm)	13	15	20
2	Spoon diameter (mm)	55	60	68
3	Spoon diameter depth ratio	4.2	4.0	3.4
4	Crust thickness (mm)	1.7	2.0	2.1
5	Extent of burnt material formation (mm)	1.6	1.5	1.7
6	Level of shrinkage	4.2	4.3	4.5
7	Oil consumption (ml)	6.6	7.4	8.2
8	Oil temperature (^{0}C)	201	210	215
9	Time of 1st turning (sec)	240	245	259
10	Time from 1st turning to 2nd turning (sec)	230	241	260
11	Frying time (sec)	470	486	519
12	Spoon volume (ml)	35	40	42
13	Variation of akara weight (kg)	0.053	0.056	0.064
14	Density (kg/ml)	0.00049	0.00056	0.00063
15	Frying rate (no/hr)	172	164	136
16	Surface area (cm^2)	35	42	44

Table 4: Result of ANOVA on the crust thickness of akara

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	13.260[a]	8	1.658	23.47	0.000
Intercept	145.622	1	145.622	1642.52	0.002
Dp	8.330	3	2.777	72.154	0.000
C	.110	2	.055	9.462	0.000
Dp * C	.050	3	.017	2.341	0.025
Error	.031	18	.000		
Total	151.980	27			
Corrected Total	13.260	26			

R Squared = 0.894 (Adjusted R Squared = 0.850)

3.2 Crust thickness

The relationship between crust thicknesses, spoon diameter depth ratio and akara concentration could be adequately expressed using multiple regression models presented as:

$$\mathbf{CT = 0.952 - 2.447D_p - 0.062C + 0.173DPC - 0.474{D_p}^2 + 0.011C^2, R^2 = 0.994} \quad (7)$$

Where: CT = crust thickness in mm, C = concentration in g/ml, Dp = Diameter depth ratio

A t-test of coefficient shows that the constants Dp, C, DPC, Dp^2 and C^2 terms made 99.4% significant contributions to the predictive capacity of the equation. In a similar vein, the ANOVA results show thatDp, C and DPC had statistical significant effect on crust thickness at 99.4% (Table 4). This implies that the crust thickness obtained at different diameter-depth ratio and concentrations are significantly different.

3.3 Level of shrinkage

The relationship between level of shrinkage, spoon diameter depth ratio and akara concentration could be adequately expressed using multiple regression models presented as:

$$SH = 6.316 - 0.514Dp - 0.226C + 0.047DPC - 0.019DP^2 + 0.003C^2, R^2 = 0.968 \quad (8)$$

Where: SH = level of shrinkage in mm, C = concentration in g/ml, Dp = Diameter depth ratio

A t-test of coefficient shows that the constants Dp, C, and Dp^2 term made 96.8% significant contributions to the predictive capacity of the equation. Similarly, the result of ANOVA shows that Dp, C and DPC had statistical significant effect on SH (level of shrinkage) at 99.4% (Table 5). This implies that the level of shrinkage obtained at different diameter-depth ratio and concentrations are significantly different.

Table 5: Result of ANOVA on the level of shrinkage of akara

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	1.767[a]	8	.221	12.58	0.000
Intercept	524.273	1	524.273	28953.61	0.000
Dp	9.740	3	3.247	51.642	0.000
C	1.420	2	.510	2.306	0.011
Dp * C	.020	3	.007	1.432	0.000
Error	.000	18	.000		
Total	570.330	27			
Corrected Total	1.767	26			

R Squared = 0.968 (Adjusted R Squared = 0.961)

3.4 Frying time

The relationship between frying times, spoon diameter depth ratio and akara concentration could be adequately expressed using multiple regression models presented as:

$TF = 478.315 - 113.270Dp + 1.624C + 9.111DPC - 17.406DP^2 + 1.079C^2, R^2 = 0.950$
(9)

Where: TF = frying time (sec), C = concentration in g/ml, Dp = Diameter depth ratio
A t-test of coefficient shows that the constants Dp, C, DPC, Dp^2 and C^2 term made 95.0% significant contributions to the predictive capacity of the equation. In a similar vein, the ANOVA results show that Dp, C and DPC had statistical significant effect on frying times at 95.0% (Table 6). This implies that the frying time obtained at different diameter-depth ratio and concentrations are significantly different.

Table 6: Result of ANOVA on the frying times of akara

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	6900.000[a]	8	862.500	751.23	0.000
Intercept	5955029.894	1	5955029.894	216421.24	0.000
Dp	5645.000	3	1881.667	263.82	0.007
C	428.500	2	214.250	126.19	0.000
Dp * C	817.000	3	272.333	78.32	0.018
Error	238.06	18	.196		
Total	6445575.000	27			
Corrected Total	6900.000	26			

R Squared = 0.950 (Adjusted R Squared = 0.938)

3.5 Oil consumption

The relationship between oil consumption, spoon diameter depth ratio and akara concentration could be adequately expressed using multiple regression models presented as:

$OC = 10.498 - 3.743Dp - 0.097C + 0.344DPC - 0.755DP^2 + 0.017C^2, R^2 = 0.985$
(10)

Where: OC = oil consumption in ml, C = concentration in g/ml, Dp = Diameter depth ratio
A t-test of coefficient shows that the constants Dp, C, DPC, Dp^2 and C^2 term made 98.5% significant contributions to the predictive capacity of the equation. In a similar vein, the ANOVA results show that Dp, C and DPC had statistical significant effect on oil consumption at 98.5% (Table 7). This implies that the oil consumption obtained at different diameter-depth ratio and concentrations are significantly different.Results show that the diameter-depth ratio of 3.4 is statistically higher that diameter-depth ratio of 4.0 and significantly lower than diameter depth ratio of 4.8.

Table 7: Result of ANOVA on the oil consumption of akara

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9.720[a]	8	1.215	7.154	0.021
Intercept	1337.859	1	1337.859	3251.72	0.000
Dp	9.290	3	3.097	1.843	0.001
C	.085	2	.043	.721	0.000
Dp * C	.250	3	.083	.284	0.000
Error	.000	18	.000		
Total	1488.240	27			
Corrected Total	9.720	26			

R Squared = 0.985 (Adjusted R Squared = 0.981)

3.5 Density

The relationship between variation of density, spoon diameter depth ratio and akara concentration could be adequately expressed using multiple regression models presented as:

$$D = 0.001 + 0.000Dp - 1.476E\text{-}005C - 3.146E\text{-}005DPC - 6.533E\text{-}005DP^2 + 3.035E\text{-}006C^2,\quad R^2 = 0.993 \qquad (11)$$

Where: D = Density kg/ml, C = concentration in g/ml, Dp = Diameter depth ratio

A t-test of coefficient shows that the constants Dp, C, DPC, Dp^2 and C^2 term made 99.3% significant contributions to the predictive capacity of the equation. In a similar vein, the ANOVA results show that Dp, C and DPC had statistical significant effect on density of akara 99.3% (Table 8). This implies that the density obtained at different diameter-depth ration and concentrations are significantly different.

Table 8: Result of ANOVA on density and spoon diameter ratio on akara concentrations

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	5.347E-008[a]	8	6.683E-009	124.896	.000
Intercept	8.142E-006	1	8.142E-006	42631.052	.000
Dp	4.567E-008	3	1.522E-008	326.289	.007
C	2.025E-009	2	1.012E-009	62.324	.000
Dp * C	3.725E-009	3	1.242E-009	1.231	.617
Error	.000	18	.000		
Total	8.963E-006	27			
Corrected Total	5.347E-008	26			

a. R Squared = 0.993 (Adjusted R Squared = 0.986)

3.6 Surface area

The relationship between variation of surface area, spoon diameter depth ratio and akara concentration could be adequately expressed using multiple regression models presented as:

$$D = 107.675 - 33.638Dp - 0.413C + 3.674DPC - 9.723DP^2 - 0.033C^2,$$

$R^2 = 0.939$

(12)

Where: SA = surface area in cm², C = concentration in g/ml, Dp = Diameter depth ratio

A t-test of coefficient shows that the constants Dp, C, DPC, Dp^2 and C^2 term made 93.9% significant contributions to the predictive capacity of the equation. In a similar vein, the ANOVA results show that Dp, C and DPC had statistical significant effect on surface area at 93.9% (Table 9). This implies that the surface area obtained at different diameter-depth ratio and concentrations are significantly different.

Table 9: Result of ANOVA on surface area in cm²

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	404.667[a]	8	50.583	196.73	.000
Intercept	39042.300	1	39042.300	24518.68	.000
Dp	372.000	3	124.000	172.81	.000
C	29.500	2	14.750	10.065	.000
Dp * C	.000	3	.000	.004	.000
Error	.000	18	.000		
Total	43845.000	27			
Corrected Total	404.667	26			

R Squared = 0.993 (Adjusted R Squared = 0.986)

3.7 Burnt materials

The relationship between burnt materials, spoon diameter depth ratio and akara concentration could be adequately expressed using multiple regression models presented as:

$$D = 2.061+1.078Dp - 0.073C – 0.147DPC +0458DP^2 +0.009C^2,$$

$R^2 = 0.929.$

(13)

Where: BM = extent of burnt materials in mm, C = concentration in g/ml,
Dp = Diameter depth ratio

A t-test of coefficient shows that the constants Dp, C, DPC, Dp^2 and C^2 term made 92.9% significant contributions to the predictive capacity of the equation. In a similar vein, the ANOVA results show that Dp, C and DPC had statistical significant effect on burnt materials at 92.9% (Table 10). This implies that the burnt materials obtained at different diameter-depth ration and concentrations are significantly different.

Table 10: Result of ANOVA on the variation of burnt materials on akara concentrations

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	.307[a]	8	.038	15.921	.000
Intercept	69.713	1	69.713	2689.387	.000
Dp	.208	3	.069	48.696	.000
C	.047	2	.024	53.294	.000
Dp * C	.052	3	.017	2.82	.107
Error	.170	18	1.070		
Total	74.310	27			
Corrected Total	.307	26			

R Squared = 0.993 (Adjusted R Squared = 0.986)

4. CONCLUSION

The evaluation of frying parameters and physical characteristics using the traditional frying method for different pan diameter-depth ratio and batter concentration revealed the following:

Crust thickness, level of shrinkage, oil consumption and burnt material increased with increase in concentration. Frying time, weight, density and surface area also increases with increase in concentration. Crust thickness, frying time, weight, density, surface area and oil consumption decreased with increase in diameter-depth ratio.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Effects of Moisture Content on some Physical Properties of Okra Seeds Variety

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ABSTRACT

Some physical properties of four varieties of okra seeds NHAe47-4, LD88, V-35 and 'Elesoagbonrin' were determined at moisture content levels of 7, 14, 21 and 28 percent (wet basis). The properties determined were size and shape, mass, 1000-seed weight, sphericity, porosity, true and bulk densities, surface and projected areas. The axial dimensions, geometric mean diameter, individual seed mass, 1000-seed weight increased as moisture content increase for the four varieties. The obtained mean values are: 0.08 g (seed mass), 6.11mm (major diameter), 5.09mm (medium diameter), 4.68 mm (minor diameter), 5.26 mm (geometric mean diameter), 98.5 % (sphericity), 1.2 g/cm^3 (true density), 0.61 g/cm^3 (bulk density), 74.67 % (porosity), and 56.78 g (1000-kernel weight). The effect of moisture content was highly significant on the properties ($p < 0.05$) except for bulk density and porosities. Among variety, mass and bulk density of seed was found not significant. Average number of seed per pod was 114 and the shape was considered round. Therefore, the results of this study would serve as data base for the design of Okra pods and seeds processing, handling and storage equipment.

Keywords: Okra seed, physical properties, moisture content, variety.

1. INTRODUCTION

Okra (*Abelmoschus esculentus(L)Moench*) is a herb of the family of Maluaceae. It is one of the most important vegetables widely grown throughout the tropics especially in West Africa for its tender fruits, young leaves and seeds. Okra seed (dry) has high potential as a good source of oil and protein for human diets, which is one of the problems in diets of most developing countries of the world, like Nigeria. Okra like other so-called minor legumes has paucity of information on it physical properties which should be investigated and exploited as a cheap source of nutrients to augment the shortage of protein and oil in the diets of large section of the population for proper growth and development in accordance with the recommendation of Irtwange and Igbeka (2002) for Africa yam bean.

Moisture content is a vital parameter which is an influential factor on all crop processing procedures and other physical properties (Ilori *et al*, 2010 and Igbeka, 2013). Adejumo *et al* (2011) studied the effect of moisture content and variety on selected mechanical properties of okra and found out that the force of impact and compression decreased as moisture content was increased and varied among the varieties. Gupta and Das (1997), studied physical properties of sunflower seeds and kernels as a function of moisture content, in the range of 4 - 20 % d.b, the bulk density of the rewetted seed decreased from 462 to 434 kg/m^3, true density increased from 706 to 765 kg/m^3, porosity increased from 34.3 to 43.3 %. Suthar and Das (1996), studied the effect of moisture content of 5 - 40 % d.b on the physical properties of Karingda [citrullus lanatus (Thumb) Manst] seeds. Bulk density, terminal velocity and angle of repose increased linearly, while true density and porosity decreased linearly with increased moisture content.

Moreover, Jain and Bal (1997), developed equation for calculating volume, surface area and sphericity of a single grain of pearl millet. The surface area and volume of single pearl millet were found to be 12.5 mm^2 and 3.8 mm^3 for hybrid variety and 16.4 mm^2 and 5.8 mm^3 for the traditional variety; sphericity of the grain was 0.94 and the bulk density varied between 830 and 866 kg/m^3. The grain density was found to be about 1600 kg/m^3 and Porosity varied between 45 and 49 %.

Oje and Ugbor (1991), determined some physical properties of oil-bean seeds at moisture content 4.55 % d.b; the major diameter ranged from 60 to 70 mm and thickness 9 - 19 mm. It has a low average sphericity of 0.6, roundness of 0.4, density of 1.12 g/cm^3 higher than that of water. Arora (1991), determined engineering properties like size, diameter, volume, bulk density, particle density and porosity of 3 varieties of rough rice (Oryza sativa) at 8.10 - 27.23 % moisture levels, and found out that the properties were linearly dependent upon moisture content. Gowda *et al* (1995), studied the effects of moisture content (8.24 - 27.01 %) on physical properties of Soybean CV. Maple Belle seeds. The seed length, width and thickness, sphericity, volume and 1000-seed weight increased with increased moisture content while solid density and bulk density decreased. Orji (2001), studied some physical properties of Breadfruit seed at moisture content of 37.5 % (wb), and obtained geometric mean diameter of 7.3 x 10^{-3} m - 6.6 x 10^{-3} m, density of 1097.83 - 1214.29 kg/m^3.

Dutta *et al* (1988), determined the dependence of physical properties of Gram on moisture content and obtained average 1000-grain weight of 0.173 kg, a mean surface area of 133.4 mm^2 and sphericity of 74 % at 10.9 % m.c d.b, bulk density and kernel density decreases in moisture range 9.64-31.0 % db. Carman (1996), evaluated the physical properties of lentil seed as a function of moisture content at 6.5-32.6 % (d.b). The average diameter, thickness, unit mass and volume of seed were 6.64 mm, 2.65 mm, 0.070 g and 49.08 mm^3 respectively. The bulk density decreased, while porosity, projected area, terminal velocity, the static and dynamic co-efficient of friction increased linearly with increased moisture content. Kulkarni *et al.* (1993), determined spatial dimensions of soybean cv.js7224 and found out that the seed dimensions increased linearly with increased moisture content (8 -11.4% d.b). Ilori *et al.* (2016), studied the effects of moisture content on some physical properties of Corchorus Olitorius seed and observed that within 9.86 to 17.69% db moisture content, bulk density, true density and porosity decreased from 0.6965g/cm3 to 0.6146g/cm3, 1.2223g/cm3 to 1.1364g/cm3 and 38.42 to 35.26% respectively.

A search through literature revealed little on physical properties of okra, thus, the need to establish some of the physical properties as data base for the development of its processing machinery.

2. MATERIALS AND METHODS

The initial moisture content of the four varieties of Okra NHAe47-4 and LD88 (NIHORT), V-35 (IAR&T) and 'Elesoagbonrin' (Yoruba) was determined by the oven method (ASAE Standards, 1993). Methods developed by Visvanathan *et al* (1996) were used for sample preparation to obtain desired moisture content. Equation as:

$$Bf = \frac{Ai(100-a)}{100-b} \quad (1)$$

$$Q = \frac{Ai(b-a)}{100-b} \quad (2)$$

Where, Bf = Final mass of the sample after drying (kg), Ai = Initial mass of the sample, (kg), a = Initial moisture content of sample, % (wb),b = Final (desired) moisture content, % (wb),Q = Mass of water to be added, (kg)

2.1 Shape, Size and Sphericity

Shape and size are inseparable physical properties and are both generally necessary if an object is to be satisfactory described.

Thirty seeds were randomly selected from each variety as samples. Three linear dimensions of each seed namely major, intermediate and minor diameters were measured (Fig 1). The shapes of seeds were compared with the charted standards (Moshsenin, 1980) and the equivalent diameter and sphericity of each seed were determined using the following equation proposed by Jain and Bal (1997).

$$\text{Equivalent Diameter, } DE = (D_1 D_2 D_3)^{1/3} \quad (3)$$

$$\text{and sphericity, } \emptyset = \left[\frac{D(2D_1 - D)}{D_1^2}\right]^{1/3} \quad (4)$$

Where D_1 is largest principal dimension, mm ; D_2 is second largest principal dimension, mm ; D_3 is smallest principal dimension, mm and D is $(D_2D_3)^{½}$

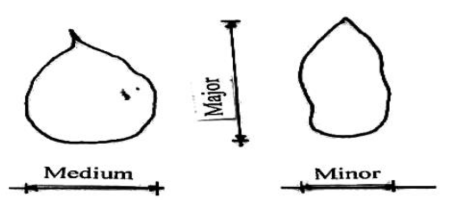

Fig 1: Linear Dimensions of Okra Seed

2.2 Bulk and True Densities

The bulk density of dry okra seed at different moisture contents were determined by filling a container (an open top cylinder of 20 mm diameter and 20 mm high) of known self-weight to the brim with okra seed and weighed to determine the net weight of the seed. Uniform density was achieved by tapping the container 10 times in the same manner in all measurements, the bulk density was calculated as:

Bulk Density (g/cm^3) = $\frac{Weight\ of\ sample(g)}{Volume\ \ occupied\ (cm^3)}$ (5)

The volume of seeds was determined using the equation proposed by Jain and Bal (1997) given as:

Volume of seed (cm^3) = $V_1 = \frac{\pi D^2 D_1^2}{6(2D_1 - D)}$ (6)

Where, $D = (D_2 D_3)^{1/2}$; D_1 = major principal dimension, mm; D_2 = intermediate principal dimension, mm and D_3 = minor principal dimension, mm.

True density (g/cm^3) = $\frac{Weight\ of\ sample(g)}{Volume\ \ of\ water\ displaced\ (cm^3)}$ (7)

2.3 Porosity

Porosity of dry okra seeds were determined theoretically from bulk and true densities of seeds using the relationship presented by Jain and Bal (1997) as follows:

$$P_P = \frac{P_b}{1 - P_t} \quad (8)$$

Where, P_b is bulk density; P_P is particle density and P_t is porosity.

2.4 Thousand-kernel Weight of Okra Seed and Surface Area

Thousand-kernel weight (TKW) was determined by weighing 1000 seeds using an electronic weighing balance having sensitivity of 0.01 g. The surface area of seed was determined by equation developed by Jain and Bal (1997); as:

$$S = \frac{\pi D D_1^2}{(2D_1 - D)} \quad (9)$$

Where, S is surface area, mm^2; $D = (D_2 D_3)^{1/2}$ (geometric mean); D_1 = largest principal dimension, mm; D_2 = second largest principal dimension, mm and D_3 = smallest principal dimension, mm.

2.5 Statistical Experimental Design and Analysis

A - 2 x 4 factorial in completely Randomized Design, (CRD) experimental design was used with a total of 960 observations (4 variety x 4 moisture content levels x 30 samples) each for major, intermediate, minor and equivalent diameters, sphericity, bulk and true densities, porosity, surface area of seeds respectively and 480 observations for 1000-seed weight. The means were separated using Duncan multiple and ANOVA.

3. RESULTS AND DISCUSSIONS

3.1 Spatial Dimensions

The effect of moisture content on the major, medium, minor and geometric mean diameters of four okra seed varieties are as shown in Table 1 to 4. It was observed that the diameters increased with increase in moisture content. The seed major diameter of variety NHAe47-4 increased from 5.89 to 6.64 mm, medium 5.07 to 5.37 mm, minor from 4.65 to 4.95 mm and geometric means from 5.18 to 5.61 mm. V-35 seed diameter increased from 6.02 to 6.39 mm (major), 4.95 to 5.35 (medium), 4.57 to 4.81 mm (minor) and 5.16 to 5.45 mm (geometric mean). The seed diameter of variety LD88 increased from 5.5 to 6.39 mm (major), 4.64 to 5.21 mm (medium), 4.28 to 4.65 mm (minor) and 4.78 to 5.37 mm (geometric mean) and seed diameter of variety 'Elesoagbonrin' increased from 6.02 to 6.25 mm (major), 4.79 to 5.23 mm (medium), 4.65 to 4.86 mm (minor) and 5.18 to 5.41 mm (geometric mean).

Okra seed major, medium, minor and geometric mean diameters show a positive correlation between increase in dimensions and moisture content increase with high R^2 values. The relationships are logarithmic ($R^2 = 9.0 – 9.9$) as presented in Fig. 1 to 4 and Table 5. Similar results have been reported by other investigators like Arora (1991) for 3 varieties of rough rice (*Oryza sativa*) at 5 moisture content levels, Gowda *et al* (1995) for soybeans cv. Maple Belle seeds at 8.24 – 27.01 % moisture content range, Orji (2001) for breadfruit seeds at 37.58 % moisture content and Kulkarni *et al* (1993) for soybean cv.js 7224 at 8 and 11.4 % (d.b) moisture content. The seed dimension ranges are 6.06 to 6.14, 5.06 to 5.11, 4.62 to 4.67 and 5.22 to 5.26 mm for major, medium, minor and geometric mean diameters and the shape is round (fairly spherical).

The size and shape of okra seed affect its processing and handling. On the separation of the seed and chaff, if the screen hole is too large, this may result in unclean seeds, while too narrow a hole may lead to reduced cleaning efficiency. For optimum performance of pulse/grain thresher, concave clearance and sieve openings have to be carefully selected. The obtained results are therefore useful in developing the crop threshing machinery.

Table 1. Overall Average of some Physical Properties of Okra Seed

	M_s g	Diameter (mm) M_A	M_E	M_I	G_M	S_P %	T_D g/cm^3	B_D g/cm^3	P_O %	K_W g
Means	0.08	6.11	5.09	4.68	5.26	98.58	1.20	0.61	74.67	56.78
Std. dev.	0.06	0.35	0.25	0.27	0.22	0.55	0.90	0.24	43.40	29.11
Minimum	0.04	5	4	4	4.56	94.34	0.61	0.47	0.06	35.90
Maximum	0.08	8	5.9	5.3	5.92	100	12.31	0.98	99.92	78.01

M_S = Mass, M_A = Major, M_E = Medium, M_I = Minor, G_M = Geometric mean, S_P = Spherisity, T_D = True density, B_D = Bulk density, P_O = Porosity, K_W = 1000 kernel weight, 95% Confidence limit

Table 2. Moisture Content Effects on some Physical Properties of Okra Seed

Mc	M_S G	Diameter (mm) M_A	M_E	M_I	G_M	S_P %	T_D g/cm^3	B_D g/cm^3	P_O %	K_W g
7%	0.06^{C}	5.86C	4.92^{D}	4.56 C	5.08^{C}	98.71^{A}	1.08^{B}	0.65^{A}	74.08^{A}	49.39^{D}
14%	0.07^{BC}	6.08^{B}	5.05^{C}	4.69 B	5.23^{B}	98.61^{A}	1.13^{B}	0.62^{A}	74.73^{A}	54.41^{C}
21%	0.09^{A}	6.10^{B}	5.10^{B}	4.67 B	5.25^{B}	98.58^{A}	1.48^{A}	1.04^{A}	74.91^{A}	59.07^{B}
28%	0.08^{B}	6.41^{A}	5.29^{A}	4.80 A	5.46^{A}	98.42^{B}	1.10^{B}	0.56^{A}	74.94^{A}	64.27^{A}
LSD	0.01	0.07	0.05	0.07	0.05	0.00003	0.0002	0.61	0.11	1.61

Mc = Moisture content, M_S = Mass, M_A = Major, M_E = Medium, M_I = Minor, G_M = Geometric mean, S_P = Spherisity, T_D = True density, B_D = Bulk density, P_O = Porosity, K_W = 1000 kernel weight

Table 3. Variety Effects on some Physical Properties of Okra Seed

Variety	M_S g	Diameter (mm) M_A	M_E	M_I	G_M	S_P %	T_D g/cm^3	B_D g/cm^3	P_O %	K_W g
NH47	0.08^{A}	6.19^{A}	5.19^{A}	4.82^{A}	5.38^{A}	98.73^{A}	1.10^{B}	0.61^{A}	42.94^{C}	55.64^{B}
V-35	0.07^{A}	6.05^{A}	5.06^{B}	4.69^{B}	5.27^{C}	98.55^{B}	1.15^{B}	0.62^{A}	99.88^{A}	50.39^{C}
LD 88	0.08^{A}	5.96^{B}	4.97^{C}	4.40^{C}	5.06^{D}	98.36^{C}	1.42^{A}	0.66^{A}	99.86^{A}	55.25^{B}
Elesso	0.07^{A}	6.16^{A}	5.11^{B}	4.79^{A}	5.32^{B}	98.68^{AB}	1.11^{B}	0.98^{C}	99.89^{A}	65.85^{A}
LSD	0.01	0.07	0.05	0.05	0.03	0.0003	0.0002	0.61	0.02	0.65

M_S = Mass, M_A = Major, M_E = Medium, M_I = Minor, G_M = Geometric mean, S_P = Spherisity, T_D = True density, B_D = Bulk density, P_O = Porosity, K_W = 1000 kernel weight

Table 4. Analysis of Variance for some Physical Properties of Okra Seed

S_V	DF	M_S g	Diameter mm M_A	M_E	M_I	G_M	S_P %	T_D g/cm^3	B_D g/cm^3	P_O %	K_W g
Mc	3	7.17*	78..13*	63.04*	17.75*	88.72*	6.05*	5.43*	1.00 NS	0.01 NS	120.42*
V_A	3	0.77NS	17.08*	26.97*	119.57*	117.55*	11.52*	3..25*	0.67 NS	3.80E7*	766.28*
MxV	15	3.60*	31.49*	28.53*	40.73*	84.51*	6.80*	1.01N	0.93 NS	1.03NS	412.20*
Error	442										
Total	474										

SV = Source of variance, M_S = Mass, M_A = Major, M_E = Medium, M_I = Minor, G_M = Geometric mean, S_P = Spherisity, T_D = True density, B_D = Bulk density, P_O = Porosity, K_W = 1000 kernel weight

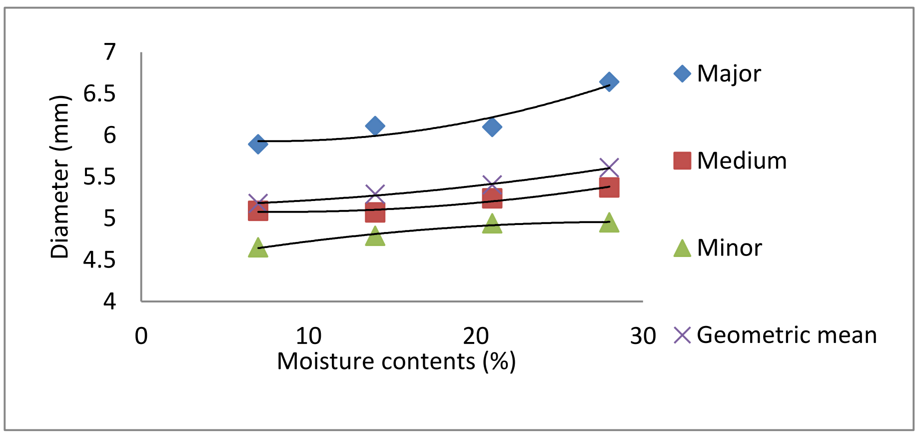

Fig. 1. Effcts of moisture content on NHAe-47 diameters

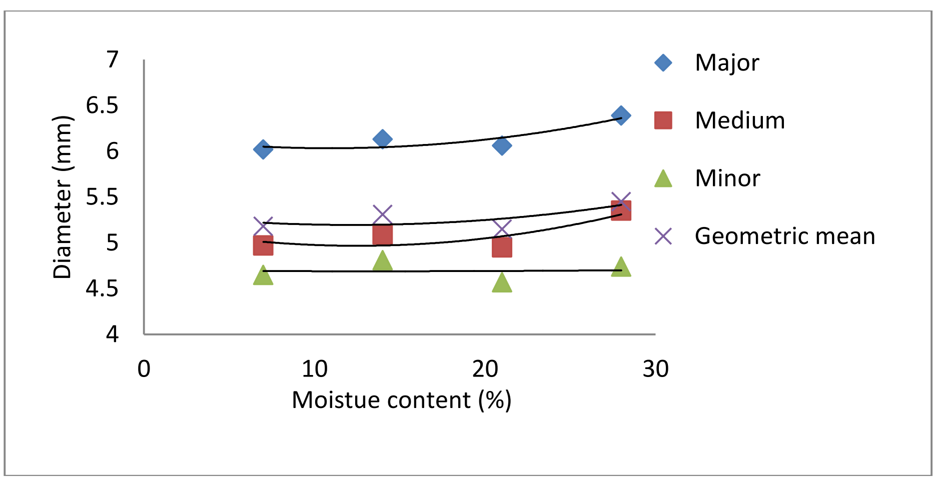

Fig. 2. Effects of moisture content on V-35 diameters

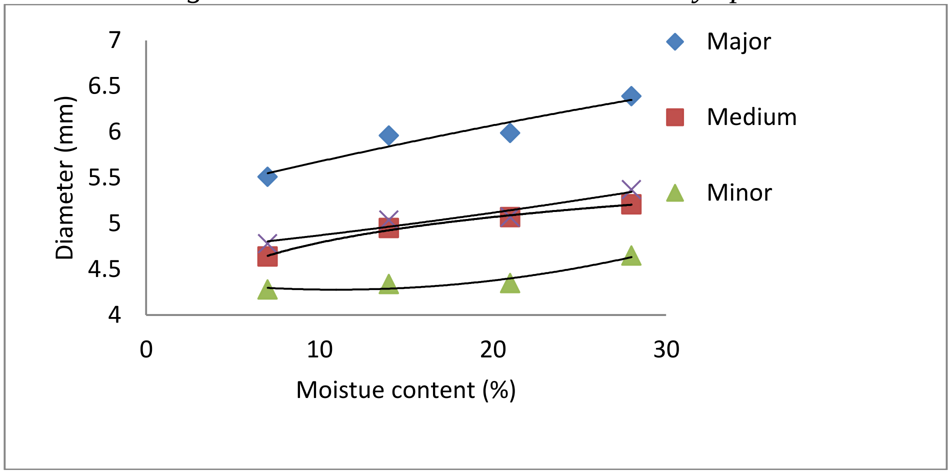

Fig. 3. Effects of moisture content on LD88 diameters

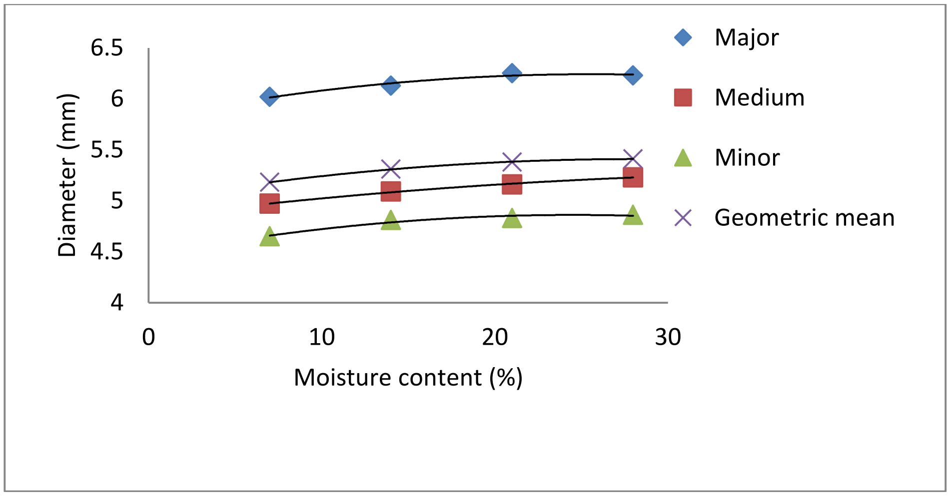

Fig. 4. Effects of moisture content on ‘Elesoagbonrin’ diameters

The information on the interaction between okra varieties and moisture content (Tables 3 and4) are necessary in knowing whether a screen specified for one variety at a given moisture content can be used for another at the same or different moisture content, thus reducing the number of screens in processing the four varieties in the moisture content range of 7 to 28 %.

Table 5. Regression Equations for Physical Properties of Okra Seed in the Moisture range of 7 to 28%

Parameter	Variety	Non- linear Regression Equation	R^2
Diameter	NHAe-47	$M_A = 0.001Mc^2 – 0.0025Mc + 6.025$	0.90
		$M_E = 0.000Mc^2 – 0.012MC + 5.127$	0.955
		$M_I = -0.000Mc^2 +0.038Mc + 4.407$	0.981
		$G_M = 0.000Mc^2 + 0.002Mc + 5.145$	0.995
	V- 35	$M_A = 0.001Mc^2 – 0.024Mc + 6.165$	0.797
		$M_E = 0.001Mc^2 – 0.035Mc + 5.19$	0.685
		M_I= SE-05Mc^2 – 0.001Mc + 4.697	0.002
		$G_M = 0.000Mc^2 – 0.021Mc + 5.322$	0.502
	LD88	$M_A = - 0.00Mc^2 = 0.047Mc + 5.232$	0.919
		$M_E = 0.402Ln(Mc) + 3.863$	0.994
		$M_I = 0.001Mc^2 – 0.026Mc+ 4.425$	0.930
		$G_M = 0.00Mc^2 + 0.018Mc + 4.665$	0.028
	'Elesoagbonrin'	$M_A = -0.000Mc^2 + 0.033Mc + 5.807$	0.966
		$M_E = -0.000Mc^2 + 0.021Mc +4.832$	0.996
		$M_I = -0.000Mc^2 + 0.032Mc + 4.462$	0.975
		$G_M = - 0.000Mc^2 + 0.028Mc + 5.005$	0.999
Spherisity	NHAe-47	$-0.002Mc^2 + 0.063Mc + 98.52$	0.630
	V-35	$0.002Mc^2 – 0.083Mc + 99.04$	0.725
	LD88	$0.002Mc^2 – 0.125Mc + 99.44$	0.999
	'Elesoagbonrin'	$0.000Mc^2 – 0.00Mc + 98.62$	0.402
True Density	NHAe-47	$-0.001Mc^2 +0.047Mc +0.73$	1
	V-35	$-0.000Mc^2 + 0.008Mc +0.097$	0.122
	LD88	$0.001Mc^2 + 0.063 +0.757$	0.61
	'Elesoagbonrin'	$0.000Mc^2 + 0.013Mc + 0.957$	0.931
Bulk Density	NHAe-47	$-0.000Mc^2 + 0.007Mc + 0.582$	0.996
	v-35	$-0.003Mc + 0.675$	0.993
	LD88	$0.000Mc^2 - 0.012Mc + 0.852$	0.866
	'Elesoagbonrin'	-5E-05Mc^2 – 0.001Mc + 0.597	0.815
Porosity	NHAe-47	-5E-05Mc^2 + 0.002Mc + 99.08	0.981
	V-35	$-0.000Mc + 99.89$	0.8
	LD88	$0.000Mc^2 – 0.026+100.0$	0.474
	'Elesoagbonrin'	5E-05Mc^2 - 0.001Mc+ 99.88	0.933
1000 Kernel Weight	NHAe-47	$-.006Mc^2 + 0.894Mc + 42.43$	0.999
	V-35	$0.001Mc^2 + 0.507Mc + 40.92$	0.999
	LD88	$-0.008Mc^2 + 0.939Mc + 41.78$	0.999
	'Elesoagbonrin'	$0.016Mc^2 + 0.351 Mc + 53.52$	0.995

The moisture content and variety had effect on okra seeds; thus, for the same screen to be used for cleaning it must be well selected to take care of the variations due to differences in size.

3.2 Sphericity

The sphericity of okra seed decreased for NHAe47-4, V.35 and LD88 save for 'Elesoagbonrin' that increased with increase in moisture content. NHAe47-4 decreased from 87.7 to 84.2 %, V-35 from 87.3 to 85.5 %, LD88 from 86.5 to 84.1% and 'Elesoagbonrin' increased from 98.5 to 98.8 %. All the relationships are expressed in Figure 5. There is no significant difference between means of sphericity for NHAe47-4, V-35 and LD88 at 7,14 and 21 % moisture content (Table 2).

Sphericity was observed to decrease for 3 varieties NHAe47-4, V-35 and LD88), but for 'Elesoagbonrin', it increased with increase in moisture content (7-28 % w.b). The observed variation is due to the fact that the shape of 'Elesoagbonrin' is different, thus it's sphericity. The results are in accordance with the observation of Oje and Ugbor (1991) for oil bean seed at moisture content of 4.55 % (d.b), Dutta *et al* (1988) for Gram at 10.9 % moisture content (d.b). Gowda *et al* (1995) observed increase at 8.24 – 27.01 % for soybean cv. Maple Belle seeds. The variations observed could be attributed to the large increase in the seed length relative to the width and thickness for the NHAe47-4, V-35 and LD88 varieties contrary to 'Elesoagbonrin' through out the moisture content range of 7 to 28 % (w.b). There exists a positive correlation between sphericity and moisture content with high R^2 values (0.4 to 1). Moreover, analysis of variance shows that the effects of moisture content and variety are significant at 5 % levels.

Sphericity values of okra seed for the four varieties are in the range 88.7 - 89.5 % and this is within the range of 32-100 % recommended by Mohsenin (1986) for most agricultural crops. The overall mean sphericity value for okra seeds was 89.1∀0.6 %. The high value indicates favourable characteristic for rolling of the seeds on surfaces, thus assisting in the design for processing, handling and storage equipment such as separators, conveyor and silos.

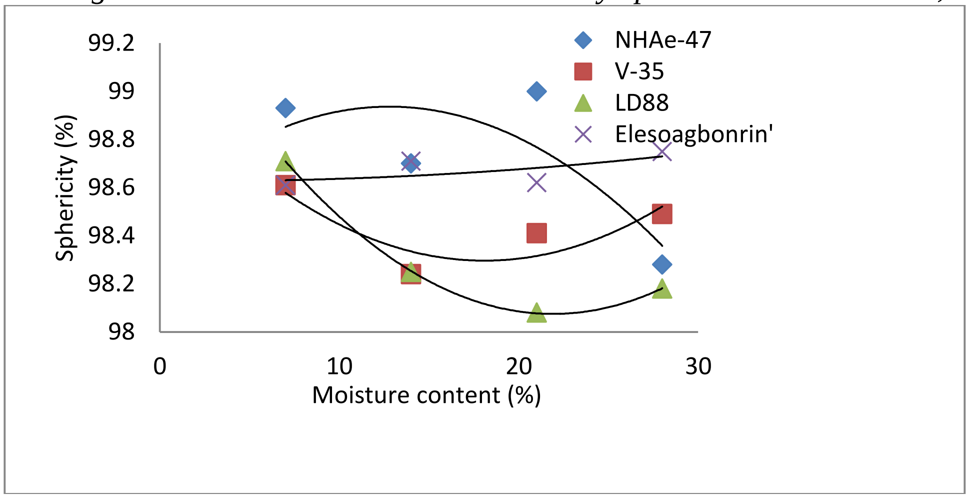

Fig. 5. Effects of moisture content on seed sphericity

3.3 Gravimetric Properties

The gravimetric properties (true and bulk densities, porosity and a thousand kernel weight) of the four varieties at 7 to 28 % moisture content are shown in Tables 1 to 5 and Figures 6 to 9.

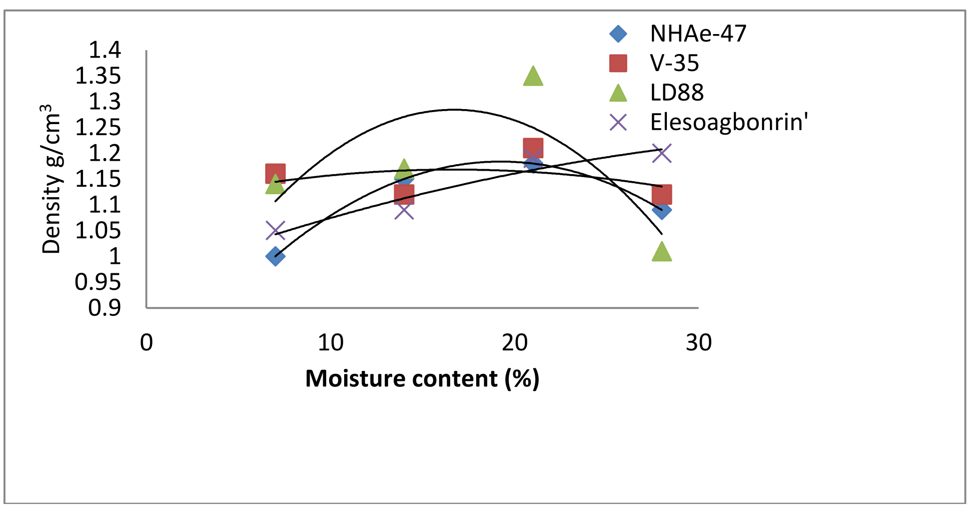

Fig. 6. Effects of moisture content on okra seed true density

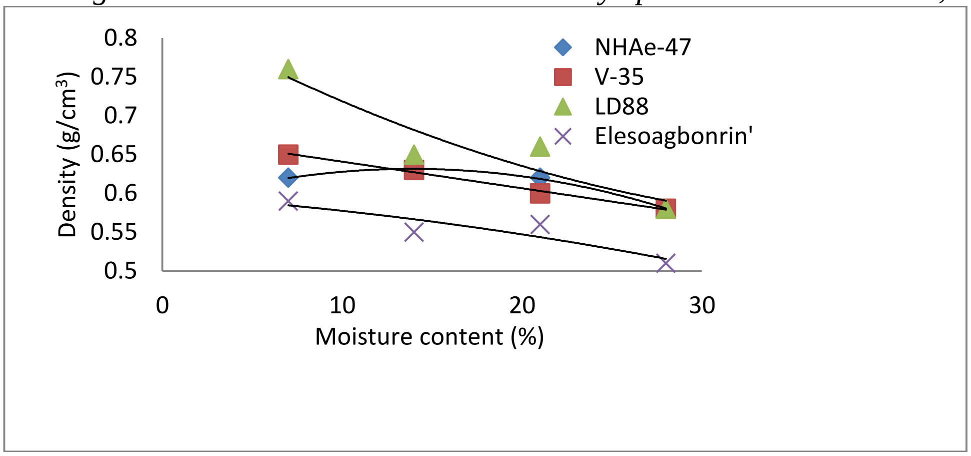

Fig. 7. Effects of moisture content on okra seed bulk density

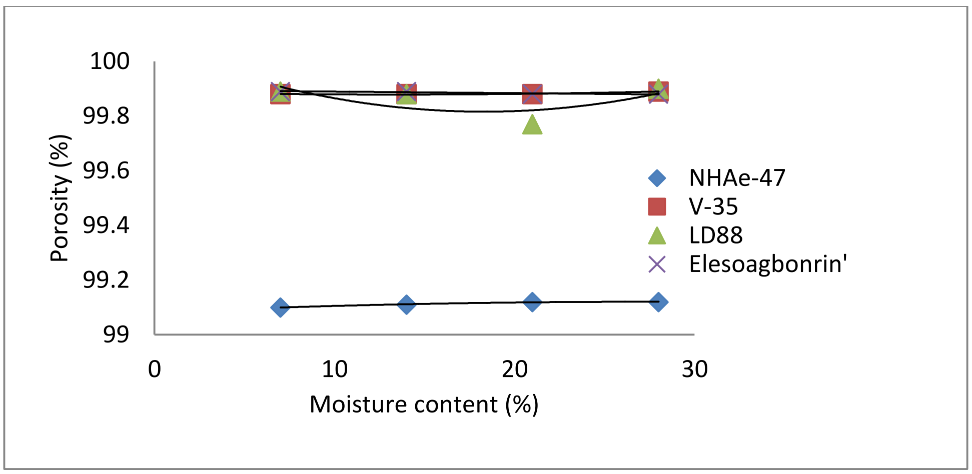

Fig. 8. Effects of moisture content on okra seed porosity

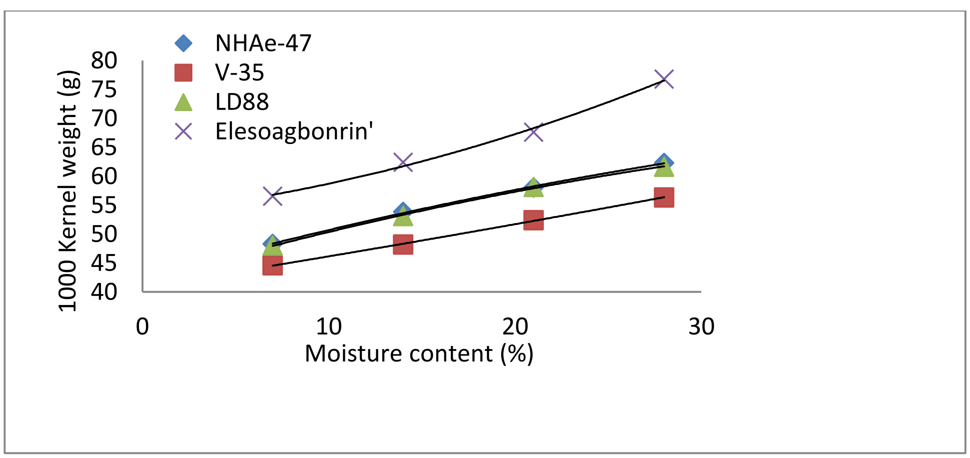

Fig. 9. Effects of moisture content on okra seed 1000 kernel weight

3.3.1 True and Bulk Density

The effect of moisture content on okra seed true density shows that NHAe47-4 increased from 1g/ cm^3 at 7 % to 1.18 g/cm^3 at 21 % then decreased to 1.09 g/cm^3 at 28 % moisture content, V-35 increased from 1.01 g/cm^3 to 1.21 g/cm^3. LD88 increased from 1.14 g/cm^3 to 1.29 g/cm^3 at 21 %, then decreased 1.01 g/cm^3 at 28 % moisture content and 'Elesoagbonrin' increased from 1.05 to 1.20 g/cm^3.

Bulk densities of the seed decreased with increase in moisture content. NHAe47-4 decreased from 0.62 to 0.58 g/cm^3, V-35 from 0.65 to 0.58 g/cm^3, LD88 from 0.75 to 0.58 g/cm^3 and 'Elesoagbonrin' from 0.59 to 0.51 g/cm^3 at 7 to 28 % moisture content. All relationships among the dimensions are as expressed in Figures 6 and 7. There is no difference between means of the seed true density at 7, 14 and 28 % moisture content and seed bulk density for all varieties (Tables 2 and 3).

The true density of okra seed is not consistent. 'Elesoagbonrin' increased consistently, but NHAe47-4 and LD88 increased within the range of 7 to 21 % moisture content and there after decreased, V-35 decreased slightly with increase in moisture content (7 to 28 % w.b). The seed true density is in the range of 1.10 - 1.14 g/cm^3 similar to Oje and Ugbor (1991), for oil bean seed at 4.55 % (d.b) of 1.12 kg/m^3; Orji (2001), for bread fruit seed (1097.93-1214.29 kg/m^3) at 37.5 % (w.b). The increased true density results are in accordance with Gupta and Das (1997) for sun flower seeds at 4-20 % (d.b), Sultar and Das (1996) for karingda (Citrullus lanatus (Thumb) Manst seeds at 5-40 % (d.b), while, V-35 decrease is as observed by Oje *et al* (1999) for melon seed, Visuanathan *et al*., (1996), for neem (Azadirachta india) nut at 7.6-21 % (w.b), Gowda *et al* (1995), for soybean cv. Maple Bello seed at 8.24-27.01 %, Dutta *et al* (1988) for gran at 9.64-31 % (d.b). The inconsistency of Okra true density among varieties is in agreement with Waziri and Mittal (1983), that Agricultural material pose special problems in determining their physical properties because of their diversity in shape, size, moisture content and maturity levels.

Bulk densities of seed decreases, with increase in moisture content; suggesting that increase in the mass of seed under-weigh the volume, thus, the increase in bulk mass of seed is negligible in contrast to the volume of the seed. The decrease in seed bulk density disagrees with Gupta and Das (1997), for sunflower kernels at 4-20 % (d.b); Sultar and Das (1996) observation for karingda (Citrullus lanatus (Thumb) Manst) seeds at 5-40 % (d.b), Gowda *et at* (1995) for soybean cv Meple Belle seeds at 8.28-27.01 %. The decrease in seed bulk density with increase in moisture content agrees with Gupta and Das (1997) for sunflower seed at 4-20 % (d.b) , Visvanathan *et al* (1996) for Neem (Azadirachte India) nut at 7.6-21 % (w.b); Dutta *et al* (1988) for Gram at 9.64-31.0 % moisture content (d.b). The mean bulk density of okra seed (0.61 g/cm^3), was found to be lower than that of pearl millet grain reported by Jain and Bal (1997).

The analysis of variance (Table 4) shows that there is a significant difference in moisture content effect on seed true and bulk densities at 5% level. Likewise the varietals effect on seed true and bulk densities are significantly different at 5 % level, except the seed true density that is not significant. The interaction between variety and moisture content are also significant. The true and bulk densities of seed are in the range 1.10 -1.14 g/cm^3 and 0.60 - 0.61 g/cm^3 respectively.

In agricultural produce processing, the true and bulk densities are of important practical application. The knowledge of density is useful in the design of silos and storage bins, processing and handling machines, maturity and quality evaluation of products, which are essential to grain marketing. Others include determination of Reynolds number, thermal properties in heat transfer problems, chemical composition, separation of products by flotation etc. Therefore the true and bulk densities of okra pod and seed are essential to the machine hopper and threshing drums design, bagging and storage of the products.

3.3.2 Porosity

NHAe47-4, V-35 and LD88 seed porosity increased from 37.5 %, 42.6 %, 33.2 % to maximum values of 45.8 %, 48.3 % and 47.8 %, then decreased to 43.2 %, 43.4 % and 41.6 % at moisture content of 7 %, 21 % and 28 % respectively. 'Elesoagbonrin' increased from 43.3 % to 54.4 % at 7 to 28 % moisture content. All the relationships are as expressed in Figure 8.There are no significant differences (5 % level) between means of seed porosity at 7 to 28 % moisture content (Tables 2 and 3).
Generally, the seed porosity increased with increase in moisture content though not linear. The non-linear behaviour of okra seed porosity with moisture content is due to the hydroscopic nature of the dry crop.

The result for the seed porosity obtained is not analogous to that observed by Sultar and Das (1996) for karingda (Citrullus lenatus (Thumb) Manet) seeds at 5-40 %, Visvanatha *et al.,* (1996) for neem (Azadirachta India) nut, (1991) for rough rice (Oryza sativa) at 8.1-27.25 %. This might be due to the fact that as okra seed absorb water, it swells radially; thus, it becomes more spherical. The increase in seed porosity with increase in moisture content is in agreement with Carman (1996) for lentil seed at 6.5-32.6 % (d.b).

Analysis of variance shows that the effects of moisture content on porosity of okra seeds are not significant while the varietal effects are significant (5 % level). The interactions of moisture and variety showed no significance for the seed 5 % level.

The utilization of okra seed porosity can be seen in the area of drying (heat and air flow), storage and aeration, bagging and marketing of seed and design of processing and plant machinery.

3.3.3 Thousand-kernel Weight

Thousand-kernel weight of okra seed increased with increase in moisture content. NHAe47-4 increased from 48.34 g to 62.30 g, V-35 from 44.60 g to 56.34 g, LD88 from 48.03 g to

61.66 g and 'Elesoagbonrin' from 56.48 to 76.77g. All their relationships are as expressed in Figure 9. Tables 1 to 3 show that there is different between means of 1000-kernel weight of okra seed at all moisture levels and between varieties. The relationships between 1000-kernel weight and moisture content gave very high R^2 values (1), showing that the increased in 1000-kernel weight and size of the seeds were mainly caused by the added water. Analysis of variance shows that there is significant difference between mean of 1000-kernel weight on moisture content, variety and their interactions at 5 % level. 1000-kernel weight for okra seed is in the range of 56.48 to 57.15 g at 7-28 % (w.b) moisture content.

The increased in 1000-kernel weight with increase in moisture content is in agreement with Visvanathan *et al* (1996) for neem (Azadirachta India) nut at 7.6 - 21 % (w.b), Gowda *et al.,* (1995), for soybean cv MapleBette seeds at 8.24-27.01 % and less than that for gram as reported by Dutta *et al* (1988). The increase in seed 1000-kernel weight with increase in moisture content is because the increase in moisture content increases the water content (by weight) in the size of the seed.

3.3 Number of Seeds per Pod, Seed/Chaff ratio, and Mass of Seed

The results of number of seeds per pod, seed/chaff ratio at 10 % moisture content and mass of seed (7 to 28 % moisture content) are presented in Table 6. Analysis of variance is presented in Table 7. The grand mean number of seeds per pod is 114. There is no difference between means of the number of seeds per pod for varieties NHAe47-4 and LD88, also between V-35 and 'Elesoagbonrin' at 5 % level. The average number of seeds per pod are 126, 107, 123 and 101; seed/chaff ratio on mass bases are 1.33, 1.33, 2.00 and 1.29; for the four varieties respectively (Table 8).

The mass of seed increased with increase in moisture content. This is because the absorbed water increases the self-weight of the seed. Tables 1 to 4 show that there is no significant different between means of NHAe47-4 and 'Elesoagbonrin' mass of seed. The mass of seed is significant at 5 % on moisture content levels and among the varieties. The mean value of mass of seed is 0.08 g for NHAe47-4, 0.07 g for V-35, 0.08 g for LD88 and 0.08 g for 'Elesoagbonrin'. The grand mean value is 0.07 g at moisture content of 7 to 28 %.
The analysis of variance shows that the effect of variety on number of seeds per pod is significantly different at 5 % level. NHAe47-4 gave the highest value but not significantly different from LD88, then followed by V-35 which is not significantly
different from 'Elesoagbonrin' at 5 % level. Variation in the parameters are due to diversity of agricultural material properties in agreement with Waziri and Mittal(1983),who state that agricultural materials pose special problems in determining their physical properties.

Table 6 Means Number of Seed per Pod

No. Of Seed Per Pod	Means	Std Error	Lower Bound	Upper Bound
Overall Average	114	2.88	101	120
NHAe47-4	125.70[a]	5.76	114.03	137.37
V-35	106.50[b]	5.76	94.83	118.17
LD88	123.20[a]	5.76	111.53	134.87
Elesoagbonrin	101.10[b]	5.76	89.43	112.77

10% Moisture content. 95% confidence interval.

Table 7 Analysis of Variance for No. Seed per Pod

Source Of Variance	Df	Number Seed Per Pod
Variety	3	4.469*
Error	36	
Total	39	

* = Significantly different at 5%

8.1.1.1 Table 8. Seed/Chaff Ratio

Rep	1	2	3	Average
NHAe47-4	1.33	1.33	1.33	1.33
V-35	1.31	0.99	1.58	1.29
LD88	2.00	1.71	2.53	2.08
'Elesoagbonrin'	**1.29**	**1.21**	**1.35**	**1.31**
Average				1.5

The number of the seeds per pod is applicable in calculating the machine threshing capacity and the amount of seed produced. While the projected and surface areas are usefully in obtaining the drag force, design of storage bin, processing and handling equipment for the crop.

4. CONCLUSIONS

From the results obtained in this study, the following conclusions were drawn;

i Linear dimensions of seed, equivalent diameter, thousand- kernel weight, true and bulk density of seed and porosity increased with increase in moisture content, while seed sphericity, bulk density of seed decreases except the sphericity of 'Elesoagbonrin' which increased slightly with increase in moisture content.

ii The four okra varieties (NHAe47-4, V-35, LD88 and 'Elesoagbonrin') seeds are different with respect to linear dimensions, equivalent diameter, number of seed per pod, bulk densities, sphericity, porosity, thousand-kernel weight, except the true density that is not statistically different.

iii The seed mean diameters were 6.11 mm (major), 5.09 mm (medium), 4.68 mm (minor), 5.26 mm (geometric mean) and the mean sphericity of 98.58 % is high enough to be assumed as round shape during the analysis of rate processes.

iv The true densities of seed was higher than the bulk densities with range 1.10 – 1.23 g/cm^3 (true) and 0.47 – 0.98 g/cm^3 (bulk).

v The mean number of seeds per pod was 114. This parameter varied significantly among the varieties.

vi The seed/chaff ratio was 1.5.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Determination of Water Productivity of Cassava in Ibadan, South western Nigeria

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ABSTRACT

The response of yields to the actual water (effective rainfall) used by cassava, was the main area of study of this project. A twenty data point (20 years) was processed using CROPWAT 8.0 model using fixed percentage (80%) method, the model was used to run the 20 years daily rainfall data collected from NIMET (Nigeria Meteorological Agency) Oyo State from 1994 to 2013 (20 years) while the cassava yield was collected from FAOSTAT website. The rainfall pattern for the annual period of cultivation for cassava was determined through the planting and dates of the crop. The results of the annual water productivity values show that there was a very low water productivity of 0.9kg/m^3 in 2012 while 2013 recorded the highest water productivity of 2.2 kg/m^3. The early planting of cassava after rainfall started in the month of March which contributed to the high yield recorded in 2010, 2011 and 2013. The poor performance of cassava in 2012 could be due to the following; the variety used, the soil type, the plant's age at harvest, and the rainfall intensity and distribution during that particular year. The trend of the results was used to determine the alternative cost of water if the farm would be fully irrigated. It was gathered that 7000 litres of untreated water would be supplied to any farthest location at ₦12,000. Therefore, the cost was determined based on the yield and the water used annually.

Keywords: Water productivity, cassava, effective rainfall, Cropwat, rainfall data, Nigeria.

1. INTRODUCTION

Cassava (*Manihot esculenta)* is generally cultivated as an annual crop in the tropics and subtropical regions for its edible starchy tuberous root. Cassava is known as a major source of carbohydrates. Cassava is the third largest source of food carbohydrates in the tropics, after rice and maize (FAO, 1995). Cassava is a major staple food in the developing world, providing a basic diet for over half a billion people. It is one of the most drought-tolerant crops, capable of growing on marginal soils. Nigeria is the world's largest producer of cassava, while Thailand is the largest exporter of dried cassava. Cassava is important source of food in the tropics. It plays a particularly important role in agriculture in developing countries, especially in sub-Saharan Africa, because it does well on poor soils and with low rainfall. Water is the most common liquid on our planet, essential to all life forms and it is also important for crop need. The need of water is increasing sharply throughout the world which is one of the most burning issues of current time. Fresh water resources are depleting due to global climatic changes, rash use of surface water, and misuse of ground water and fast increasing industrial pollution. World need for food and crop demand is increasing day by day because of rapid increase in population. (Bastiaanssen *et al.*, 2000).

As competition for increasingly scarce water resources intensifies, irrigation is under growing pressure to produce "more crops from fewer drops" and to reduce its negative environmental impacts, including soil salinization and nitrate contamination of drinking water. Greater use of water-saving precision technologies, such as drip and micro-irrigation, will make an important contribution to sustainable intensification. Irrigation water requirements are particularly abundant in the works under several surfaces, crop water requirements, crop yield and evapotranspiration as influenced by water accessibility, crop water modeling and irrigation scheduling techniques.CROPWAT is one of the models extensively used in the field of water management throughout the world. It is an application software used for irrigation planning and management. It facilitates the estimation of the crop evapotranspiration, irrigation schedule, crop water requirement and yield reduction under varying weather conditions (FAO, 2000).

Rainfall determines the potential of any region in term of crops to be produced, farming system to be adopted, the nature and sequence of farming operations to be followed and to achieve higher agricultural productivity. The objectives of this study were therefore to estimate the effective rainfall using CROPWAT 8.0 model, evaluate the crop water productivity of cassava on annual basis for the period of twenty (20) years, and calculate the cost of alternative water used for cassava production for the entire period of twenty years on annual basis.

Among the models, CROPWAT has been the most widely used for estimation of evapotranspiration and crop water requirement. Since there are few weather stations in the study areas, data required for the Penman-Monteith method has normally been extrapolated from representative weather stations nearby. The weather data available for this study will be processed using CROPWAT to estimate evapotranspiration and crop water requirement.

2. MATERIALS AND METHODS

The study was carried out using Ibadan (Nigeria) as a case study area. Ibadan lies approximately between latitude $7^0 39^I$ N and longitude $3^0 90^I$ E of Nigeria and altitude 238m above the sea level (Google earth, 2015). The area lies within the southwest savannah zone of Nigeria. The average length of the dry season is about 121-151 days (October to March) during which little or no precipitation occurs. Means daily air temperatures (minimum and maximum) range between 23.6^0C and 33.2^0C. The wind speed ranges from 50.3 km/day in December to 735 km/day in April, with a north eastern to south western wind direction dominating from November through April. The soil is a medium loam, which has developed on deeply weathered Pre-Cambrian Basement Complex rocks but overlain by Aeolian drift of varying thickness (Ogunwole, 2000).

2.1 Climatic Data

The climatic data used for this work were obtained from the data files of Ibadan over a period of Twenty years (1994-2013) from the Nigerian Meteorological Agency (NIMET) and was imputed into CROPWAT-8.0 for windows. The weather data are being generated from the automatic weather station of the agency (NIMET), which relatively records accurate climatic data of its environments.

2.2 Cassava Yield Data

The cassava yield data used for this study for the period of twenty years (1994-2013) was obtained from Food and Agriculture Organization Statistics (FAOSTAT, 2015). The data was calculated per hectare on annual basis.

2.3 Determination of Reference Crop Evapotranspiration

The Reference Evapotranspiration (ET_o) represents the potential evaporation of a well-watered grass crop. The water needs of other crops are directly linked to this climate parameter (Mohammed, 2009). In order to calculate reference evapotranspiration (ET_o), the respective climate data should be collected from the nearest and the most representative meteorological stations. Several institutes and agencies may keep climatic records such as the Irrigation Department, the Meteorological Service or nearby Agricultural Research Stations and may provide information on climatic stations inside or in its vicinity (Allen *et al*., 1998). For this work, the data have been obtained from both the automatic weather station of NIMET and FAOSTAT. Daily climatic data of the year 1994-2013 were used. The climatic data used is rainfall data and the second data used was the cassava yield data. Although several methods exist to determine $ET_{o,}$ the Penman-Monteith Method has been recommended as the appropriate combination method with the climatic data; temperature, sunshine, humidity, windspeed, (FAO, 1998).

The FAO Penman-Monteith method to estimate ET_o is expressed as;

$$ET_O = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2\,(e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad \ldots\ldots\ldots\ldots(1)$$

Where: ET_O = Reference evapotranspiration (mm day^{-1})

R_n = Net radiation at the crop surface (MJ m^{-2} day^{-1})

G = Soil heat flux density (MJ m^{-2} day^{-1})

T = Mean daily air temperature at 2 m height (^oC)
$\mu2$ = Wind speed at 2 m height (ms^{-1})
e_s = Saturation vapour pressure (kPa)
e_a = Actual vapour pressure (kPa)
Δ = Slope vapour pressure curve (kPa $^oC^{-1}$)
γ = Psychrometric constant (kPa $^oC^{-1}$)

For this project, The United States Department of Agriculture, Soil Conservation Service method on CROPWAT-8 was used to determine the effective rainfall on monthly basis which accumulated to annual effective rainfall. The USDA, SCS method for calculation of effective rainfall is described in a FAO publication (Dastane, 1978). The method is implemented in models for planning and management of irrigation as the CROPWAT model, where the USDA, SCS method is the default method for calculation of effective rainfall among other four methods (Marica, 2013).

2.4 Determination of Cassava Crop Water Productivity

Water Productivity is more directly linked to overall ambitions in water-scarce or water-costly situations than in systems which are supplied with plentiful, low value water. WP is most meaningful as an indicator as water resources become increasingly scarce. Assessment may be required for the whole system or parts of it, defined in time and space with the formula below,

$$WP = \frac{Agricultural\ produce}{water\ used\ or\ consumed} \quad .....(2)$$

In this project, the annual agricultural yield or benefit of cassava was obtained from the FAOSTAT for the period of twenty years (1994-2013) on yearly basis and the rainfall data obtained from NIMET was processed to determine the amount of water required by the plant at that particular period of time or Water Used or Consumed. With the equation 2 above, the annual water productivity was calculated for the specified period of time. Due to the water productivity calculated, it was easy to predict the amount of water that will be needed in the cassava production annually.

2.5 Cost of Water Applied

Economics of water contributes towards improved allocations of water and the costs of water used and also the full social benefits of the goods and services that water provides.
In this study, the cost of the quantity of water used was determined by considering the cost of water supply by the water tankers from the Oyo State Water Corporation, Eleyele, Ibadan. It was discovered that the price for which the water is delivered depends on the distance. Therefore, for the farthest location supply of 7,000 litres of untreated water, the cooperation charges ₦12,000. With this knowledge, the quantity of water used annually from 1994 to 2013 was calculated annually. This also helps to predict and have the foreknowledge of the amount of money to be spent on irrigation or supply of water if the cassava production is on the large scale, particularly for exportation.

3. RESULTS AND DISCUSSION

Table 1 below shows the rainfall pattern based on the planting and harvesting dates of cassava for the period of 20 years. From the rainfall pattern it was seen that it took nine (9) months for the cassava to germinate, some were assumed planted early while some were planted late based on the daily rainfall data obtained. Figures 1, 2 and 3 below shows effective rainfall versus cassava yield; water productivity and cost of alternative water for irrigation respectively.

Table 1: Rainfall pattern during cassava cultivation period

Year	Mar (mm)	Apr (mm)	May (mm)	June (mm)	July (mm)	Aug (mm)	Sept (mm)	Oct (mm)	Nov (mm)	Dec (mm)	Jan (mm)	Total Rainfall (mm)
1994	-	88.9	301.2	63.6	164.0	67.0	211.5	246.6	19.5	0.0	-	1,162.3
1995	127.8	81.3	146.7	129.9	220.7	260.1	139.3	213.1	20.2	-	-	1,339.1
1996	-	122.1	188.3	231.4	116.9	161.4	226.5	84.9	0.0	0.4	-	1,131.9
1997	-	141.9	104.7	154.1	63.6	98.8	151.7	170.5	1.6	9.0	-	895.9
1998	-	126.9	198.5	259.5	114.2	177.3	80.3	263.4	0.0	0.0	-	1,220.1
1999	-	-	189.8	226.9	230.3	162.7	149.5	154.9	24.4	0.0	19.0	1,157.5
2000	-	-	112.6	104.0	149.8	183.6	241.0	144.2	19.6	0.0	18.8	973.6
2001	-	-	145.9	194.2	93.5	52.1	229.1	63.0	1.9	0.2	1.0	780.9
2002	-	79.4	116.6	189.3	180.3	168.9	62.6	254.4	74.1	0.0	-	1,125.6
2003	-	101.0	129.4	203.7	205.7	107.6	283.8	153.8	39.9	0.0	-	1,224.9
2004	-	55.0	181.4	223.6	100.6	136.5	142.0	228.5	0.7	0.0	-	1,068.3
2005	-	123.0	111.1	165.2	152.4	92.5	352.7	160.6	3.7	0.0	-	1,161.2
2006	-	67.1	107.6	167.1	98.8	104.9	148.8	188.0	256.1	4.9	-	1,143.3
2007	-	65.9	176.6	229.4	133.3	356.6	178.4	168.8	71.5	10.8	-	1,391.3
2008	-	98.7	64.9	204.3	283.5	161.9	199.7	92.9	0.0	24.7	-	1,130.6
2009	-	104.4	130.8	146.7	229.4	74.3	111.5	117.8	2.1	0.0	-	917.0
2010	131.6	70.8	204.4	167.4	107.1	205.7	256.5	240.5	101.4	-	-	1,485.4
2011	38.6	36.2	68.6	143.3	140.5	308.1	244.6	163.6	0.6	-	-	1,144.1
2012	38.4	214.6	221.1	145.5	87.7	104.4	190.3	182.5	15.7	-	-	1,200.2
2013	37.3	67.2	105.2	124.5	126.4	10.6	128.5	163.7	29.8	-	-	793.2

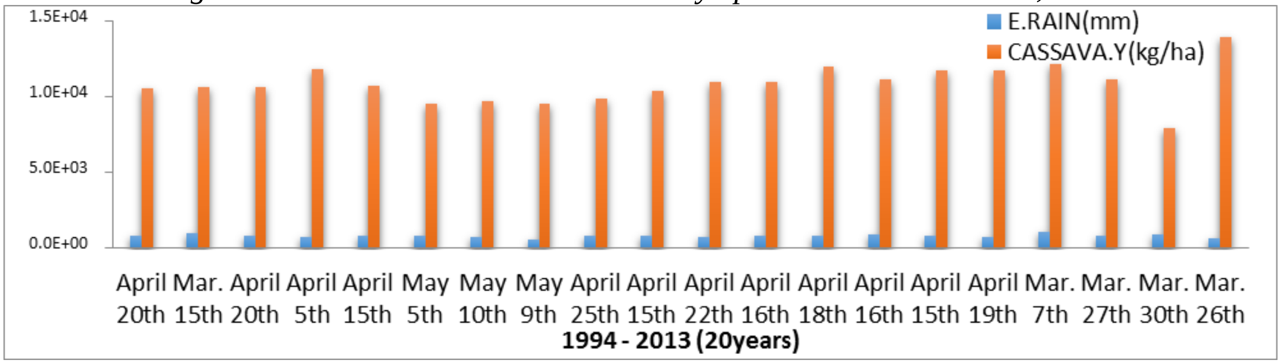

Figure 1: Effective rainfall versus cassava yield.

3.1 Water Productivity

The Figure 2 below shows the trend of water productivity across the years (1994 - 2013). Total rainfall values was computed from the weather station for a period of twenty (20) years in order to estimate the amount of rainfall that was recorded on yearly basis. Also to know the trend of rainfall that was recorded for 20 years. Effective rainfall was computed from CROPWAT 8.0 using fixed percentage (80%) method. From the data collected, maximum rainfall was recorded in the 17th year (March 7 – November 12) with a value of 1485.4mm, while the minimum value was recorded in the 8th year (May 10 – January 10) with a value of 780.9mm. Effective rainfall was computed in order to know the amount of water in terms of rainfall that is available for the crop (cassava). The maximum and minimum values for effective rainfall were 1037.1mm and 577.8mm respectively.

Table 2: Water productivity table between 1994-2013 (20 Years)

Year	Planting Date	Harvesting Date	Total Rainfall (mm)	Effective Rainfall (mm)	Cassava Yield (Kg/Ha)	Effective Rainfall (mm^3/Ha)	Effective Rainfall (m^3)	Water Prod. (Kg/m^3)
1994	April 20th	Dec. 23rd	1162.3	777.4	10592.8	7774000	7774	1.362593
1995	Mar. 15th	Nov. 17th	1339.1	949.6	10667.1	9496000	9496	1.123326
1996	April 20th	Dec. 22nd	1131.9	808.5	10664.6	8085000	8085	1.31906
1997	April 5th	Dec. 10th	895.9	702.6	11881.8	7026000	7026	1.691119
1998	April 15th	Dec. 20th	1220.1	829.2	10746.1	8292000	8292	1.29596
1999	May 5th	Jan. 10th	1157.5	814.6	9599.8	8146000	8146	1.178468
2000	May 10th	Jan. 17th	973.6	718.8	9700	7188000	7188	1.349471
2001	May 9th	Jan. 10th	780.9	577.8	9601.2	5778000	5778	1.661682
2002	April 25th	Dec. 27th	1125.6	819.8	9901.3	8198000	8198	1.20777
2003	April 15th	Dec. 20th	1224.9	858.4	10402.3	8584000	8584	1.211824
2004	April 22th	Dec. 28th	1068.3	769	11001.1	7690000	7690	1.430572

2005	April 16th	Dec. 21th	1161.2	789	10990.2	7890000	7890	1.392928
2006	April 18th	Dec. 27th	1143.3	842.2	12000.3	8422000	8422	1.424875
2007	April 16th	Dec. 17th	1391.3	921	11202.6	9210000	9210	1.216352
2008	April 15th	Dec. 20th	1130.6	790.8	11800.4	7908000	7908	1.49221
2009	April 19th	Dec. 11th	917	702.6	11767.9	7026000	7026	1.674907
2010	March 7th	Nov. 12th	1485.4	1037.1	12215.5	10371000	10371	1.177852
2011	March 27th	Nov. 30th	1144.1	776.8	11210.8	7768000	7768	1.443203
2012	March 30th	Nov. 27th	1200.2	870.7	7958.5	8707000	8707	0.914035
2013	March 26th	Nov. 30th	793.2	644.8	13947.4	6448000	6448	2.163058

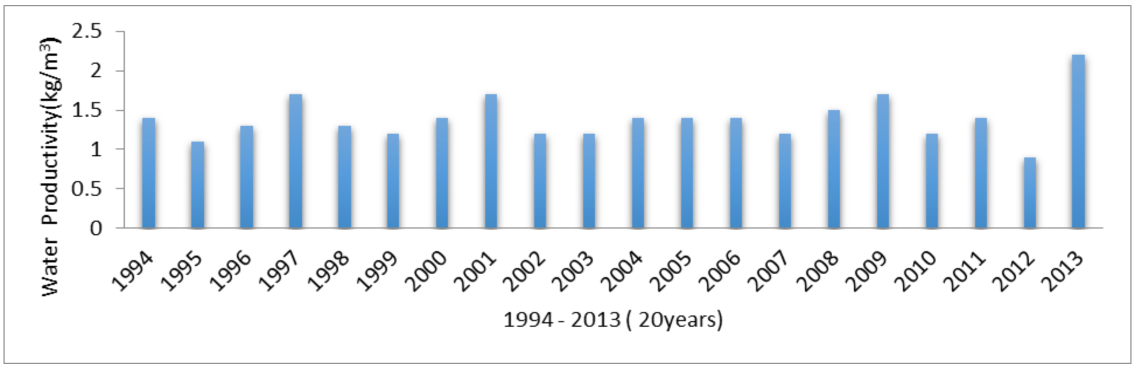

Figure 2: Water productivity

3.2 Cost of Alternative Water

Table 3: Annual water cost

Year	Cassava Yield (Kg/Ha)	Effective Rainfall (m^3)	Effective Rainfall (litre)	Cost of water Used (₦)
1994	10592.8	7774	7774000	13324636
1995	10667.1	9496	9496000	16276144
1996	10664.6	8085	8085000	13857690
1997	11881.8	7026	7026000	12042564
1998	10746.1	8292	8292000	14212488
1999	9599.8	8146	8146000	13962244
2000	9700.0	7188	7188000	12320232
2001	9601.2	5778	5778000	9903492
2002	9901.3	8198	8198000	14051372

2003	10402.3	8584	8584000	14712976
2004	11001.1	7690	7690000	13180660
2005	10990.2	7890	7890000	13523460
2006	12000.3	8422	8422000	14435308
2007	11202.6	9210	9210000	15785940
2008	11800.4	7908	7908000	13554312
2009	11767.9	7026	7026000	12042564
2010	12215.5	10371	10371000	17775894
2011	11210.8	7768	7768000	13314352
2012	7958.5	8707	8707000	14923798
2013	13947.4	6448	6448000	11051872

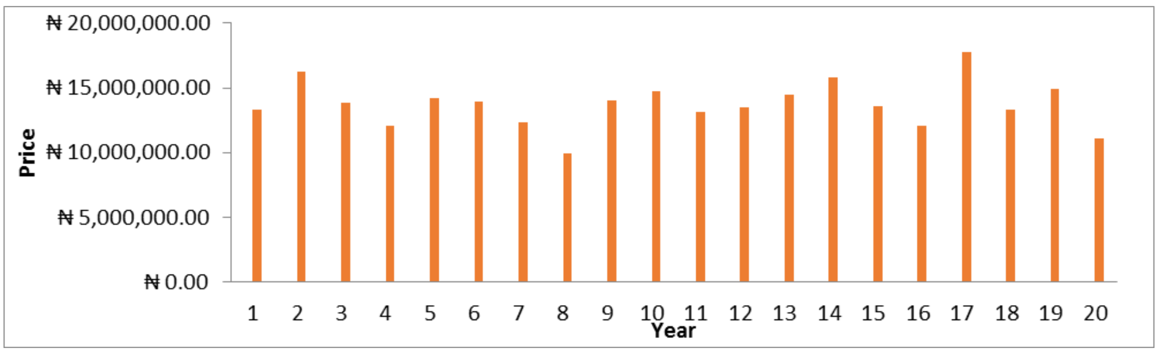

Figure 3: Cost of water

The maximum yield of cassava in kg/ha was recorded to be 13,947.40 as at the 20th year (2013) which was planted on the 26th of March and harvested on the 30th of November, with an effective rainfall of 644.8mm. Based on the trend of data collected, it shows that the maximum yield was recorded at low rainfall which can be linked to the cost of water that can be used in replacement for effective rainfall (irrigation).

From the figure above, the cost of water used in replace of rainfall on yearly basis (i.e. 1994 – 2013). The maximum cost of water used was observed on year 17 (2010) with the maximum price of ₦17,775,894. The minimum cost of water used was observed on year 8 (2001) with the minimum price of ₦9,903,492.

These costs are important to determine so that it could be valued along with the main cost of cassava like in the determination of virtual water. This is applicable mostly in countries like Israel where water is very scarce. When cassava is produced, the value of the cost of water used for the production is added to the selling price in case of export. Similar thing should be employed in this research so as to attach value to our water. Planting early in the rainy season will generally produce the highest yields as shown in Table 2. All the cassava planted early in the month of march in the 1995, 2010, 2011 and 2013 had a better yield compare to others except in some few occasions and this was due to the fact that the plants have adequate soil moisture during the most critical part of their growth cycle.

However, research has shown that yields can vary according to the variety used, the soil type, the plant's age at harvest, and the rainfall intensity and distribution during any particular year. One or more of the aforementioned factors could be responsible for the low yield in 2012.

4. CONCLUSION AND RECOMMENDATION

Based on the yield shown above, effective rainfall and water productivity observed to be maximum in the 20th year (2013), the cost of water was calculated to be ₦11,051,872 in which the costs is low compare to other years. This amount can be used to purchase water need for cultivation of cassava in dry season when irrigation is needed in order to obtain maximum yield. The cost of water used can also be used to calculate the concept of virtual water.

It is strongly recommended that other parameters like sunshine hour, temperature etc, should also be put into consideration in determining the water productivity for the production of cassava as this will shed more light on the crop yield to water use relationship. Since the effective rainfall was determined using Cropwat 8.0 model, it is advised to use other models rainfall data for this study.

It is as well recommended that Nigeria federal government parastatals and research institutes should be willing to assist in researches by their willingness to release data and useful materials to assist in further research works.

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Optimization of Some Mineral Contents of Dried Osmo-pretreated Onion Slice (*Allium cepa*)

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ABSTRACT

This study was conducted to optimize three mineral contents viz: vitamin C, manganese, and iron of dried osmotic pre-treated onion slice using response surface methodology (RSM). The osmotic process parameters used were osmotic solution concentration (OSC) [5% (w/w), 10% (w/w), 15% (w/w) and 20% (w/w)] prepared from common salt, osmotic solution temperature (OST) [35°C, 40°C, 45°C and 50°C] and osmotic process duration (OPD) [30 minutes, 60 minutes, 90 minutes and 120 minutes]. Onion slices (3mm) of constant weight of 40g were dehydrated through the osmotic medium inside a waterbath system. Immediately after osmotic dehydration, all pre-treated and some control (untreated) samples were dried at a constant temperature of 60°C in a fabricated cabinet dryer. To design the experiment, RSM under central composite design in Design Expert 6.0.6 computer software package was used, the design gave 8 factorial points, 6 axial points and 6 replicates at the centre point and data was obtained. The software was also used to analysed the data obtained, optimised the process and present all results with 3-dimensional plots, considering the three input process parameters. The optimal values for vitamin C, manganese and iron were selected at different combination of osmotic process parameters based on their desirability. From the desirable value on the response surface plots, the optimum (maximum) value of vitamin C and manganese was found to be 76.22 mg/100g and 2.39 mg/1000g respectively both at osmotic solution concentration of 20% (w/w) and osmotic process duration of 120 minutes; while for iron, the optimized value was 1.9187 mg/1000g at osmotic solution concentration of 20% (w/w) and osmotic solution temperature of 47.50°C. It was further observed that the dried pre-treated onions had values closer to fresh sample than control (untreated) samples for all the three mineral contents considered.

Keywords: Osmo-dehydration, Onion, Response Surface Methodology (RSM), Minerals, Optimization, Nigeria.

1. INTRODUCTION

Onion (*Allium cepa*) is an important spice crop extensively grown in almost all part of the world. Its susceptibility to various weather conditions had encouraged its production across the globe. Onion varies in size, color, firmness and strength of flavor. It is often referred to as "poor man's orange" because they are good source of vitamins, particularly Vitamin A and C. It is also a rich source of minerals such as iron and manganese. The pungent taste of onion is due to volatile oil Ally-propyl-disulphide present in it and they can be used either as salad or spice or for cooking with other vegetables (Alabi *et. al*., 2016). A global review of area and production of major vegetables shows that onion is ranked second in area of vegetables and third in production in the world, among seven vegetables, namely onion, garlic, caulifower, green peas, cabbage, tomato and green beans (FAO, 2003). Onion can be produced both in winter and summer. The yield of summer onion is 4-5 times more than winter onion. The summer onion is more perishable than winter onion and cannot be keep more up to 30 days due to its perishable nature. About 40-50% post-harvest losses are observed in onion during storage, transportation and marketing (BARI, 2003). The postharvest losses of this vegetable are quite serious and therefore drying or dehydration is necessary to increase its shelf-life. Dehydration of onions to onion flakes prevent post-harvest losses and can be converted into powder for utilization in the different product preparations such as soup, baby foods, noodles, extruded product coating, and all food item preparation. Also, dehydrated onion flakes and powder is very helpful to working women which will help as service pack. Onions can be dried from initial moisture content of about 82% to 8% or less, a moisture content save for storage and processing (Kalse *et al*., 2012). In addition to the conservation effect of drying on onion, drying reduces its weight and volume significantly and therefore decreases its transportation and storage costs. However, the challenges in fruits and vegetables drying are to reduce the moisture content of the product to a level where microbiological growth will not occur and simultaneously keep the high nutritive value.

Traditionally, agricultural products are exposed to direct sunlight which makes them prone to shrinkage, introduction of (sand and stones) foreign materials and product fouling by insect/pest infestation. These defects make sun drying unsuitable for drying agricultural materials (Iyanda, 2012). Isiaka *et al* (2011), developed and used a low energy forced convection solar dryer to dried sliced tomato, in determining the flow rate over a period. It was reported that the rate of drying was high at the initial period (that is, the first day) compared with the subsequent days showing that the cell sap of tomatoes expand quickly at the effect of solar energy and got its moisture move out rapidly; a process which is detrimental to tomatoes nutrients: viz color, and carotenoid compounds.

The use of modern (mechanical) air drying been a better alternative to direct sun drying usually takes time depending on the humidity in the air during drying process, the uniformity of the slices or pieces and the efficiency of the dryer used. Another disadvantage of mechanical dryers is that they bring agricultural products to undesirable changes in colour, texture, flavor and loss in nutritive value. Meanwhile, onion nutrients, flavor and color are generally perceived as important quality attributes and are strong in volatile compounds which tend to be lost during drying. The volatile compounds responsible for aroma and flavor of onions exhibit low boiling points and, accordingly, are often lost during high temperature drying. Maillard browning reactions induced by high temperature drying process decreases nutritional values, changes the color and flavor and induces textural changes (Alabi *et al.*, 2016). However, recent findings is tailored towards a novice way of drying such as osmotic dehydration that will reduce the moisture content of agricultural materials and at the same time preserve their nutritional qualities.

Osmotic dehydration is the process in which water is partially removed from cellular materials when they are placed in concentrated (hypertonic) solution of soluble solute. It is one of the simple and economical methods of extending the shelf-life of perishable products; and it preserves the colour, flavor, and texture of food from heat, thereby improving the nutritional, sensory and functional characteristics of products (Singh *et al*., 2006). It consumes less energy than air or vacuum air drying processes because it can be done at low or ambient temperature, and has the tendency of preserving the wholesomeness of the product (Chavan and Amarowicz, 2012).

However, a new method of drying in combination with osmosis (in which partial dehydration of the onion slices are brought about by immersing them in osmotic solution using controlled heat transfer applications and then drying) could be a good solution to post-harvest losses of onions and increase its availability for both industrial and domestic uses at its conserved mass and nutritional qualities considering its importance. Therefore, the optimization of some mineral contents of onions is required to be able to determine possible combination of input parameters during osmo-drying process.

Optimization is the process of finding actions that maximize or minimize the value of an objective function. It is a kind of process that systematically comes up with solutions that are better than the solution used before. This definition can also be adopted into drying process, by saying that, optimization of drying is the process of finding the best conditions under which the drying of a given product can be done in order to get the best product after drying. Some of the techniques of optimization are differential calculus, linear programming, sequential technique, simultaneous technique etc. Knowledge of osmotic drying kinetics of food materials is essential to design, optimize and control the drying process.

Kumar *et al.*, (2012) carried out the optimization of foaming condition of tomato juice using Response Surface Methodology. The optimized conditions of various input variables i.e %EA, %CMC and WT were found to be 11.45%, 0.33% and 5.21 min respectively which on validation was found to give stable foam structure.

1.1 Factors influencing osmotic dehydration process.

Some of the factors influencing osmotic dehydration process are: products maturity level, product variety, pre-treatments, temperature, nature and concentration of osmotic agents.

Others include agitation, product geometry, and product pieces to osmotic solution ratio, physio-chemical properties, additives, structures and pressures affecting the osmotic dehydration process.

1.1.1 Product geometry
The shape, size and thickness of products are other influencing factors. Water loss increases with surface area of products. In general, Chavan and Amarowicz (2012) suggested a sample size of 3mm to a maximum of 10mm in rectangular, ring or cube shape for use in osmotic dehydration process. Furthermore, Panagiotu *et al.*, (1998) reported that the size of fruit samples had effect on water loss. Rahaman (1992) observed that the coefficient of distribution of water decreased with increase in temperature and surface area.
Pointing *et al*., (1996) reported that apple slices were reduced to 50% of their original weight by osmo-drying them in 60-70^0 Brix of sugar solution.

1.1.2 Osmotic process duration
Jalali (2005) conducted a research on mango and pineapple; He considered three process parameters viz: Osmotic process duration, osmotic process temperature and osmotic process duration at different levels. He reported that increase in osmotic process duration (immersion time) gave an increase in weight loss, but the weight of occurrence decreased.

1.1.3 Osmotic solution temperature
According to Chavan and Amarowicz (2012), the studies on the optimization of duration of osmosis process showed that mass exchange took place at the maximum rate within the first two of osmotic treatment. Their findings also reveal that the higher the temperature, the higher the rate of osmotic dehydration process; however, the temperature must not exceed 60^{0}C because higher temperature tends to destroy the cell membranes of products.
Charles (2010) reported that temperature is an important factor affecting the kinetics of mass transfer during osmotic dehydration process materials that permit the osmotic dehydration process to take place in combination with liquid especially water. It is their presence in liquid that would generate an osmotic pressure which would lead to the usual countercurrent flows of liquid and solid out of and into the products respectively during osmotic dehydration process. The commonly used osmotic agents are sucrose and glucose for fruit, and sodium chloride for vegetables. Other agents are calcium chloride, malt dextrin, corn syrup or mixture of these agents (Chavan and Amarowicz 2012; Singh *et al.*, 2006).

Response surface modeling and optimization of chromium (VI) removal from aqueous solution was conducted by Krishna *et al*., (2013) where pH and adsorbent dosage were considered as input parameters. Percentage removal of chromium (VI) was found to be 97.6% at optimum conditions; adsorbent dosage (10.1869 g/l) and pH 1.9. Their model and experimental data showed that the model was able to predict the removal of chromium (VI) from aqueous solution using B. flabellifer coir powder efficiently.

1.1.4 Osmotic solution concentration

Many researchers have studied the effect of osmotic solution concentration on mass transfer of osmotic dehydration process. All of them reported that, the higher the concentration, the faster the rate of osmotic dehydration process (Chavan and Amarowicz 2012). Torreggani (1993) suggested that higher concentration for osmotic dehydration process for more than 50% weight reduction should be avoided; if not there would be decrease in osmotic rate with time.

2. MATERIAL AND METHODS

2.1 Material

Material used include: fresh onions, stainless steel tray, stainless knife, distilled water, cabinet tray dryer and desiccator with desiccants.

2.2 Sample Preparation

2.2.1 Osmotic Dehydration: Fresh samples of onions of better grades were washed in clean water and sliced into a uniform thickness of 3mm with the use of a stainless knife on a stainless steel tray (See figure 1). After this, 50g of each sample were measured by an electronic sensitive weighing balance and soaked in a hypertonic (NaCl) solution of four different concentrations (5, 10, 15 and 20% (w/w). The four levels of osmotic solutions were prepared by mixing 5g, 10g, 15g and 20g of NaCl with 100ml of distilled water respectively. In other word 5g, 10g, 15g, and 20g of solute in 100g of distilled water to form a four levels of osmotic solutions of 0.05, 0.1, 0.15 and 0.2 % (w/w) respectively. The samples were then immersed in a water bath continuously stirred to maintain a uniform temperature not higher than ±1°C for the four temperature levels 35, 40, 45^{o} and 50°C. Samples were removed from the osmotic solution after 30, 60, 90, and 120 minutes of immersion. Excess water on the surface was rinsed with flowing water and drained off under a fan to eliminate posterior weight and weighed using a digital balance.

Figure 1: Sample of fresh onions after cutting

Figure 2: Samples after osmotic dehydration

From the experiment, after the osmotic dehydration, reductions in masses of samples were noticed (less than 50g that was introduced for osmotic dehydration). As a result of this, a uniform sample mass of 40g was used for each sample combination, and properly re-arranged on the drying trays for drying.

2.3 Drying Procedure

During the last stage of sample pre-treatment, the drying equipment (mechanical dryer) constructed by Omodara (2011) was connected to the power source and switched on; the drying temperature in the mechanical dryer was 60^{o}C and pre-set on the temperature regulator (thermocouple). It was left for some times until the inside temperature reached the pre-set value. During this period, the inside temperature of the dryer was also checked occasionally with a portable mercury-in-glass thermometer in order to ensure that the value displayed on the screen of the thermocouple was the actual inside temperature of the dryer. Samples were carefully placed inside the dryer, the door of the dryer was closed and the time was noted. This marked the commencement of the drying operation. The masses of the samples were then taken in every 30 minutes. This process continued until a crispy texture was felt on the sample and when the samples gave constant or near constant mass values. During drying operation, the trays were occasionally randomized in a uniform order on their racks in order to ensure uniformity of drying operation to all samples.

2.4 Output Parameters

The qualitative output parameters determined after drying the samples were Vitamin C, Manganese, and Iron. The procedures used were those of AOAC (1990).

(i) Determination of Vitamin C.

Quality analysis was carried out in the Chemistry Laboratory, University of Ilorin, Nigeria. Vitamin C was determined using the Techniques stated in AOAC (1990). 20ml of extract of onion juice was pipetted into a 250ml standard flask and made up to the mark of the standard flask with distilled water. 25ml was pipetted from the solution into conical flask, and 25 ml of KIO_3 (potassium iodate) was added followed by 40 ml of 0.5M H_2SO_4. 10 ml of 10% of KI potassium iodide was added to the solution to generate brown colour, and was titrated with sodium thiosulphate until the colour changed to pale yellow. 2 drop of starch indicator was added and blue black colour appeared and finally titrated to colourless. The titre value was therefore used in computing vitamin C as demonstrated in equation (1):

$$Vitamin\ C\left(\frac{mg}{100g}\right) = \frac{titre\ value\ x\ 0.212\ x100}{weight\ of\ sample} \qquad (1)$$

(ii) Determination of Manganese and Iron.

The method used is aqua regia for the digestion of the sample. 2 grams of the sample was weighted and put into the digestion flask. HNO_3 and NCl were added to it in the ratio 3:1. The digestion flask was heated on the heating mantle until the solution was cleared. The solution was allowed to cool and finally filtered with filter paper and make up the solution to 100 ml. The solution was then subjected to AAS analysis to determine the amount of Manganeze (Mg) and Iron (fe) present in the sample, AOAC (1990).

2.5 Statistical Analysis for Osmotic Dehydration of Onion

Data obtained from osmotic dehydration of onion were subjected to the statistical analysis of variance (ANOVA) using a standard Design Expert version 6.0.6. The result of the statistical analysis of variance were conducted to determine the significance and fitness of quadratic model developed and also to determine the significant effect of individual variable on a chosen response (nutrient).

A standard method called central composite design (CCD) in Box-Behnken design was employed to study the independent variables. The significance of this method to fitting a quadratic surface, optimizing the factors with a minimum number of experiments and analyzing the interaction between factors made it a suitable choice. Different levels of independent variables considered for the study were (i) A; Osmotic Solution Concentration (5 w/w, 10 w/w, 15w/w and 20 w/w); (ii) B; Osmotic Process Duration (30 minutes, 60 minutes, 90 minutes and 120 minutes); and (iii) C; Osmotic Solution Temperature (35^{o}C, 40^{o}C, 45^{o}C and 50^{o}C). A 2^3 full factorial CCD for the three independent variables, consisting of 8 factorial points, 6 axial points and 6 replicates at the center points totaling 20 experiments were employed for the optimization.

Table 1 shows the summary of the result output for osmotic dehydration of onion. The result shows the range of response (nutrients) and levels of independence variables.

Table 3: Summary of the result output of osmotic dehydration of onion

Study Type: Response Surface				**Experiment:** 20			
Initial Design: Central Composite			**Blocks:** No Blocks				
Design Model: Quadratic							
Response	**Name**	**Units**	**Obs.**	**Minimum**	**Maximum**	**Trans**	**Model**
Y1	Vitamin C	mg/100g	20	72.56	76.96	None	Quadratic
Y2	Manganese	mg/1000g	20	2.08	2.64	None	Quadratic
Y3	Iron	mg/1000g	20	1.50	2.18	None	Quadratic
Factor	**Name**	**Units**	**Type**	**Low Actual**	**High Actual**	**Low Coded**	**High Coded**
A	OSC	g/dm^3	Numeric	5.00	20.00	-1.000	1.000
B	OPD	mins	Numeric	30.00	120.00	-1.000	1.000
C	OST	^{o}C	Numeric	35.00	50.00	-1.000	1.000

2.5.1 Data Analysis

The data obtained were analyzed following the outlined procedures of the software for RSM in order to obtain the 3-dimensional (3-D) plots that relate the three process conditions with each of the output parameter (mineral contents) and desirability values for optimum process conditions.

3. RESULTS AND DISCUSSION

3.1 Model Development

The model was built using all the possible relationship between the process conditions manipulated (Osmotic Solution Concentration, Osmotic Solution Temperature and Osmotic Process Duration) and the measured output (Vitamin C, Manganese and Iron) with a view to selecting models that appropriately capture the relationship between the input and output parameters. In doing this we explored individual relationships one at a time by keeping other process parameters constant. This is to ensure clear interpretations and for the avoidance of ambiguity. The model built therefore take cognizance of the various relationships exhibited between the process conditions and the output. The process modeling technique in Design Expert version 6.0.6 computer software was used, the data obtained for Vitamin C, Magnesium and Iron were modeled. The essence is to find a functional relationship that can adequately relate process parameters (Osmotic Solution Concentration, Osmotic Solution Temperature and Osmotic Process Duration) to the measured output (vitamin C, Manganese and Iron).

From the regression analysis carried out, the best performing functional models were developed, one for each measured parameter as seen in equation 2 for Vitamin C. The criteria for adjudging these models were the value of their adjusted coefficient of multiple determinations R^2, prediction error sum of squares PRESS (also called deleted residuals), R^2 for prediction, and coefficient of variation CV. Models were checked for adequacy using these statistics and those found to be adequate were selected from among the other possible combinations of the models as shown in table 2.

Table 4: Analysis of Variance showing residual sum of squares for the models developed

1. Analysis of variance for vitamin C						
Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**	
Model	18.263298	9	2.029255	5.383208	0.0073	significant
A	1.8192375	1	1.819238	4.826073	0.0527	
B	1.2832583	1	1.283258	3.404227	0.0948	
C	0.3160975	1	0.316097	0.838543	0.3814	
A2	0.4782286	1	0.478229	1.268645	0.2863	
B2	0.920303	1	0.920303	2.441379	0.1492	
C2	10.201839	1	10.20184	27.06343	0.0004	
AB	1.39445	1	1.39445	3.699196	0.0833	
AC	1.46205	1	1.46205	3.878526	0.0772	
BC	0.21125	1	0.21125	0.560404	0.4713	
Residual	3.7696025	10	0.37696			

Lack of Fit	1.8942525	5	0.37885	1.010079	0.4957	
Pure Error	1.87535	5	0.37507			
Cor Total	22.0329	19				
Regression Statistics for Model Adequacy						
Std. Dev.	0.6139709		R-Squared	0.86891		
Mean	74.525		Adj R-Squared	0.67493		
C.V.	0.8238455		Pred R-Squared	0.220075		
PRESS	17.184003		Adeq Precision	8.671531		
2. Analysis of variance for manganese						
Source	**Sum of Square**	**DF**	**Mean of Square**	**F Value**	**Prob > F**	
Model	20.26703	9	2.251892	6.185605	0.0126	significant
A	5.729113	1	5.729113	15.737	0.0054	
B	0.0008	1	0.0008	0.002197	0.9639	
C	1.702013	1	1.702013	4.67517	0.0674	
A2	2.448026	1	2.448026	6.724357	0.0358	
B2	0.640421	1	0.640421	1.75914	0.2264	
C2	2.813921	1	2.813921	7.729415	0.0273	
AB	0.024025	1	0.024025	0.065993	0.8046	
AC	6.0516	1	6.0516	16.62283	0.0047	
BC	0.819025	1	0.819025	2.249738	0.1773	
Residual	2.548375	10	0.364054			
Lack of Fit	2.548375	3	0.849458			
Pure Error	0	4	0			
Cor Total	22.8154	19				
Regression Statistics for Model Adequacy						
Std. Dev.	0.603369		R-Squared	0.888305		
Mean	33.57		Adj R-Squared	0.744696		
C.V.	1.797344		Pred R-Squared	-0.78713		
PRESS	40.774		Adeq Precision	10.06726		

PRESS	0.2428		Adeq Precision	9.451112		
3. Analysis of variance for iron						
Source	**Sum of Squares**	**DF**	**Mean of Square**	**F Value**	**Prob > F**	
Model	0.108601	9	0.012067	5.566248	0.0170	significant
A	1.25E-05	1	1.25E-05	0.005766	0.9416	
B	0.04205	1	0.04205	19.39703	0.0031	
C	0.005513	1	0.005513	2.542834	0.1548	
A2	0.019901	1	0.019901	9.180179	0.0191	
B2	0.00348	1	0.00348	1.605393	0.2457	
C2	0.001112	1	0.001112	0.512876	0.4971	
AB	0.01	1	0.01	4.61285	0.0688	
AC	0.024025	1	0.024025	11.08237	0.0126	
BC	0.0036	1	0.0036	1.660626	0.2385	
Residual	0.015175	10	0.002168			
Lack of Fit	0.015175	3	0.005058			
Pure Error	0	4	0			
Cor Total	0.123776	19				
Regression Statistics for Model Adequacy						
Std. Dev.	0.04656		R-Squared	0.8774		
Mean	0.358824		Adj R-Squared	0.719771		
C.V.	12.97581		Pred R-Squared	-0.9616		
PRESS	0.2428		Adeq Precision	9.451112		

$$
\begin{aligned}
Vitamin\ C = {} & +54.40924 - 0.44808 * OSC - 0.010395 * OPD + 1.12001 * OST \\
& + 3.23850E - 003 * OSC^2 - 1.24793E - 004 * OPD^2 - 0.014958 \\
& * OST^2 + 1.23704E - 003 * OSC * OPD + 7.60000E - 003 * OSC \\
& * OST + 4.81481E - OO4 * OPD * OST \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)
\end{aligned}
$$

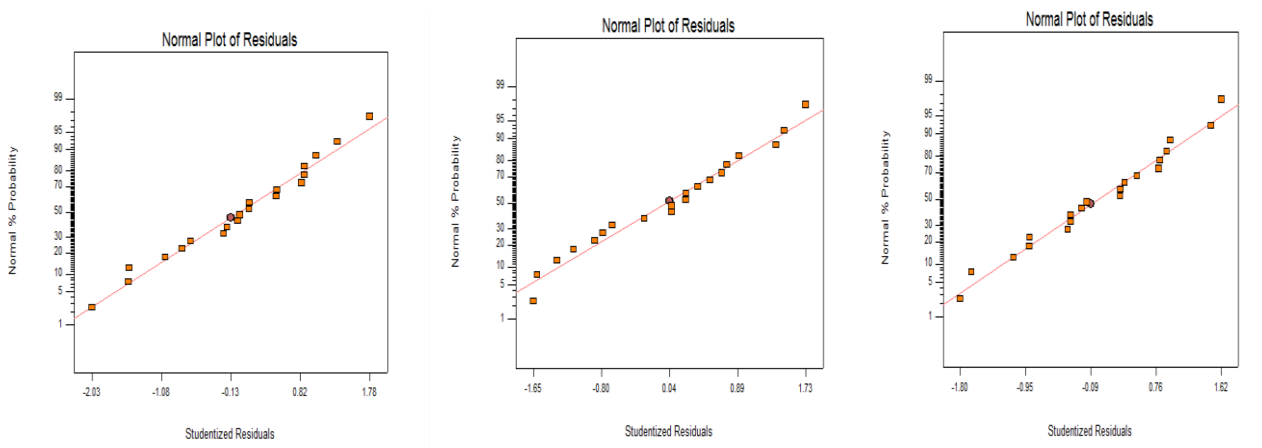
Where: OSC = Osmotic Solution Concentration
OPD = Osmotic Process Duration
OST = Osmotic Solution Temperature

3.2 Model Validations

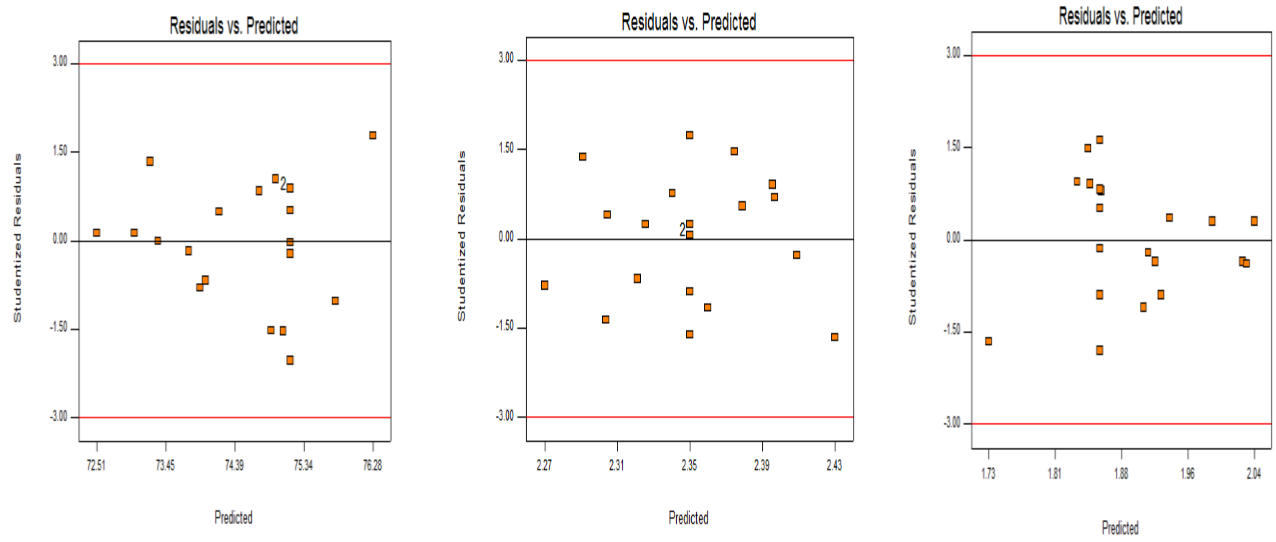
Model validation ensures that the model meets its intended requirements in terms of the methods employed and the results obtained. The ultimate goal of model validation is to make the model useful in that the model should be able to address the right problem, provides accurate information about the system being modeled and to make sure the model can be actually put to use. In the case of this research work, the models equations were developed to predict (vitamin C, manganese and iron) nutrients from possible combination of input parameters. Therefore, the models obtained were validated using the graphical method.

Figure 3 shows a typical Normal Probability Plot of the Expected Normal Values (Rankit) vs. the Residuals. The plots in figure 4 examines the error structure to ensure that the residuals behaves as expected, i.e., if the errors are distributed normally. The graphs clearly showed that the residual plots are not heavy tailed, i.e. spread about the straight line. Rather the residuals fell on straight line for all the process output observed. This implies that the assumption of normality of the residuals was not violated.

The assumption of constant error variance was also checked using the plots of residuals vs predicted responses. The plots in figure 4 show bands around 0 with constants width. This implies that the error variance is stable with respect to predicted responses for all the observed parameters.



a b c



a **b** **c**

Figure 4. a-c: Plot of residuals versus predicted values for (a) vitamin C (b) manganese (c) iron

3.3 Optimized Value of Process Conditions and the Output

Optimization deals basically with finding optimum (maximum or minimum) settings of parameters (process conditions) in mathematical model in order to obtain a desired output or response value.

The optimized values of process conditions namely; osmotic solution concentration, osmotic solution temperature and osmotic process duration preset at their various levels for the optimum (maximized) values of the process output are as presented in Table 3. The all process parameters and process output were optimized. The result in Table 3 can be summarized as follows;

The results of the optimization of the mineral contents analyzed for osmo-dehydration under different input variables were 76.22 mg/100g, 2.39 mg/1000g and 1.91 mg/1000g for vitamin C, manganese and iron respectively. The goal of the optimization is to achieve high nutrients capability of the osmo-dried product considering their importance in humans' health. The higher the value of vitamin C, manganese and iron in the dried onion, the better the health benefits to the consumer as earlier mentioned, hence the justification of the optimization. The optimum values of osmotic solution concentration, osmotic process duration and osmotic solution temperature from Box–Behnken design were found to be 20 g/g, 120 minutes and 44^{o}C respectively.

Table 3: Optimal values of input variables for respective minerals

Number	OSC	OPD	OST	Vitamin C	Manganese	Iron	Desirability	
1	20.00	120.00	44.02	76.2203	2.39801	1.9123	0.659183	Selected
2	20.00	117.46	44.04	76.2056	2.39691	1.9077	0.655084	
3	20.00	120.00	41.66	76.1069	2.40702	1.90177	0.652756	
4	20.00	115.87	44.22	76.1967	2.3956	1.90561	0.652529	

3.3.1 Vitamin C (mg/100g)

The relationship of actual and predicted value of vitamin C performs by the software is presented in Figure 5.

The R^2 (0.86891), Adj. R^2 (0.67493) values and the close correlation observed between the predicted and actual values for vitamin C as plotted in figure 5 is an evidence that the regression model represents the experimental data well.

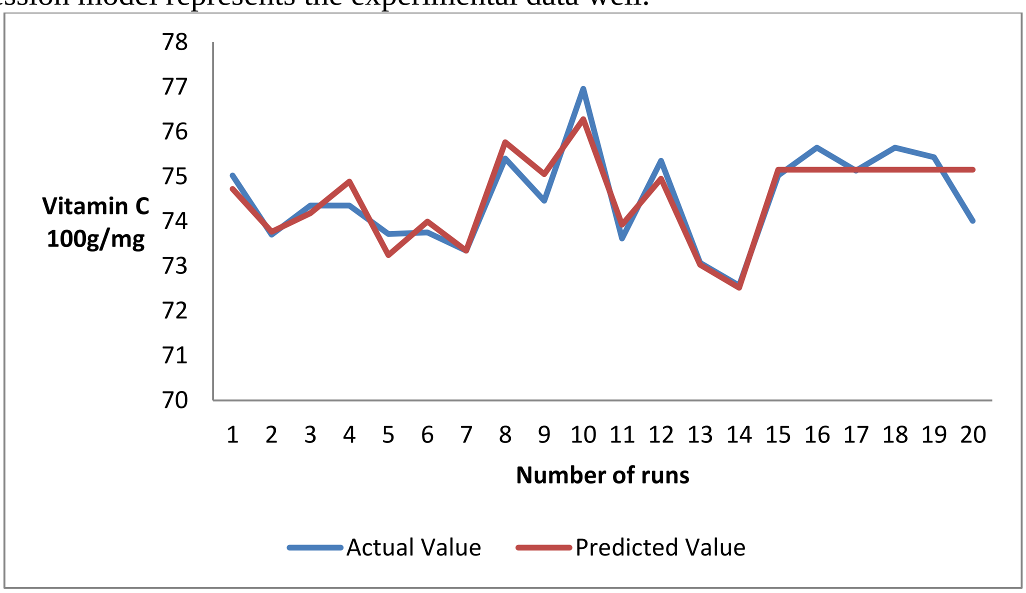


Figure 5: Actual value Vs predicted value for vitamin C

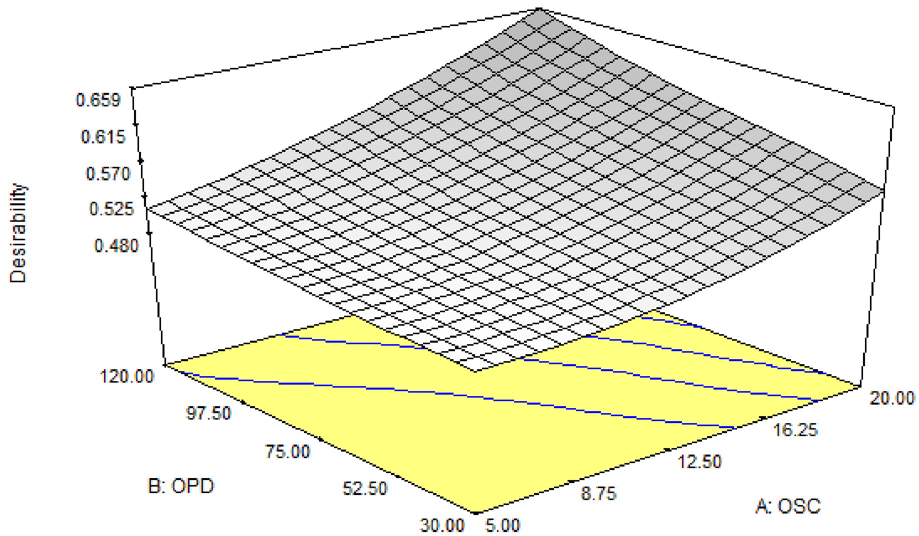


Figure 6a: 3 – D Plot showing desirability value of optimum process conditions for Vitamin C

Figure 6a shows the desirability value of optimum process conditions for vitamin C in 3 - dimension form, while figure 6b shows the optimum value of vitamin C with respect to process conditions A: OSC and B: OPD. The selected desirability of 0.6591 is the closet value to one, which is an important pre-determined factor of optimization. The optimized value of 76.22 mg/100g for vitamin C was obtained at corresponding values of 20 w/w and 120 minutes osmotic solution concentration and osmotic process duration respectively. Meanwhile, the control (untreated) sample contained 38.20 mg/100g after drying and the fresh onion sample contained 78.00 mg/100g; a value nearly close to the optimized value (76.22 mg/100g) obtained from the osmo-dried onion. However, osmotic dehydration technique as a means of food preservation helps in retaining nutrients as agreed by Alabi *et al*., (2016) during drying and preservation of food materials.

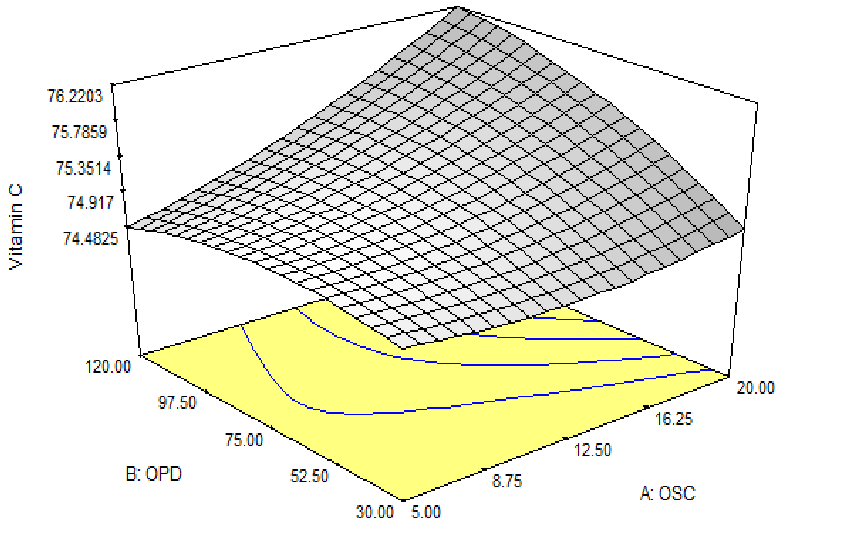


Figure 6b: 3-D Plot for optimum value of vitamin C

3.3.2 Manganese

The empirical relationship between the response (manganese) and the independent variables is expressed by the following quadratic model adsorption. The model equation shows that only the independent variables had significant effect on manganese excluding their interaction.

$$Manganese = +2.42192 + 4.86383E - 003 * OSC + 3.96431E - 004 * OPD - 3.83414E - 003 * OST \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Figure 7 shows the plot between the predicted and actual values for manganese. From the figure, it is evidence that the regression model represents the experimental data well.

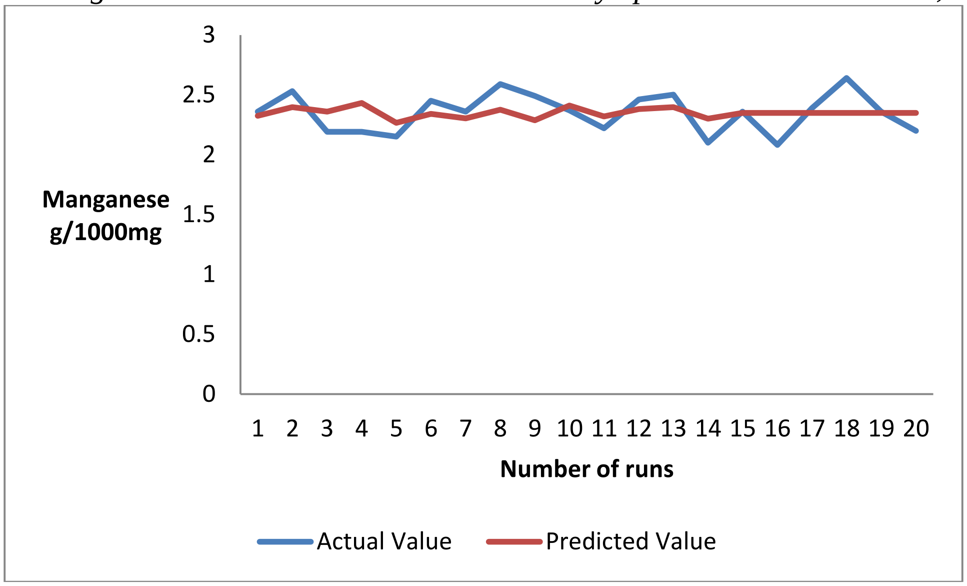


Figure 7: Actual value Vs predicted value for manganese

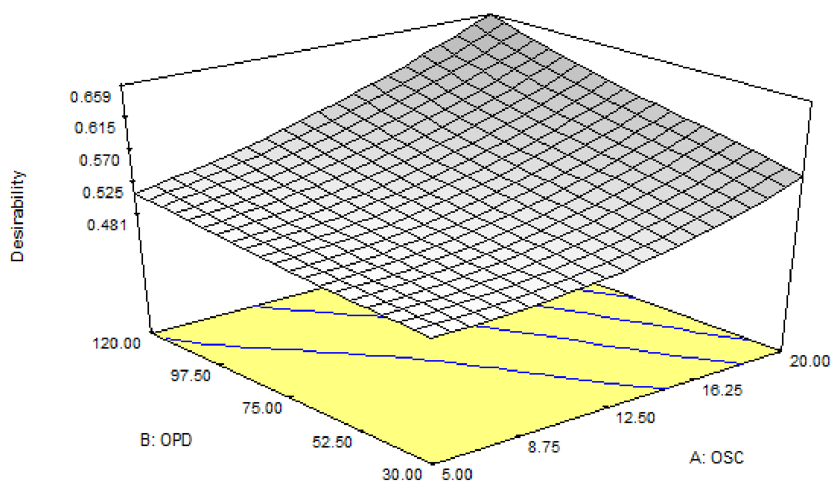


Figure 8a: 3 –D Plot showing desirability value of optimum process conditions for manganese

Figure 8a shows the desirability value of optimum process conditions for manganese in 3 - dimension form, while figure 8b shows the optimum value of manganese with respect to process conditions A: OSC and B: OPD at a selected desirability of 0.658. The optimized value of 2.39 mg/1000g for manganese was obtained at osmotic solution temperature of 45°C and corresponding values of 20 w/w and 120 minutes osmotic solution concentration and osmotic process duration respectively. Meanwhile, the control (untreated) sample contained 0.99 mg/100g after drying and the fresh onion sample contained 4.00 mg/1000g; a value nearly close to the optimized value (2.39mg/1000g) obtained from the osmo-dried onion. The amount of manganese contained in untreated samples was low compare to the amount contained in fresh sample. This however support the finding of Singh *et al.*, (2006) was stated that osmotic dehydration helps in preserving quality of products.

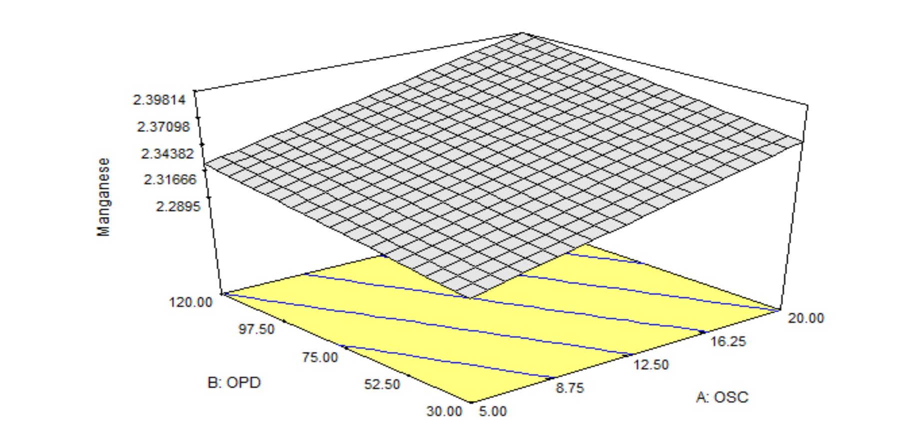


Figure 8b: 3-D Plot for optimum value of manganese

3.3.3 Iron

The empirical relationship between the response (iron) and the independent variables is expressed by the following quadratic model adsorption$Iron = +1.00399 - 0.031699 * OSC + 1.02071E - 003 * OPD + .043262 * OST + 4.27317E - 004 * OSC^2 + 3.02023E - 005 * OPD^2 - 4.52638E - 004 * OST^2 - 8.88889E - 005 * OSC * OPD + 6.22222E - 004 * OSC * OST - 1.03704E - 004 * OPD * OST$ … … … … … … … … … … … … (4) The R^2 (0.8774), Adj. R^2 (0.71977) values and the close relationship between the actual and predicted values of iron as shown in figure 9 demonstrated that the regression model represented the experimental data well.

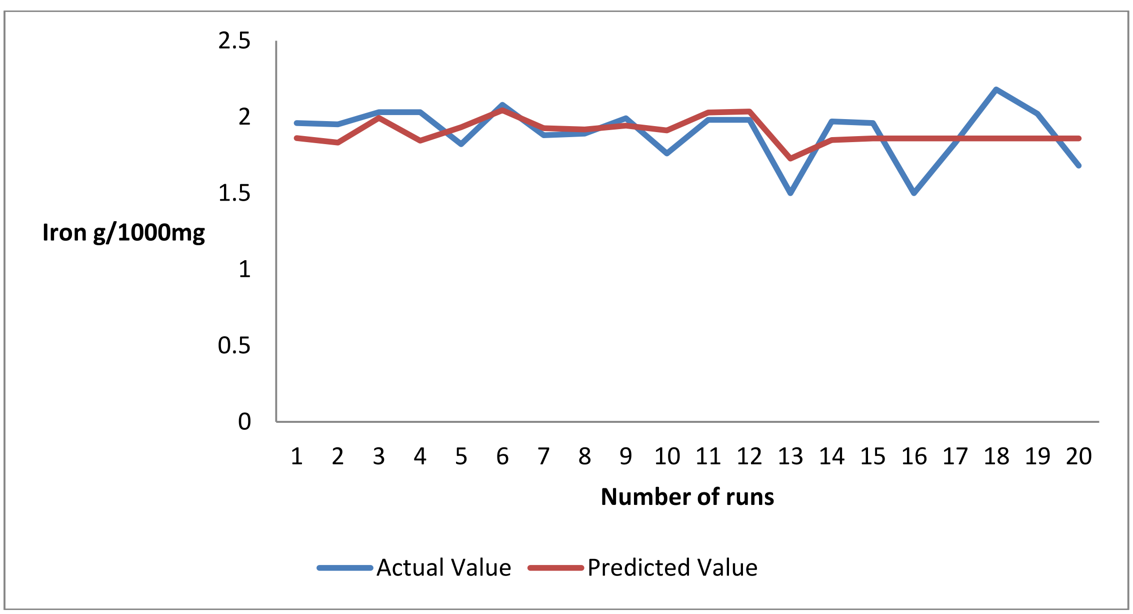


Figure 9: Actual value Vs predicted value for iron

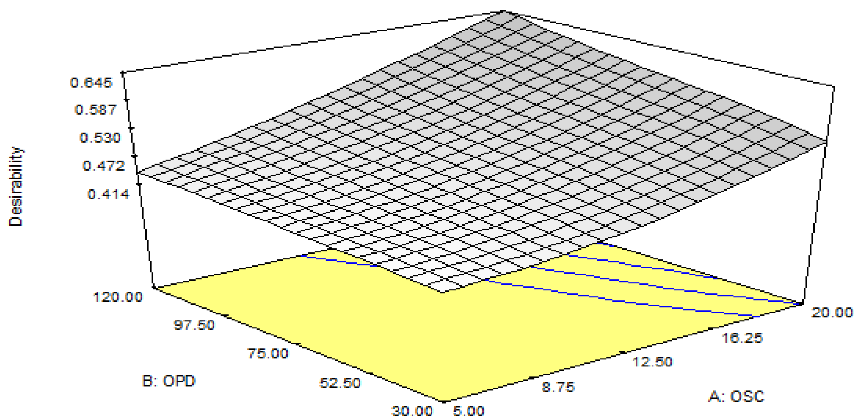


Figure 10a: 3 –D Plot showing desirability value of optimum process conditions for iron

Figure 10a shows the desirability value of optimum process conditions for iron in 3 -dimension form, while figure 10b shows the optimum value of iron with respect to process conditions A: OSC and B: OPD at a selected desirability of 0.645. The optimized value of 1.9187 mg/1000g for manganese was obtained at osmotic solution temperature of 47.50^{o}C and corresponding values of 20 w/w and 120 minutes osmotic solution concentration and osmotic process duration respectively. At osmotic solution temperature slightly above 48^{o}C and OSC of 20 w/w, iron content start to decrease. The iron level of osmo-dried onion was normal (1.9187 mg/1000g) within the range of dietary allowance for males (1.37 mg/day) and for females (2.94 mg/ day) as recommended by FAO/WHO (1988) in their technical report series. However, the control (untreated) sample contained 0.7912 mg/1000g after drying while the fresh onion sample contained 3.00 mg/1000g of iron. This result show significant differences in control (untreated) dried samples as compare to fresh samples. The amount of iron contained in untreated samples was low compare to the amount contained in fresh sample and thus support the finding of Singh *et al.*, (2006).

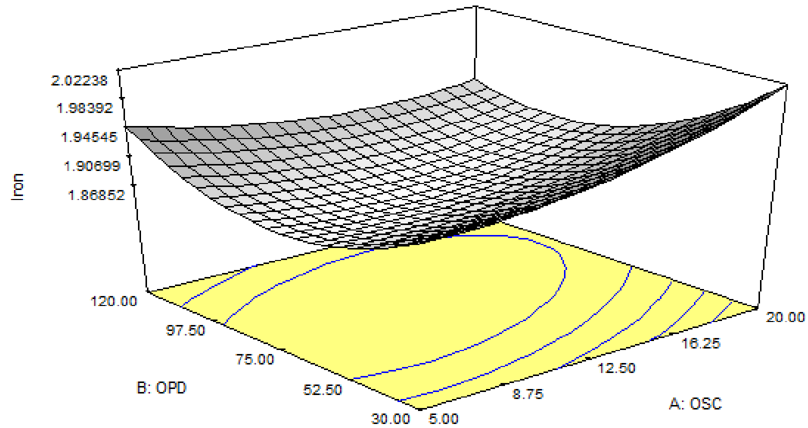


Figure 10b: 3-D Plot for optimum value of iron

4. CONCLUSION

Optimization of process variables on the mineral content of onion was investigated using central composite design of response surface methodology. Osmotic solution concentration (OSC), osmotic process duration (OPD) and osmotic solution temperature (OST) were the independent variables considered, while mineral composition (response variables) are vitamin C, manganese and iron. Results showed that OSC, OPD and OST all had a significant effect on the minerals among which OST had the most pronounced effect ($P < 0.005$). The optimization of the analyzed responses shows that the maximum value for vitamin C (76.22 mg/100g) was obtained at 20% w/w, 120 minutes and 44°C osmotic solution concentration, osmotic process duration and osmotic solution temperature respectively. This maximum value was selected at 0.6592 level of desirability. For manganese, the value was 2.39 mg/1000g at 20% w/w osmotic solution concentration, 120 minutes osmotic process duration and at 45°C osmotic solution temperature at 0.658 level of desirability; while for iron it was 1.9187 mg/1000g at 20% w/w osmotic solution concentration, 120 minutes osmotic solution duration and 47.50°C osmotic process temperature, selected at 0.645 level of desirability. Dried pre-treated onions had nutrients values closer to fresh samples than control (dried unpretreated) samples for all nutrients considered. This finding proved that osmo-dehydration technique is a better means of improving and preserving product nutrients.

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Simulation of A Conceptual Fresh Tomato Fruits Packaging Container for Transportation

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ABSTRACT

Tomato is a tender and compression-sensitive fruit. It is a viscoelastic material that mostly experience compressive stress when packaged in unit loads, resulting in deformation, bruising and/or complete failure of the fruit. Harvested tomato fruits in Nigeria are packaged in traditionally woven raffia baskets and transported in open trucks making them highly susceptible to mechanical damage. An inefficient packaging system is a disadvantage to tomatoes marketing due to its direct influence on cost, quality and overall postharvest losses. The need for an effective tomato packaging container that could ameliorate postharvest losses becomes expedient, hence, in this study, a packaging container for fresh tomato fruits was conceived. The container was developed in automated computer aided design (AUTO-CAD) and verified with a computer simulation using 2016 3-Dimensional solid works software. The static analysis, solid mesh, and free body forces were set and the simulation installed and attached. The material properties used was Acrylonitrile Butadiene Styrene (ABS) of linear elastic isotropic, tensile strength of $4 \text{ X } 10^7$ N/m^2, elastic and shear modulus of $2.41 \text{ X } 10^9$ N/m^2 and $8.622 \text{ X } 10^8$ N/m^2 respectively with a mass density of 1070 kg/m^3. The simulation was run assuming a normal force of 200N exerted on the weight of the tomatoes, and a corresponding reactive force considered. Stresses on the container base and handles, ability to stack, drop and buckling tests were simulated. Simulation results revealed that the conceived container when developed can withstand the transportation rigor with insignificant damages to the packaged tomato.

Keywords: Tomato, simulation, stresses, packaging container, Solid works

1.0 INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is a staple fruit vegetable, a member of the *Solanaceae* family (Abdullah *et al.,* 2004). It is one of the most important vegetables worldwide (SaeedAwan *et al.,* 2012) Tomato is a compression-sensitive fruit (Babarinsa and Ige, 2014), being a viscoelastic tender material that experiences compressive stress when packaged in unit loads, resulting in deformation, bruising and/or complete failure of the fruit. Food losses are on the increase in recent times. About 1.3 billion tons of food is predicted to be lost each year (Gustavsson *et al.*, 2011). In Nigeria where the agriculture sector contributes more than 30% of the GDP and employs about 70% of the labor force (Olayerni *et al.*, 2012), high postharvest losses has continued to be observed in food supply chains of perishable agricultural commodities like fruits and vegetables (Idah *et al.,* 2007a; Parfit *et al.,* 2010). Conservatively, 90% of food supply from developing nations like Nigeria is wasted as a result of deterioration (Onifade *et al.*, 2013); another estimated loss of 40 – 50% of tomatoes are at post-harvest stages (Olayemi *et al.,* 2010). Furthermore, Idah *et al.* (2007b) stated an estimated loss of fruits and vegetables commonly in the tropics occurred between production areas and consumption points to be between 50 – 70% (Olanrewaju et al., 2018). In Nigeria, freshly harvested tomato fruits are packaged in traditionally woven raffia baskets and transported in open trucks making them highly susceptible to mechanical damage due to poor packaging container and inappropriate transport system (Babarinsa and Ige, 2012; Ebimieowei and Ebideseghabofa, 2013). An inefficient packaging system is a disadvantage to tomatoes marketing as it has direct influence on cost, quality and overall postharvest losses.

Verbal interviews conducted by the researcher received significant percentage of complaints from tomato marketers and consumer. Postharvest losses was generally traced to packaging failure resulting from poor design or inappropriate selection and use. However, a well-designed tomato container is expected to contain, protect, and identify the produce, satisfying everyone from grower to consumer. Containers should be designed to protect tomato against damage during transportation and distribution and as well provide enough venting for rapid and uniform heat transfer during transportation and distribution (Clément *et al.,* 2009). It became expedient to have an effective tomato packaging container that could ameliorate postharvest losses, hence, the conceived tomato packaging container that was subjected to simulation in this study, to ensure an effective tomato packaging container that could reduce postharvest losses when developed.

Tomato packaging from time immemorial started with the use of broad green leaves, graduated to gourd and earthen pots, then weaved baskets, wooden crates, cardboard crates and boxes (Shankara *et al.,* 2005). Interestingly, among the mentioned packaging containers, only weaved baskets are still commonly used today because they are readily available, easy to produce and cheap. However, the damages inflicted on tomato fruits from the use of weaved baskets are numerous, resulting in tomato damage that forces farmers to sell their products at throw away prices. Girja et al. (2009) developed a corrugated fiberboard cartons for long distance transport in India. The specifications of the boxes were capacities 15 and 20 kg, bursting strength 11±1, number and diameter of ventilations 8 and 24.5 mm. Compression-drop and vibration tests were done on the peti box to determine its strength and weakness for long truck journeys. The boxes were generally acceptable by its users despite its deficiency of use during rain resulting in transporting products in covered van. Moreover, Pathare et al. (2012) reviewed the design of packaging vents for cooling fresh horticultural produce. Also, Abubakar, (2009) developed and evaluated the performance of an improved packaging for mass transportation of tomato. He developed a 15 kg rectangular wicker basket and transported fresh tomato fruits with it. His results were quite impressive. Idah et al. (2012) simulated transport damage on fresh tomato fruits by subjecting packaged tomato fruits in basket and plastics to some level of vibration in the laboratory. The simulation assumed that packaged tomato fruits travelled a distance of not less than 1000 km, considering vibrations subjected to the tomato fruits as a result of bad roads and vehicles transporting them.

2.0 METHODOLOGY

The concept of the packaging container was adapted from the conventional commonly used wicker baskets for packaging fresh tomato fruits with weight intervals of 20 – 40 kg. A sketch was made and developed into drawings using automatic computer aided design (AUTO-CAD) as shown in Figure 1. Design calculations was done considering appropriate plastic materials, weight, durability, ergonomics and other techno-economic factors.
The workability of the conceptual drawing was verified by subjecting the auto-cad drawing to a computer simulation using 2016 3–Dimensional solid works software. The 3D component was fully designed (the choice of material proposed for the design, the static and dynamic stresses to be applied) with high dimension accuracy and specific material choice. The components were placed within the simulation environment after setting the static analysis, solid mesh, and free body forces (Figure 2) on the computer and the simulation were installed and attached.

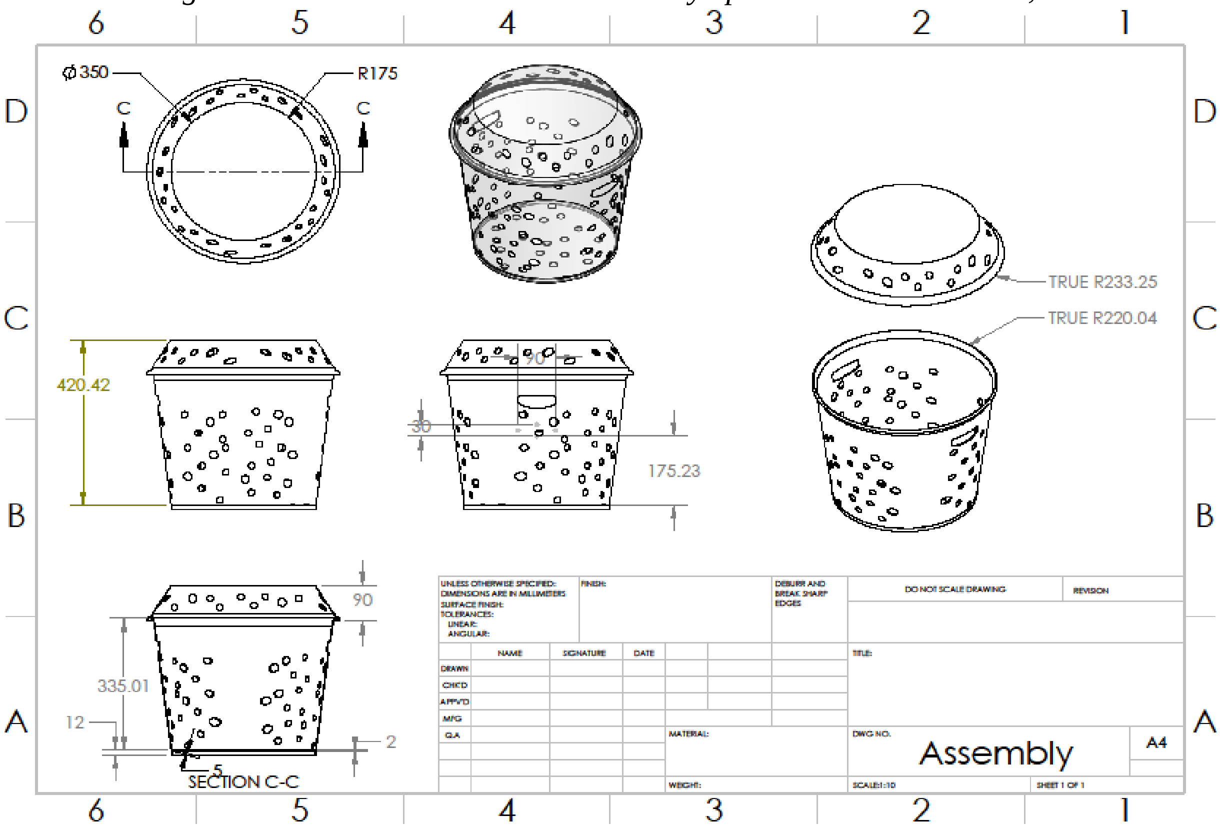

Fig. 1: Isometric, orthographic and plan Projections of the proposed packaging container

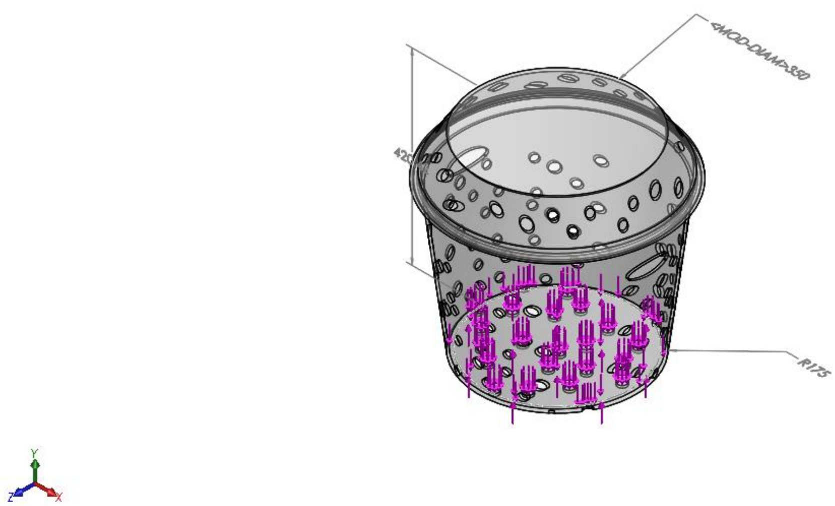

Figure 2: Initial installation of simulated components on the software

In running the simulation, an assumption of a single large tomato as presented in Figure 3 was made to reduce the processing workload of the simulation which would have taken several days if multiple normal size tomatoes were to be used. Each tomato would have been analyzed one after the other but since a single tomato was used, the simulation only lasted few hours. The material properties were ABS of linear elastic isotropic, tensile strength of 4 X 10^7 N/m^2, elastic and shear modulus of 2.41 X 10^9 N/m^2 and 8.622 X 10^8 N/m^2 respectively and a mass density of 1070 kg/m^3(Olanrewaju et al., 2017). The simulation was run with a normal force of 200N exerted on the weight of the tomatoes, and a corresponding reactive force taken.

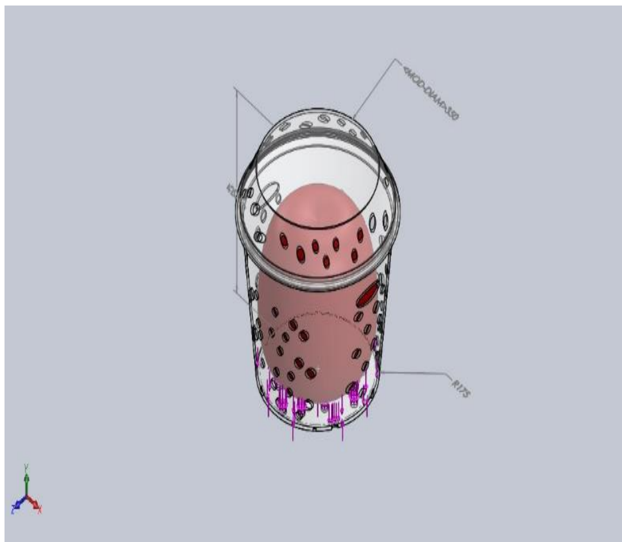

Fig. 3: A single large tomato size

In simulating the base test; the container loaded with tomato was placed inside the simulation environment, gradual force was exerted on top of the container until it reaches 200N. The stress distribution on the container was observed especially on the base as presented in Figure 4. The container handles was subjected to a tensile stress when loaded and placed in the simulation environment. The stress subjected on the handle was from a gradual force applied on each of the handle towards different direction. The reaction of the handles and the entire container to this stress is seen in Figure 5. More so, the stack-ability test was done by placing 10 containers filled with tomatoes on top of one another inside the environment of the simulation. The containers placed on top of one another was assumed to be 30 kg each when filled with fresh tomato fruits. The effects of the stack was observed on the bottom most container and presented in Figure 6. A drop test was done by placing a loaded container in the simulation environment, then dragged up to a height of 1 meter before it was abruptly dropped. The effect of the drop was studied as presented in Figure 7. Finally, the buckling test was done by subjecting the loaded container inside the simulation environment with a compressive force. A gradual force was applied at the top and bottom of the container. The behavior of the container was studied and presented in Figure 8. The responses of the test from the simulation was explained using coloration.

3.0 RESULTS AND DISCUSSION

The results of the simulation were interpreted using the color scale on the right side of each chart. The blue color designates the lowest value on the scale while red represents the highest, hence, within a stress test; blue areas indicate areas with least stress, while red are areas with the highest stress with reference to the scale. Though, red does not actually mean bad, but merely highest stress experienced.

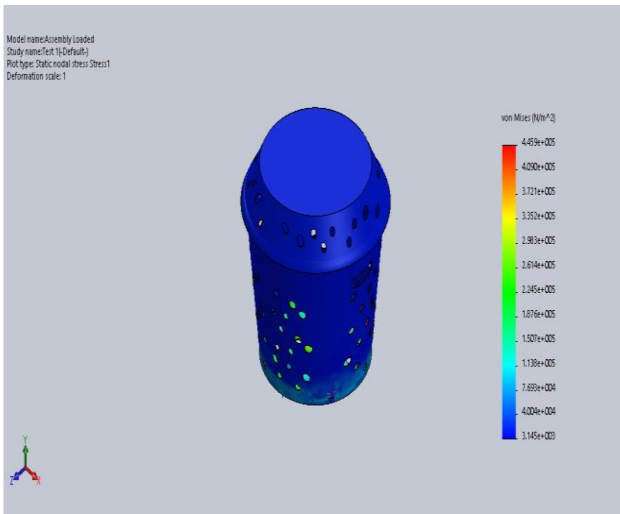

Fig4: Stresses on base

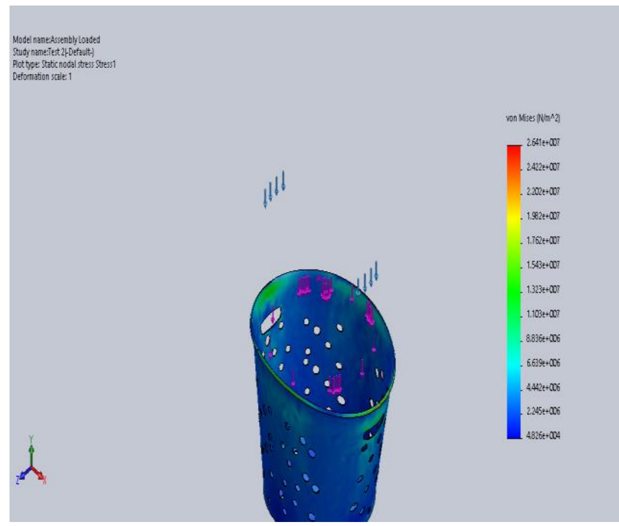

Fig 5: Stress on handles

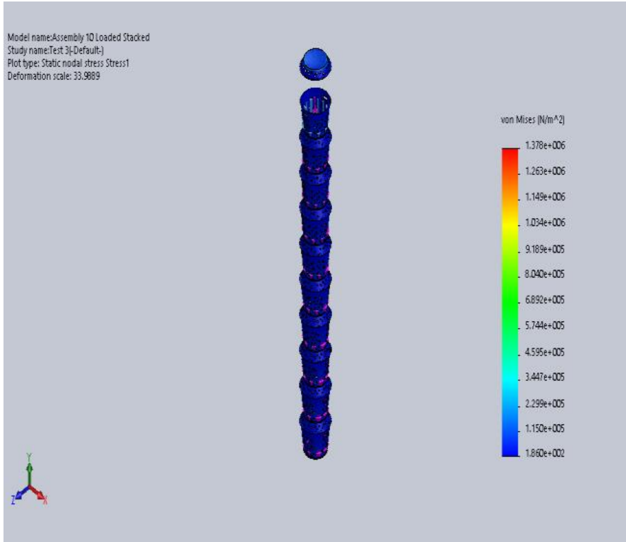

Fig 6: Stack ability test (Stack of 10)

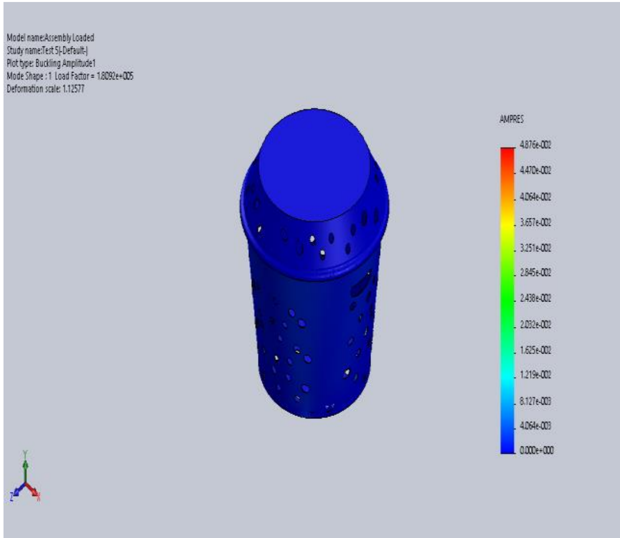

Fig 7: Drop test

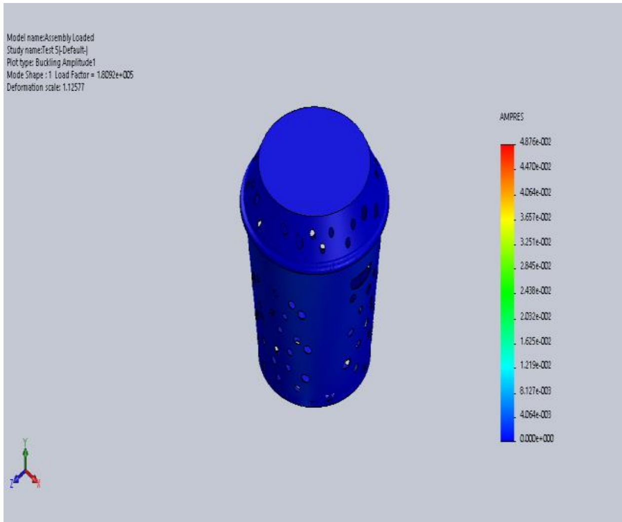

Fig 8: Buckling test

4.0 DISCUSSIONS

As observed from Figure 4, the stress chart showed that the container base is stressed between 1.507 X 10^5 N/m^2 to 2.983 X 10^5 N/m^2. The stressed experienced was a normal one, due to the fact that the base of the packaging container receives bulk of the load (dead and applied load). However, the stress experienced poses no threats to either the container or, the tomato fruits packaged in it. The handles of the packaging container as presented in

Figure 5 was found to have stresses between the values of 6.639 X 10^6 N/m^2 to 8.836 X 10^6 N/m^2. Such high values were recorded as a result of the flexibility of the material selected; causing the handle slots to bulge when it is lifted. This effect is not a deficiency, rather, an advantage that results from the flexural properties of the chosen material as explained by Rachida and Ismahane (2011) in their study. Also, Figure 6 revealed that the base of the first seven containers from below were stressed between 1.149 X 10^6 N/m^2 to 1.263 X 10^6 N/m^2, a relatively smaller stress when compared with studies conducted by Babarinsa and Ige (2014). The first bottom 3 containers bears the highest stress while the top 3 containers were least stressed. Stresses on the bottom most 3 containers were basically as a result of the collective dead and applied load when stacked on top of one another. It is normal for the bottom most container to bear the highest stress during stacking, however, it is recommended that the stack height should be 5 containers. This is to maintain the minimum allowable stress and ensure longevity of the packaging container.

Moreover, Figure 7 was found to have concentrated stresses between 3.883 X 10^6 N/m^2 to 7.765 X 10^6 N/m^2 around the centroid of the packaging container; such stress concentration was an indication of a uniformly distributed stress along the circular walls of the container when accidentally or intentionally dropped from a height not more than 1 m without causing serious damage to the tomatoes. This result agrees with the study of Idah *et al.*, (2007b). Figure 8 was found to have a least buckling value of not more than 4.064 X 10^3 N/m^2. These values were found to be adequate for the rigor of the intended use as a result of the material selected. These study results are in agreement with the study of Idah *et al.*, (2012); Venus et al., (2013) and Girja *et al.*, (2009).

A Summary of the simulated results is tabulated and presented in Table 1.

Table 1: Summary of Computer Simulation Results

Test	**Purpose of Test**	**Observation**	**Inference**	**Remarks**
Stress on base	Determine the ability of the container to hold the tomatoes for an extended period while placed on a floor.	The analysis reveals an even distribution of the weight along the base and low stress on the edges of the unit. Despite the thin thickness of the material the maximum displacement observed was still very low.	The modified basket will maintain its structure even when fully loaded with tomatoes	Good

Stresses on Handles	Determine the ability of the container to maintain its structural integrity while lifted and being held by the handles	The container bulges to accommodate the stress caused by the weight of the full load of tomatoes, but the bulge does not result in a permanent deformation of the container.	The bulge experienced was temporary and is expected to occur when the basket is fully loaded. Though, the Elastic limits are exceeded. The shape of the handle grip ensures a longer, gentler distribution of the stresses	Good
Stack-ability Stack of 10	Determine the filled tomato containers can be loaded on top of each other without causing failure.	The strain is distributed from the highest container down to the lowest and the design ensures the effect of it is spread throughout the container body.	The container body is easily capable of being stacked in rows of 10. The design ensures the load is stable and will not deform. But for reasons of safety and practicality, it is advised the stacked rows be limited to 5.	Good
Drop test	Determine how dropping a fully loaded container of tomatoes will affect the container when dropped from a height of 1 meters upon a hard surface.	The bottom rim of the container experiences very little stress, and little strain is experienced across the entire container and it is gently spread through the middle.	The design allows any stress from the impact to be evenly spread across the structure, no failure is expected to occur upon impact.	Good
Buckling test	Calculate the critical failure	A very low amplitude is	The design of the container	Good

	load of the container under compression to predict possible failure modes.	experienced by the container during the buckle experiment.	can withstand whatever forces it will be subjected to within the wide range of possible tomato loading situations.	

5.0 CONCLUSION

Studies conducted on the simulated conceived packaging container for fresh tomato fruits was found to be appropriate for tomato packaging and transportation in Nigeria. When the container is eventually developed, it is expected to address the postharvest challenges as related to fresh tomato fruits packaging and transportation. Moreover, the simulation information that this study provided has added to the data bank for developing an appropriate fresh tomato fruits packaging container for transportation.

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Design, Construction and Performance Evaluation of a Motorized Tomato Slicing Machine

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ABSTRACT

One of the major methods of tomato preservation is drying before storage. Tomatoes are best dried when sliced and slicing of tomato had been considered difficult operation as it is usually done manually. The manual means of slicing tomato is energy and time consuming and of course prone to injury when not done carefully. To solve the problems encountered in slicing of tomatoes**,** a motorized tomato slicing machine which is capable of conserving human energy, reducing time spent in slicing, providing safety as well as hygiene to users and serves as a source of income to small and medium scale farmers was designed, constructed and tested. Fully riped tomato sample was obtained and classified into three (Large, medium and small), evaluation of the machine performance was done based on the classifications and slicing efficiency, output capacity and percentage damage were calculated. The machine was designed to cut tomatoes into slices of 2.45cm thickness. The percentage damage, slicing efficiency and output capacity for large, medium and small tomatoes were 3.33%, 93.33% and 179.25kg/hr, 5%, 88.33% and181kg/hr, 5%, 81.67% and 178kg/hr respectively. The results of the study showed that the motorized machine can slice tomatoes effectively and satisfactorily.

Keywords: Preservation, Slicing, Drying, Motorized, Efficiency.

1. INTRODUCTION

Tomato (*Solanumlycopersicum L.*) is one of the most popular produce and extensively consumed vegetable crop in the world (Grandillo*et al.*, 1999). It can be eaten raw in salads or as an ingredient in many dishes and in drinks (Alarm *et al.*, 2007). Tomatoes and tomato-based foods provide a wide variety of nutrients and many health-related benefits to the body. Tomato contains high amount of lycopene, a type of carotenoid with anti-oxidant properties (Arab and Steck, 2000) which is beneficial in reducing the accidence of some chronic diseases (Basu and Imrhan, 2007) like cancer and many other cardiovascular disorders (Freeman and Reimers, 2010). Other studies have also shown that consumption of tomatoes and tomato-base foods can be linked to reduce incidence of a variety of cancers in general, including pancreatic, lung, stomach, colorectal, oral, bladder, and cervical cancer (Giovannucci, 1999). A study done by researchers at Manchester and Newcastle

Universities revealed that tomato can protect against sun burn and helps in keeping skin youthful. With these nutritional benefits of the perishable tomatoes, it is very important to be processed and preserved to ensure its availability during off season. Over 45% (750,000 metric tons) of tomatoes produced in Nigeria is estimated as annual loss due to poor food supply chain management, price instability resulting from seasonal fluctuation in production (Ugonna*et al*., 2015). Therefore, it is very important to process and preserve tomatoes to ensure its availability during off season.

2. MATERIALS AND METHODS

2.1 Materials

Materials used in the construction of motorized tomato slicing machine includes mild steel, stainless steel, cast iron, Gear motor, Electric motor, Synthetic Rubber and bearings etc.

2.2 Design Consideration

A number of factors were considered in the design of the machine which includes:

i- Functional requirement

ii- Cost effective factors

iii- Reliability factors

iv- Resistance to environmental factors

2.3 Design Calculation

The motorized tomato slicing machine was designed and constructed. The description of its various units are as follows:

2.3.1 Shape and size of tomato

Tomatoes are usually round, oval and cylindrical in shape and have a diameter ranging between 30mm to 80mm depending on the type. Shape and size are important in the design of components that handles the tomatoes like the hopper, the conveyor, knives arrangement and particularly the inner and outer clearance. The clearance should be slightly larger than the thickness of the tomato to allow the free passage and movement of the tomato.

2.3.2 Design of Hopper

The hopper is made up of four welded metal sheets slanting towards an opening to form a trapezium. It has two openings; the larger upper opening is for introducing the tomato while the smaller lower opening connects the hopper to the conveying unit. The capacity of the hopper is 2.5kg of tomatoes.

2.3.3 Belt conveyor speed, capacity and length

The conveyor belt is found in the conveying unit which is powered by an electric motor via a gear motor. The belt conveyor is made of canvass material for the belt, rollers, bolts and nuts for the tomato support. The speed of the conveyor is given by

$$V = \pi D \qquad (1)$$

Where:

V = belt speed, m/s
D = diameter of roller in, m
Capacity is the product of speed and belt cross sectional area. Generally, belt capacity (kg/sec) is given by:

$$BC = 3.6 \times A \times \rho \times V \qquad (2)$$

Where:
BC = belt capacity, kg/s
A= belt sectional area (m^2);
ρ = material density (kg/m^3); and
V= belt speed (m/s)
Length of the belt is given as:

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C \qquad (3)$$

2.3.4 Shaft design

The material for the design of the shaft is very important as it contributes to the strength and rigidity of the shaft. In this design mild steel was used because it is available, economical and can give required strength. From the power transmission, various members such as pulleys and others are mounted on the shaft. Hannah and Stephens (1981) has given the formula for the determination of the minimum diameter (D) of a shaft loaded in torsion and bending as the shaft will be subjected to combine torsional and bending.

$$D^3 = \frac{16}{\pi\tau}\sqrt{(K_t \times M_t)^2 + (K_b \times M_b)^2} \qquad (4)$$

Where:
K_t = combined shock and fatigue factor applied to torsional moment (K_t=1)
K_b = combined shock and fatigue factor applied to bending moment (K_b=1.5)
M_t = torsional moment (Nm)
M_b = bending moment (Nm)
τ = allowable mild steel shear stress of shaft (Nm^{-2})

2.3.5 Determination of pulley diameter

The allowable diameter of the pulley was obtained using the expression given by Aaron (1975).

$$N_1 D_1 = N_2 D_2 \qquad (5)$$

Where,
N_1 = speed of driving motor, rpm
N_2 = speed of driven shaft, rpm
D_1 = diameter of driving motor pulley, mm
D_2 = diameter of driven pulley, mm
The belt speed (V) was obtained from the equation below as:

$$V = \pi N_1 D_1/60 \qquad (6)$$

Where: V = velocity, m/s

2.3.6 Determination of belt length

The belt length was obtained using equation of Khurmi and Gupta (2005) as:

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C + \frac{(D_2 - D_1)^2}{4C} \qquad (7)$$

Where:

L = length of belt, mm
C = distance between the center of driving and the driven pulleys, mm
D_1 = diameter of driving pulley, mm
D_2 = diameter of driven pulley, mm

2.3.7 Angle of contact between the belt and pulley

Angle of contact is the angle of contact at the smaller pulley. It can be obtained from the equation below as given by Khurmi and Gupta (2005)

$$\theta = (180° - 2\alpha)\frac{\pi}{180} \quad (8)$$

$$\sin\alpha = \frac{r_1 - r_2}{C} \quad (9)$$

Where:
θ = angle of contact in radians
α = Wrap angle of the smaller pulley in degree
r_1 and r_2 = radii of the driving and driven pulleys respectively, mm
C = distance between the center of driving and the driven pulleys, mm

2.3.8 Tension in belt

The relationship between the tight and slack tensions in term of coefficient of friction (μ) and the angle of contact is given by Khurmi and Gupta (2004) as:

$$2.3\log(T_1/T_2) = \mu\Theta \quad (10)$$

Where:
T_1 = Tension in the belt on the tight side, N
T_2 = Tension in the belt on the slack side, N
μ = Coefficient of friction between the belt and pulley = 0.25
θ = angle of contact in radians

2.3.9 Power requirement

An electric motor of 2hp with 1430rpm was used to operate the slicing machine.

$$P = T \times \omega \quad (11)$$

$$\omega = \frac{2\pi NT}{60} \quad (12)$$

Where;
T=torque, Nm
ω =speed in radians
N= speed of shaft

2.3.10 Weight of knives

The weight of the knives is affected by the length, width, thickness and density of the material used. Thus the selection of right length, width and thickness of slicing knife is very essential as it directly affects the slicing effectiveness. The weight of slicing knife was calculated using expression given by Khurmi and Gupta (2005):

$$W_K = l \times w \times t \times \rho_k \times g \quad (13)$$

Where:
W_k= knife weight, N
t = knife thickness, m
L_k = Knife length, m
w= Knife width

g = acceleration due to gravity, m/s^2

ρ = knife density = Kg/m^3

2.3.11 Impact force required to shear fresh tomato

Considering the shear strength of fresh tomato and area under shear, the impact force required to shear fresh tomato may be obtained from the following expression:

$$F_T = A_T + \tau_T \qquad (14)$$

Where:

F_T = Force required for shearing fresh tomato

A_T = Area under shear

τ_T = Shear strength of the compressed tomato

The area under shear can be determined using the following equation;

$$A_T = \pi \frac{DT^2}{4} \qquad (15)$$

The area of larger tomatoes of thickness ranging from 0-62 mm and the equivalent diameter can be calculated by the following expression given by (Hossein*et al.*, 2015)

$$D_T = [\mathrm{L}\times\frac{(W+T)^2}{4}]^{1/3} \qquad (16)$$

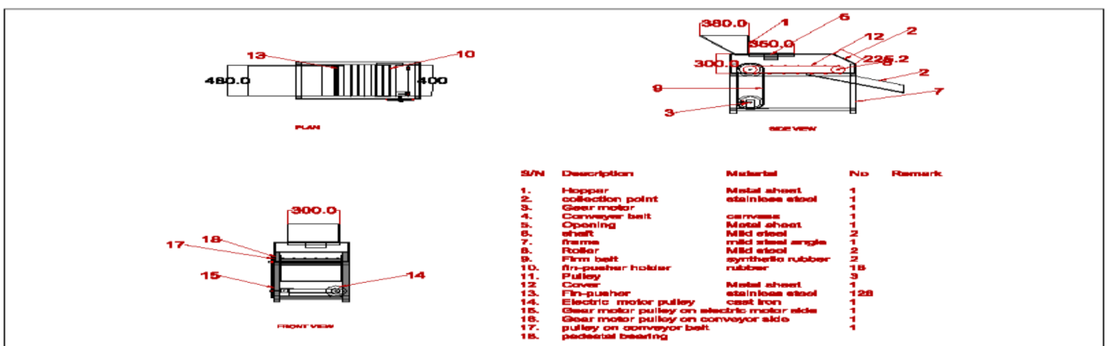
Where:

D_T = Equivalent diameter of the tomato, in (cm)

L = Length of the tomato, in (cm)

W = Width of the tomato, in (cm)

T = Thickness of the tomato, in (cm)



S/N	Description	Material	No	Remark
1.	Hopper	Metal sheet	1	
2.	collection point	stainless steel	1	
3.	Gear motor		1	
4.	Conveyer belt	canvass	1	
5.	Opening	Metal sheet	1	
6.	shaft	Mild steel	2	
7.	frame	mild steel angle	1	
8.	Roller	Mild steel	2	
9.	Firm belt	synthetic rubber	2	
10.	fin-pusher holder	rubber	18	
11.	Pulley		3	
12	Cover	Metal sheet	1	
13.	Fin-pusher	stainless steel	128	
14.	Electric motor pulley	cast iron	1	
15.	Gear motor pulley on electric motor side		1	
16.	Gear motor pulley on conveyor side		1	
17.	pulley on conveyor belt		1	
18.	pedestal bearing			

Fig. 5 TOMATO SLICER ASSEMBLY AND PARTS LIST

2.4 Experimental procedure

The machine was switched on and allowed to run without load for some minutes to ensure that it is in good working condition. 2.5kg of large tomato sample was measured using a weighing balance. The 2.5kg of large tomato sample was fed into the hopper to the conveying unit where it is conveyed to the cutting unit. The time taken to slice the 2.5kg of large tomato sample was taken. The sliced and unsliced tomatoes were counted and weighed using the weighing balance. The procedure was repeated three (3) times for large tomato sample. The slicing efficiency (SE) and output capacity (OC) and percentage damage were calculated and recorded. The Procedure was carried out for medium and small size tomato samples.

Motorized tomato slicing machine

2.5 Performance Indices for Slicing Machine

The performance indices used were slicing efficiency, output capacity and percentage damage.

2.5.1 Slicing efficiency

The slicing efficiency measures how effective the tomatoes were sliced by the slicing machine. It is calculated using expression given by Kamaldeen and Awagu (2013) as:

$$S.E = \frac{T_S}{T_f} \times 100 \qquad (17)$$

Where:

T_S = Total number of tomatoes sliced correctly

T_f= Total number of tomatoes fed into the machine

2.5.2 Output capacity

Output capacity of the slicer measures of the quantity of the slicer can handle per unit load of operation. It is calculated using expression given by Kamaldeen and Awagu (2013) as:

$$O.C = \frac{W_T}{T} \qquad (18)$$

Where:

W_T = total weight of tomato fed into the machine in (kg)

T = total average time taken to sliced all the tomato fed into the machine (s).

2.5.3 Percentage damage

The damage percentage of the slicing machine is a measure of a level damage done by the slicing machine. It is calculated using the following expression given by (Mangesh, 2015)

$$D_P = \frac{W_d}{W_t} \times 100 \qquad (19)$$

Where:
D_P = damage percentage, %
W_d = total number of tomatoes feed into the machine
W_t = total number of tomatoes damage

3. RESULTS AND DISCUSSION

Table 1 Shows mean values of length, thickness and width of the tomato sample before slicing. So as to obtain suitable sizes of tomatoes that will give effective and uniform slices.

Table 1: Mean values of tomato dimension (Length, thickness, width)

Properties	Large 62 mm	Medium 52 mm	Small 44 mm
L	57	47	41
T	62	52	44
W	56	44	41

Table 2: Slicing efficiency for tomato sizes

S/N	Efficiency for large tomatoes (%)	Efficiency for medium tomatoes (%)	Efficiency for small tomatoes (%)
1.	86.67	93.33	73.33
2.	93.33	80.00	93.33
3.	93.33	86.67	93.33
4.	100.00	93.33	66.67

From the results large tomato have higher efficiency, this is because large tomato has enough shearing surface area exposed to the cutting element (knives).

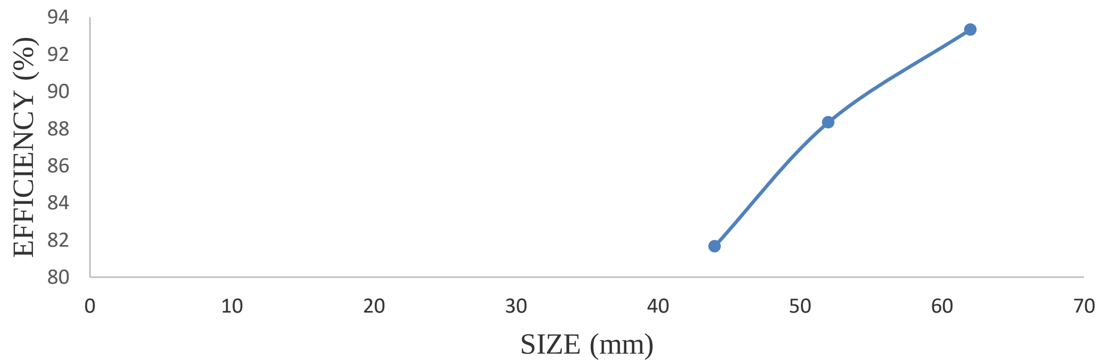


Figure 1: Relationship between slicing efficiency and tomato sizes

Table 3: Output capacity of tomato sizes

S/N	Output capacity (kg/hr.) Large Tomatoes	Output capacity (kg/hr.) Medium Tomatoes	Output capacity (kg/hr.) Small Tomatoes
1.	177	187	187
2.	178	175	180
3.	184	187	177
4.	178	175	170

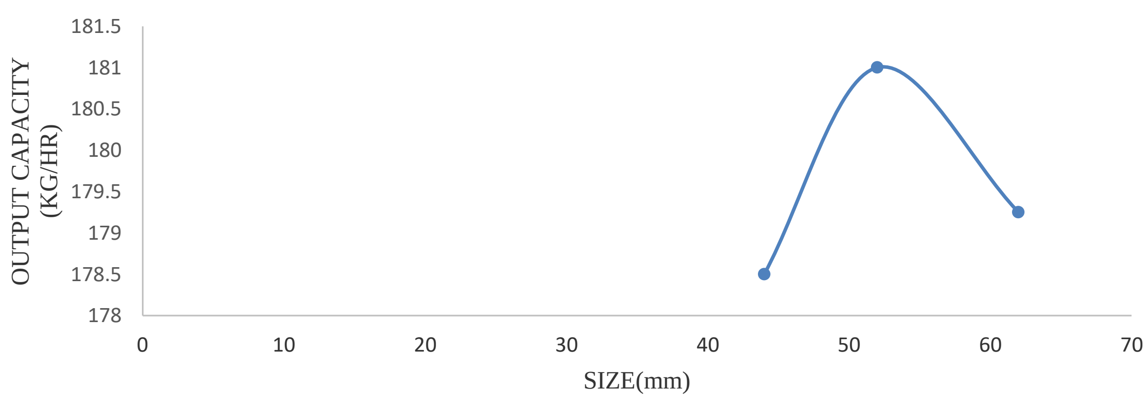


Figure 2: Relationship between output capacities and tomatoes sizes

From the above it can be seen that Output capacity of medium and large tomatoes is more compared to those of small tomatoes.

Table 4: Percentage damage of tomato sizes

S/N	% damage for large tomatoes	% damage for medium tomatoes	% damage for small tomatoes
1.	13.33	6.67	6.67
2.	0.00	6.67	0.00
3.	0.00	0.00	0.00
4.	0.00	6.67	13.33

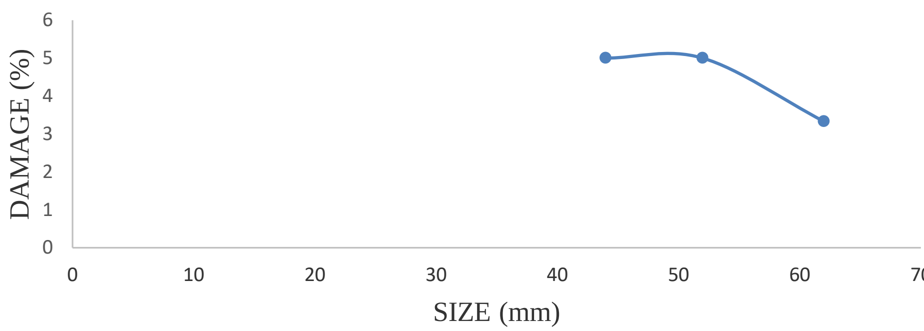


Figure 3: Relationship between damage and tomatoes sizes

From the result of the evaluation, it was found that the machine is capable of slicing tomatoes with minimum damage, slicing efficiency and output capacity of 3.33%, 93.33% and 179.25kg/hr., 5%, 88.33% and 181kg/hr., 5%, 81.67% and 181kg/hr. for large, medium and small tomatoes respectively. It produces slices of uniform thickness with standard deviation and variance of 22.5 and 507.5, 22.8 and 517.7 and 22.6, 507.5, 22.8 and 517.7 and 22.6, 22.6 and 507.5 for large, medium and small respectively.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The motorized tomato slicing machine was designed, constructed and evaluated based on three tomato sizes. It was found that the machine is capable of slicing tomatoes with slicing efficiency, output capacity and minimum damage of 93.33%, 179.25kg/hr and 3.33%, 88.33% , 181kg/hr,and 5%, 81.67%, 181kg/hr and 5%, for large, medium and small tomatoes respectively. It produces slices of uniform thickness with standard deviation and variance of 22.5 and 507.5, 22.8 and 517.7 and 22.6, 507.5 for the sizes respectively.

4.2 Recommendations

The following recommendations are suggested for further studies:

4. Provision of wheels instead of stand so as to ease pulling or pushing

5. Provision of grading mechanism for grading the tomatoes before getting to slicing chamber

6. Hygiene should be consider when selecting construction materials for mass production

7. More factors affecting the efficiency and effectiveness of the machine need to be explored.

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Water Conservation and Effective Irrigation as Veritable Impetus for Sustainable Agricultural Production in Nigeria

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ABSTRACT

Water is considered as the most critical resource for sustainable agricultural development worldwide. Climate change and recurrent drought in many of the world's dry places continue to inspire the search for economically attractive measures to conserve water. Oral interviews were conducted with personal observations. Water conservation can be achieved through better management which depends on type of irrigation technology. While sustainable agriculture production can be achieved through agricultural practices, such as soil management, irrigation and fertilizer application and disease and pest control. Type of irrigation technology, environmental conditions and the scheduling of water application impacts on the effective irrigation were discussed. The paper examined the component of irrigation scheduling. The benefits and challenges of effective irrigation in Nigeria were highlighted. This paper addressed the factors enhanced and principles associated with sustainability in agriculture. The concept of irrigation technology in term of micro-irrigation systems and its advantages was examined. The effective irrigation for sustainable water management was enumerated. Effective irrigation served as sustainable for agricultural production positively, when the site specific design limitations are understood in conjunction with an understanding of nature.

Keywords: Challenge, micro-irrigation, sustainable agriculture, water conservation,

1. INTRODUCTION

1.1.Water Conservation

Across the world, human and environmental demands for water resources have increased significantly over the last 50 years (FAO, 1999). Population and economic growth, changing social norms regarding the importance of water quality and protection of ecosystems, and long standing of the people's water-right claims have increased pressures on available water supplies particularly in the arid regions. More recently, water demands for an expanding energy sector and shifting regional water balances under climate change projections have heightened awareness of the importance of water conservation for a sustainable future for irrigated agriculture. Knowledge about the status and the social and institutional dimensions of competing uses of water resources provides a better understanding of the supply and demand challenges facing irrigated agriculture all over the world.

The security of any nation depends upon the availability of food for its citizenry. Food is derived from agriculture for its sustainability. Agriculture depends upon the soil and water which are the gift of nature. In Nigeria, despite abundance of lands for cultivating crops, the agricultural systems are seasonal in nature. Agricultural system in Nigeria depends upon the rainfall and insignificant application of conventional irrigation and usage of micro irrigation systems recently gaining prominence (Omofunmi, *et al*, 2018).
Water is considered as the most critical resource for sustainable development in most countries. It is essential not only for agriculture, industry and economic growth, but also it is the most important component of the environment, with significant impact on health and nature conservation. Currently, the rapid growth of population along with the extension of irrigation agriculture, industrial development and climate change.

Global irrigated area has increased more than six fold over the last century, from approximately 40 million hectares in 1900 to more than 260 million hectares (FAO, 1999). Omofunmi et al, (2018) reported that the majority, of the farmer (47 i.e. 60 %) adopted Sprinkler methods, 21 (27%) used drip, while 8 (10 %) and the least used Furrow and Basin with 3 (3 %) each. The usage of Sprinkler and Drip irrigation methods may be attributed to the awareness of the importance of water conservation and level of training received coupled with their educational background. Reduced water supplies due to climate change will likely further constrain already over-allocated water resources across globe, while increased water demand from alternative user groups, ecological requirements (Wall and Smit, 2005; Hall et al., 2008; IPCC Report, 2007; Brekke et al., 2009). The benefits of technology for enhancement of water conservation were reported by several researchers (Kim et al., 2000; Schaible and Ailley, 2003; Sadler et al., 2005; Fereres and Soriano, 2007; Evans and Sadler, 2008; Geerts and Raes, 2009 and Huffaker, 2010) as follows:

Improved irrigation technologies are generally productivity enhancing, requiring less land and water inputs for a given level of yield. While enhanced irrigation efficiency produces on farm water savings through reduced applications that also reduce farm water. Higher productivity and reduced water costs are important to the economic viability of a sustainable irrigated agriculture sector over the long term. Hence, Improved on farm irrigation efficiency generally results in significant water quality and environmental benefits.

1.2. Objectives
The content of the study is set out in the terms of reference as follows:
Concept of water conservation and sustainable water management; Relationship between effective irrigation and sustainable water management; Irrigation technology in Nigeria and their challenges, and Basic principles of sustainable agriculture

2. GENERAL INFORMATION

2.1. Water conservation

Schaible and Aillery (2003) highlighted that water conservation includes all the policies, strategies and activities to sustainably manage the natural resource of fresh water, to protect the hydrosphere, and to meet the current and future human demand." The best way of conserving water for agriculture is by adopting localized irrigation system

Importance of water conservation: Water conservation is primary fundamentally important to all of our lives as follows:

(i) Drinking: Water is absolutely vital for keeping us alive

(ii) Hygiene: To free from pollution, disease and infection

(iii) Agriculture: For irrigation crops, so that we can continue to grow all of the food that everybody on earth needs to survive.

(iv) Water supplies are finite: Our supplies of fresh water are finite and so must be looked after carefully.

2.2. Sustainable Water Management

Sustainable water management in agriculture aims to match water availability and water needs in quantity and quality, in space and time, at reasonable cost and with acceptable environmental impact. It depends on effective irrigation and localized irrigation systems (trickle, or drip irrigation, micro-sprayers) and irrigation scheduling. The aims of localized irrigation are mainly the application of water directly into the root system under conditions of high availability, the avoidance of water losses during or after water application and the reduction of the water application cost (less labour). Irrigation scheduling is the decision making process for determining when to irrigate the crops and how much water to apply. It forms the sole means for optimizing agricultural production and for conserving water and it is the key to improving performance and sustainability of the irrigation systems. The components of irrigation scheduling are presented in Fig. 1.

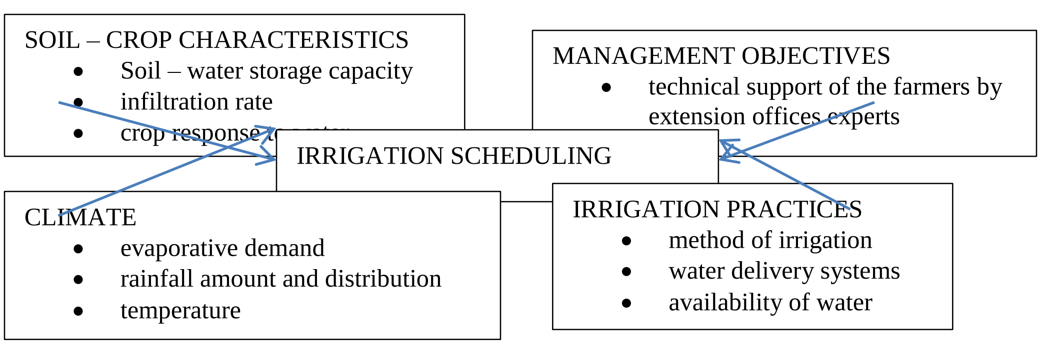

Fig. 1: Irrigation scheduling components
Source: Schaible and Ailler (2003)

2.3. Irrigation Technology

Irrigation technology to sustain Agricultural production must be appropriate technology, which is the Technology of the people for the people and by the people. Every farmer must be able to embracing it. Micro-irrigation systems are the latest irrigation technology that reduces water usage in agriculture. Micro-irrigation is a method of applying low volumes of water directly to the root zone of the crop and limiting it to the root spread volume of the soil layer. Losses of water due to surface evaporation and deep percolation are avoided. Micro-irrigation methods are indigenous and modern micro-irrigation systems

Indigenous micro-irrigation method: Indigenous method of micro-irrigation system includes:

(1) Earthen pot, (2) Sub-soil injector, and (3) suction injection

Modern micro-irrigation method: It is known as drip irrigation

2.3.1. Drip Irrigation

It is also called trickle irrigation. It is the method of localized slow application of water to the plant root zone.

Advantages of drip irrigation system include: It

(i) saves water,
(ii) reduces labour cost,
(iii) increases yields,
(iv) reduces weed problems,
(v) prevents water logging,
(vi) reduces salt concentration in the root zone,
(vii) allows chemicals/fertilizer (soluble) to be used through the system, and
(viii) controls and reduces diseases.

2.4. Effective Irrigation

Efficient irrigation technologies are a collection of irrigation solutions that promote water use efficiency by delivering water directly to the plant and enabling the farmer to control the time, location, and quantity of water application (Evans and Sadler, 2008). Efficient irrigation technologies include, but are not limited to, drip irrigation, sprinklers and it is a function of appropriate technology. Efficient irrigation production systems" allow producers to improve their nutrient management practices through chemical application efficiencies, reduced soil erosion runoff, improved salinity control, and improved drainage water quality (Brekke et al., 2009). Improving on farm irrigation efficiency also reduces nutrient loads, pesticides, and trace elements in irrigation runoff to surface waters, as well as leaching of agrichemicals into groundwater supplies, producing off-farm benefits for ecosystem habitats, endangered species recovery, biodiversity, and human health.

2.4.1. Benefits of efficient irrigation technology

Efficient irrigation technologies help small farmers improve their livelihoods by allowing for a more efficient use of inputs, such as water and fertilizer, and by enhancing the yields and quality of the crops farmers grow. A more efficient use of the following inputs has several benefits:

(i) Efficient irrigation allows farmers to (i) use less water to grow the same amount of crops; (ii) more productively farm larger areas of land by using the same amount of water; or (iii) use the same amount of water to grow higher value, more water-intensive crops.

(ii) Efficient irrigation reduces the amount of fertilizer needed per plant, as nutrients can be dissolved in the irrigation water for uniform application, reduced waste and lower labour input.

(iii) Efficient irrigation reduces energy use because less water is needed for a comparable area of irrigation, which in turn requires less energy for pumping this water. When automated, farmers are also able to easily and safely irrigate crops during times of fewer power disruptions (i.e., at night).

(iv) Efficient irrigation decreases the amount of time required for providing water to a crop area due to the regulated flow of water in the irrigation operation. This indirectly reduces time spent on weeding and applying fertilizer.

(v) The use of efficient irrigation technology improves crop yields and quality through direct impacts as well as indirect ones, such as decreased soil salinity, fewer attacks from pests and diseases, and less weed competition. In the presence of functioning markets and a favourable business environment, these changes in turn help generate higher incomes and better livelihoods for farmers.

(vi) Increase farmer income

2.4.2. Factors affect the irrigation technology adoption

While the benefits of efficient irrigation technology are clear, a number of factors are necessary to hindrance these positive impacts:

Awareness and skills: The adoption and effectiveness of efficient irrigation technology depends on farmers' initial awareness of it and their knowledge of its proper use. This includes the suitability of the farmers' land, their choice of crops, the level of intensity of cropping practices, and proper maintenance of the equipment.

Infrastructure: Required infrastructure for ensuring that farmers reap the benefits of using efficient irrigation technology and enhancing crops includes access to water, the availability of reliable roads to transport crops to markets, and access to storage facilities.

Regulatory environment: On the regulatory side, the government has a role to play in ensuring that appropriate regulations are in place, which support smallholder agriculture and ensure farmers' access to technology and markets.

Access to inputs: The availability and quality of the other agricultural inputs used by the farmer, such as seeds, fertilizer, pesticides, and machinery, can influence or magnify the positive impacts of efficient irrigation technologies.

Access to markets: The impact on smallholder incomes from using efficient irrigation technology depends on whether improved crop quality and higher yields translate into higher prices and increased market demand.

Access to finance: Finally, the lack of access to finance to purchase efficient irrigation equipment is considered to be the main constraint to technology adoption.

2.5. Potential, Constraints and Challenges of Irrigation in Nigeria

2.5.1. Irrigation potential of Nigeria**:**

(i) Five-percent of the land is suitable for irrigated agriculture.

(ii) Thirteen river basin development authorities, and funded by the ministries of Agriculture and Rural Development, and Water Resources

2.5.2. Constraints of irrigation in Nigeria

(i) Planning and design flaws.

(ii) A bias towards investment in hardware (infrastructure and machinery), thereby neglecting the software requirements (policy formulation, institutional strengthening and capacity building).

(iii) Inadequate financial resources for operations and maintenance.

(iv) Inconsistency in government policy that established the River Basin Development Authorities (RBDAs).

(v) Corruption and rent-seeking.

(vi) Lack of organized farmer groups and Water User Associations.

(vii) Inadequate skills and manpower.

(viii) Decay of irrigation infrastructure.

(ix) Lack of instrumentation

2.5.3. The challenges of irrigation in Nigeria

(i) Integrated dams and the possibility of exploiting both power generation and irrigation.

(ii) Infrastructure maintenance.

(iii) Subsidies not getting through to the end users.

(iv) Keeping young farmers on the farm in a productive and lucrative way.

(v) High cost of equipment – irrigation accessories.

(vi) Lack of information for farmers:

(vii) Crop water requirements at different crop development stages are not clearly known or understood.

(viii) Likewise, not enough is known or understood about evapotranspiration and consumptive water use.

(ix) The gross irrigation water requirement is also not well understood.

(x) Policy implementation.

(xi) Ineffective handing of irrigation from a business perspective.

(xii) Inadequate extension services.

(xiii) Power supply challenges.

(xiv) Lack of water user associations and the costs involved in obtaining water.

(xv) Lack of effective collaboration among relevant stakeholders in the country.

(xvi) Lack of understanding of the economics of water use.

2.6. Sustainable Agriculture

The word "sustain," from the Latin sustinere (sus-, from below and tenere, to hold), to keep in existence or maintain, implies long-term support or permanence. As it pertains to agriculture, sustainable describes farming systems that are "capable of maintaining their productivity and usefulness to society indefinitely. Sustainable agriculture is farming in sustainable ways based on an understanding of ecosystem services (the study of relationships between organisms and their environment). The sustainable agriculture indicates an agricultural system adopted in a particular area in which crop and animal production do not decline over time and are reasonably stable over normal fluctuations of weather. Sustainable agriculture also refers to the agricultural practices that guarantee human needs for food and fibres and at the same time protect natural resources and the quality of the environment (Edeoghon et al. 2008). Guide principles and objectives associated with sustainability in agriculture are as follows:

(i) The incorporation of biological and ecological processes into agricultural and food production practices

(ii) Using decreased amounts of non-renewable and unsustainable inputs, particularly the ones that are environmentally harmful.

(iii) Using the expertise of farmers to both productively work the land as well as to promote the self-reliance and self-sufficiency of farmers.

(iv) Solving agricultural and natural resource problems through the cooperation and collaboration of people with different skills on pest management and irrigation.

(v) Adopt methods that promote soil health, minimize water use and lower pollution levels

(vi) Incorporation both policy and management actions such as improving water conservation and storage, providing incentives for selection of drought-tolerant crop species, using reduced-volume irrigation systems and managing crops to reduce water loss

(vii) Satisfy human food and fibre needs;

(viii) Enhance environmental quality and the natural resource base upon which the agricultural economy depends;

(ix) Make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;

(x) Sustain the economic viability of farm operations; and

(xi) Enhance the quality of life for farmers and society as a whole

2.7. Effective Irrigation for the Sustainable Agricultural Production

The several ways in which effective irrigation can be sustained agricultural production are as follows:

- (i) It promotes dry season farming
- (ii) It increases crop yields
- (iii) It enhances human well-being outcomes (basic needs, e.g. clothing, shelter, health, education, social values and behaviours)
- (iv) It promotes healthy soil
- (v) It enhances environmentally friendly
- (vi) It promotes agri-business activities
- (vii) It encourages participation in farming activities
- (viii) It enhances food system activities (storing/processing of food)
- (ix) Cultivar adjustment (e.g., developing new crop varieties that are tolerant to drought, heat and salt via breeding or genetic modification)

- (x) Climate change should be an integral part of national planning

3. CONCLUSION

Start conserving water today by adopting localized irrigation system. Investments in efficient irrigation system for sustainability of the environment to meet the rising demand for food. It will generate marked improvements in farmers' incomes and standards of living, especially for small farmers who are the biggest contributors to agriculture in developing countries but typically are among the poorest and most vulnerable members of society. Effective irrigation served as sustainable for agricultural production positively, when the site specific design limitations are understood in conjunction with an understanding of nature.

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Development and Evaluation of a Laboratory Single-Screw Extruder For Production of Expanded Products

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ABSTRACT

In this study, a low-capacity laboratory-scale single-screw cooking extruder for the manufacture of expanded snacks was designed based on theoretical models and guided operating data and practices of existing cooking extruders. Construction was carried out using locally available engineering materials in modest machine shops satisfying sanitary design criteria and tested using blends of cassava and defatted soybean flours. The extruder developed has throughput, screw speed, barrel diameter and length-to-diameter ratio of 13.0 kg/h, 200 rpm, 40 mm, 12:1 and 1.908 kW, respectively. The cost of the extruder developed was estimated ₦650, 000 as at 2016. Extrudates had expansion ratio and trypsin inhibitor reduction which ranged from 1.82 to 2.98 and 61.07 to 87.93 %, respectively across all treatments. This study demonstrates that a low-capacity and affordable experimental single-screw extruders can be designed and built domestically which can be scaled-up for pilot and industrial applications for the production of expanded snacks.

Keywords: Single-screw extruder, cassava/soybean blends, expansion ratio, machine throughput, trypsin, inhibitor reduction.

1. INTRODUCTION

Extrusion cooking is a continuous, high temperature, short time (HTST) process which has become a popular, efficient and economical process for the manufacture of convenience foods of diverse textural and functional characteristics such as snacks, ready-to-eat cereals and instant flours (Milan-Carrillo *et al.* 2002). It is a process that combines several unit operations including mixing, cooking, kneading, shearing, shaping, and forming (Riaz, 2000) and therefore, removes drudgery involved in the traditional preparation of these foods. *Kokoro, kunnun zaki*, *massa* and *fura* are a few examples of a generation of Nigerian snack foods that hold a key to rapid innovation and creativity in ingredient formulation for nutritional enhancement and technological advancement through the application of extrusion cooking technology.

Several works have been done to develop highly nutritious convenience products from vast numbers of food bio-resources available in Nigeria (Obatolu, 2002; Iwe *et al*., 2004; Nkama and Filli, 2006; Nwabueze and Iwe, 2006; Filli *et al*., 2010; 2013; Oke *et al*., 2013, Oluwole *et al*., 2013) but very little attention has been paid to developing extruders with which exploratory trials (that is experiments that involve small quantities of feed materials) can be performed. This had really overworked, to the best of our knowledge the only Brabender single-screw laboratory extruder (DCE 330, New Jersey, USA) available at the Federal Polytechnic, Mubi, Nigeria. In addition, in spite of the numerous merits of extrusion technology such as its ability to handle various food ingredients, reduced processing costs, enhanced productivity, improved product quality and absence of process effluents (Haper, 1981; Riaz, 2000), the major factor militating against its wider use by local food processors in developing countries is the high cost of importation of extruders. This dearth of laboratory and, probably pilot and industrial scale extruders has really hindered the snack and allied industries in Nigeria and other developing countries (DCs) of the world. Only a few industrial units and institutions can produce extruded flour and snacks on a large-scale mainly in response to the need of international or non-governmental organizations for emergency supplies. The main reason for this is that most of these extruders are designed for large-scale operations and require very high investment and technical know-how (Mouquet *et al*, 2003).

The need has long been underscored for simpler, smaller and yet versatile machines at more affordable prices which are capable of utilizing the vast number of natural food resources (Harper and Jansen 1985) in a country such as Nigeria. These include cereal crops such as rice, millet, maize and sorghum; roots and tubers such as cassava, yam, potatoes e.t.c.; and a wide variety of legumes rich in proteins and tasty additives such as fruits, vegetables and spices. Extruders, whether single or twin-screw, thermo-mechanically cook and texurize food material and thereby facilitate many chemical and structural transformations such as conversion (gelatinisation) of starch, denaturation and cross-linking of proteins, complex transformation of lipids, the stretching or restructuring of tractile components and possible degradation of vitamins and anti-nutritional factors in legumes, colour development and other changes (Milan-Carrillo *et al*. 2002; Ilo and Berghoper 2003). These result in products that are in a dry state with typically low water activity (a_w), which do not require refrigeration storage (Filli *et al*., 2013). Such products are suitable for DCs where infrastructure for a cold supply chain is inadequate (Filli *et al*., 2010).

Despite the advantages of twin-screw over single-screw extruders as thoroughly compared by several investigators (Hauck & Ben Gera, 1987; van Zuilichem *et al*., 1984); the latter is still considered to be more relevant for DCs based on the premises that the capital investment, maintenance and energy cost of a co-rotating twin-screw extruder are about 1.5 times the cost of the counterpart single-screw extruders (Senanayake and Clarke, 1999). Single screw extruders are generally cheaper than the twin screw type owing to their simpler construction and can easily be fabricated in any local machine/metal workshop in DCs. This study aimed to design and construct a laboratory single-screw extruder, and evaluate its ability to produce expanded products from locally available agricultural raw materials using cassava and soybean flour blends as representative test materials.

2. METHODOLOGY

2.1 Design Considerations

The laboratory-scale single-screw extruder was designed and constructed from locally available engineering materials at low cost that will be compatible with local food processors budgets. The food contacting surfaces was made in stainless steel to allow for easy cleaning to prevent corrosion and contamination to meet sanitary design requirements. The components were easy to assemble, dismantle and the parts easily replaced in case of wear and/or damage. The equipment can later be scaled-up to meet the needs of pilot and/or small-scale industrial applications.

2.2 Design Approach

The approach adopted for the food extruder design is based on models of the flow rate and energy written for the metering section (Figure 1) of a plastic (polymer) extruder (Tadmor and Klein 1970; Harmann and Harper, 1974; Rauwendaal 2001) because of similarities to food (biopolymers). In addition, the operating data of existing extruder of different functionalities (shear rates) as profiled in Table 1 compiled by Rossen and Miller (1973) and Hauck (1993) was used to configure the dimensions of the extruder. This approach was reckoned to be more appropriate because there is dearth of workable equipment with which exploratory trials can be performed to model the extruder.

2.3 Design Calculations

In the design process, the capacity, shear rate expected of cooking, the level of pressure likely to be developed within the extruder barrel and rheological characteristics of the food melt are the most paramount parameters as they determine the sizes and dimensions of all the important components of the extruder such as screw, shaft diameter, barrel, die, bearings and power requirement of the extruder.

Table 1: Typical operating data for different types of extruder.

Parameters	Low shear	Medium shear	High shear
Feed moisture, %	25-75	15-30	5-15
Product density, (kgm^{-3})	320-800	160-500	32-160
Maximum barrel temperature (^{o}C)	20-65	55-145	110-180
Maximum product temperature, (^{o}C)	52	79	149
Maximum barrel pressure, (MPa)	0.6-6.2	2.0-4.0	4.0-20.0
Screw speed, (rpm)	30 - 100	100 -200	300 - 450
Shear rate, (s^{-1})	9.5	22 - 47	165
Barrel diameter-to-flight height (D/H)	7-15	5-9	7-9
Barrel length-to-diameter ratio (L/D)	5 – 22	10 - 25	2 - 15
Mechanical energy input into product (kJ.hr/kg)	0.01 – 0.04	0.02 – 0.08	0.1 – 0.16

Source: Rossen and Miller (1973); Hauck (1993)

2.3.1 Dimensioning the screw and barrel of the extruder

The barrel diameter (D), flight height (H), length-to-diameter ratio (L/D) and screw speed (N) were selected as 40mm, 3 mm, 12 and 200 rpm, respectively according to Table 1

(Figure 1) to exude medium-to-high shear rate (γ) conditions as expressed by (Haper, 1981):

$$\gamma = \frac{\pi D N}{H} \quad (1)$$

Since the object of this work was to design a laboratory cooking extruder, a reasonable small screw pitch (*l*) was selected compared to the diameter of the screw with medium value of helix angles (20^{o}) for which curvature parameters are available in the literature (Harper, 1981) and crew speed that will ensure fairly long residence times of material, high degree of mixing and uniformity of heat distribution in the channel width (W).

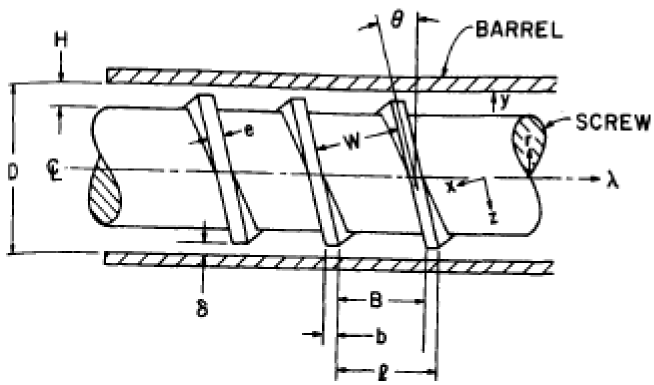

Figure 1: Geometry of an extrusion screw (Haper, 1981).

Flight tip width (b) for a single-screw extruder is given by Dzierak (1988) as D (0.08 to 0.12) = (3.2 to 4.8) mm. Any value within or around this range (5 mm) ascertains enough surface area of shear between the screw flight tips and the barrel for cooking that will not draw much motor power. As a result, screw pitch, channel width (W) and screw length of 30 mm, 25 mm and 485 mm, respectively were arrived at.

The compression ratio (CR) of the screw is one of the most important criteria defining the type (either cooking or forming) of an extruder. It is the ratio of volume of material displaced per revolution of the shaft at the feed section to the volume displaced at the compression section. In practice, CRs for extruder fall between 1 and 5 depending on the level of shear in extruders (Harper, 1981). For cooking or autogenous extruders, CR higher than 1 is all that is necessary, CR approximately 2.35 was arrived at as estimated by Singh and Bargale (2000) by carefully working on the geometry of the screw so that there would be reasonable cooking of material which will be complemented by heat transferred through the barrel from the electric band heaters of 1 kW each. Higher CR was avoided in order to prevent excessive viscous dissipation of mechanical energy to the material which will ultimately lead to uncontrollable temperature of the dough in the extruder and consequently, excessive motor power requirements.

In order to achieve compression by the screw, the option of tapered root diameter from 20 mm at the end feeding section to 33 mm at the beginning of the metering section with constant outer diameter of 39 mm and pitch of 30 mm was considered. This was chosen as not all the possibilities as elucidated by Harper (981) can be applied in a typical DCs including Nigeria because of the low level of sophistication in a typical machine shop. The feeding, compression and metering sections are 143, 225 and 135 mm in length, respectively.

The barrel of an extruder is a thick cylinder made of stainless steel. For thick wall design, maximum tangential stress (σ_{max}) at the inner surface of barrel is expressed as (Khurmi and Gupta 2010):

$$\sigma_{max} = P\left(\frac{R_o^2+R_i^2}{R_o^2-R_i^2}\right) \tag{2}$$

Hence, the thickness of the barrel should not be less than 3.5 mm.

where, σ_{max}= maximum allowable stress for cold drawn steel = 120 MPa was assumed (Khurmi and Gupta 2010), R_o = external radius of the barrel (m), R_i = internal radius of the barrel = 20 mm. Hardened stainless steel 431 heat treatable cylinder was selected for the barrel in order to resist both wear and corrosion.

2.3.2 Capacity of the extruder

The resultant volumetric flow rate (Q) of the screw length (Harper, 1979; 1981) accounting for shape correction factors of the curvature ends for drag and pressure flows is (Janssen and Moscicki, 2010):

$$Q = \frac{1}{2}\pi^2 ND^2 Hsin\theta cos\theta(1 - 0.57\frac{H}{W}) - \frac{1}{12}\frac{\pi DH^3\Delta P}{\mu L_s}sin^2\theta(1 - 0.62\frac{H}{W}) \tag{3}$$

where, H, μ, and ΔP are flight height (m), viscosity (Pa.s), and pressure (Pa) developed in the extruder die. However, equations (3 and 5) were derived for Newtonian liquids, but food melts are non-Newtonian (pseudoplastic) liquids at extrusion temperatures. Therefore, the viscosity (μ) parameter in the equations was replaced by an apparent viscosity (η) term. The apparent viscosity model of corn and soybean mixture melt (likely feed ingredients to be extruded) published by Fraiha *et al*., 2011 (a form of Power Law equation for pseudoplastic fluid) is:

$$\eta = 18770 \quad (\gamma)^{-0.86} e^{(-9.34U + 935T)} \tag{4}$$

where, where the influence of shear rate is represented by the Power law model, U is the material moisture (percentage) and T is the inverse testing temperature, in Kelvin scale. From the calculation, the machine is capable of producing 13 kg of the expanded extrudates considering the product density of 150 kg/m^3 (Table 1) having estimated η to be 2442 Pas^n.

2.3.3 Power requirements and transmission

In screw extruders, power is required primarily to turn the feed ingredients in melts by viscous mechanical dissipation in the channel, between the screw tips and the barrel and overcome the pressure at the die. All these were accounted for in the power equation developed in plastics extrusion for the same reason as discussed above. The power required is expressed as (Haper, 1979: 1981):

$$Q = \frac{p(\pi ND)^2 L_s}{sin\theta}\left(\eta \frac{\mathrm{W}}{\mathrm{H}}(\cos^2\theta + 4\sin^2\theta) \qquad + \right.$$
$$\left. \eta_\delta \; \frac{\mathrm{e}}{\delta}\right) \quad + \frac{\pi^2}{2} D^2 H \left(1 - \frac{pe}{\pi D sin\theta}\right) sin\theta cos\theta N \Delta P \qquad (5)$$

where, p, δ (m) and η_δ (Pa.s^n) are numbers of parallel channels, clearance between the flight tips and barrel (m) and apparent viscosity in the clearance but with γ_δ, shear rate in the clearance which in turn was estimated from equation 1 but H was replaced by δ.
The estimated power and SME values of 1908.4 kW and 0.15 kW.h/kg, respectively were in range of operating data values for typical high-shear extruders of 0.16 kWh/kg as shown in Table 2. This estimated theoretical SME gives credence to the design procedure. Thus, 4 kW, 3 phase AC geared reduction motor (3:1) selected will adequately supply this power to rotate the screw at a speed range of 0 to 200 rpm controlled by 50Hz frequency inverter and transmitted through a coupling plus all additional power required to overcome frictional losses.

2.3.4 Die design

Die design consists of determining the diameter and length of die (hole) to achieve the required product at a given flow rate, Q. The radius of the die (R_d) of the die opening was estimated from the relationship between shear rate in the extruder and the volumetric flow rate (Sokhey *et al*., 1997) as:

$$\gamma_w = \frac{3\mathrm{n}+1}{4\mathrm{n}}\left(\frac{4\mathrm{Q}}{\pi \mathrm{R}_\mathrm{d}^3}\right) \qquad (6)$$

where, γ_w and n are shear rate (s^{-1}) at the wall (taken as γ_δ) and power index (=0.16) according to Fraiha *et al*. (2011), respectively. This equation implies that expansion will not be achieved above a die diameter of 8.9 mm. In other to achieve expansion, seven die configurations of lower dimensions with their corresponding lengths were made to suit our objective of a laboratory extruder. Chinnaswamy & Hanna (1987) investigated the effect of die opening configurations on the expansion properties of corn extrudates and concluded that ratio of the die opening land to diameter (L/D) of not more than 3.4 increases expansion ratio of corn extrudates beyond which expansion diminishes. L/D = 3 of the die opening was thus arrived at.
In order to ensure the smooth flow of material from the screw to the die, the die assembly was machined in the shape of a cone to fit the pointed end of the screw as shown in Figure 2. The die was circular in shape and made so that it can be externally screwed to the die assembly.

2.3.5 Shaft design

Maximum shear stress theory was assumed in determining the stress that can be induced in a 30 mm diameter mild steel rod that receives the screw in a slotted hole with keyway and a pin to hold the screw in place. In maximum shear theory, axial load developed at the die was accounted for by combining it with the bending moments as (Khurmi and Gupta 2012):

$$\frac{\pi}{16} \times \tau_{max} \times d^3 = \sqrt{\left(K_m \times M + \frac{F_a d}{8}\right)^2 + (K_t \times T)^2} \qquad (7)$$

where, τ_{max}= maximum shear stress induced in the shaft (N/m^2), d = diameter of the shaft (m), F_a = axial force, d = diameter of the shaft (m), K_b *and* K_t *are* shock and fatigue factors applied to bending and twisting moment, respectively, M = bending moment (Nm), T = twisting moment (Nm). Since 42.55 MN/m^2 is less than the maximum allowable stress in the shaft with keyway and 2.5 assumed as factor of safety i.e. 56 MN/m^2 (Spotts, 1971) assuming a gradually loaded condition i.e. K_m and K_t of 1.5 and 1, respectively and twist of only 0.003 ^{o}/m (<1^o/m) induced in the shaft, hence the shaft of 30 mm is considered safe.

2.3.6 Bearing design

The shaft which was connected to a geared motor by way of coupling was supported by two bearings (Figure 2). One radial ball bearing and one taper roller (thrust) bearing which was forced onto the shaft possesses the ability to absorb both radial and axial (thrust) loads. This was mounted on the shaft just after the barrel and absorbed all forces caused as a result of the pressure developed at the die so that the axial force will not be impacted on the frame while the other (ball bearing) provides further support. From force analysis on the shaft, taper roller bearing receives 396 N and 21.36 kN of radial and axial forces, respectively while the radial ball bearing receives radial force of 263 N only. Selection of the taper roller bearing was only designed for in order to determine the service life of the bearing. A 30 mm bore diameter taper roller bearing of basic dynamic, static load ratings of 65 and 77 kN, respectively with number 4T-33206 was selected (NTN CAT. NO. 2202 – IX/E).

Table 2: Specification of main components of the developed extruder

Parameters	Dimension
Length of the screw (L), mm	485
Length of the feed section, mm	143
Length of the compression section, mm	225
Length of the metering section, mm	135
Inner diameter of the barrel (D), mm	40
Clearance between screw and barrel (δ), mm	0.5
Compression ratio (CR)	2.35
Die diameter, mm	3.0 – 7.0
Shear rate, s^{-1}	139.9
Screw speed, rpm	0 - 200
Channel width length (W), mm	25
Pitch, mm	30
Helix angle (θ), ^{o}	20
Theoretical mass flow rate, kg/hr	13
Specific mechanical energy input, kW.hr/kg	0.15
Cost of the extruder, ₦	650,000

Since F_r/F_a =0.02 < 0.55, the dynamic equivalent radial load for taper roller bearings under combined radial and axial or thrust loads is given by (NTN CAT. NO. 2202 – IX/E):

$$P_a = 1.2F_R + F_a \quad (8)$$

where, F_r = radial load (N), F_a = axial or thrust load (N), yielding 22 kN and 17,000,000 and 1416 of life in revolutions and hours, respectively assuming service factor of 1 for uniform and steady load.

Table 2 shows the specifications of the major components of the extruder while Figure 2 and 3 show the side and plan views of the fabricated extruder.

2.4 Heating, Cooling and Temperature Control

Heating of the barrel to give the required additional thermal input and temperature control for cooking the food was done by two band heaters each having a capacity of 1 kW mounted on the last two barrels. Two temperature controllers were included on the control panel with their respective thermocouples sensing the temperature inside the barrels. Barrel close to and the feed inlet barrel were not provided with heater to avoid premature gelatinization of the starchy materials and blockage of the feed.

2.5 Mechanisms of Operation of the Developed Extruder.

Raw ingredients (starchy and/or proteinaceous) were pre-grounded, blended and pre-conditioned usually into a granular or flour form before being fed into the feed section by improvised screw

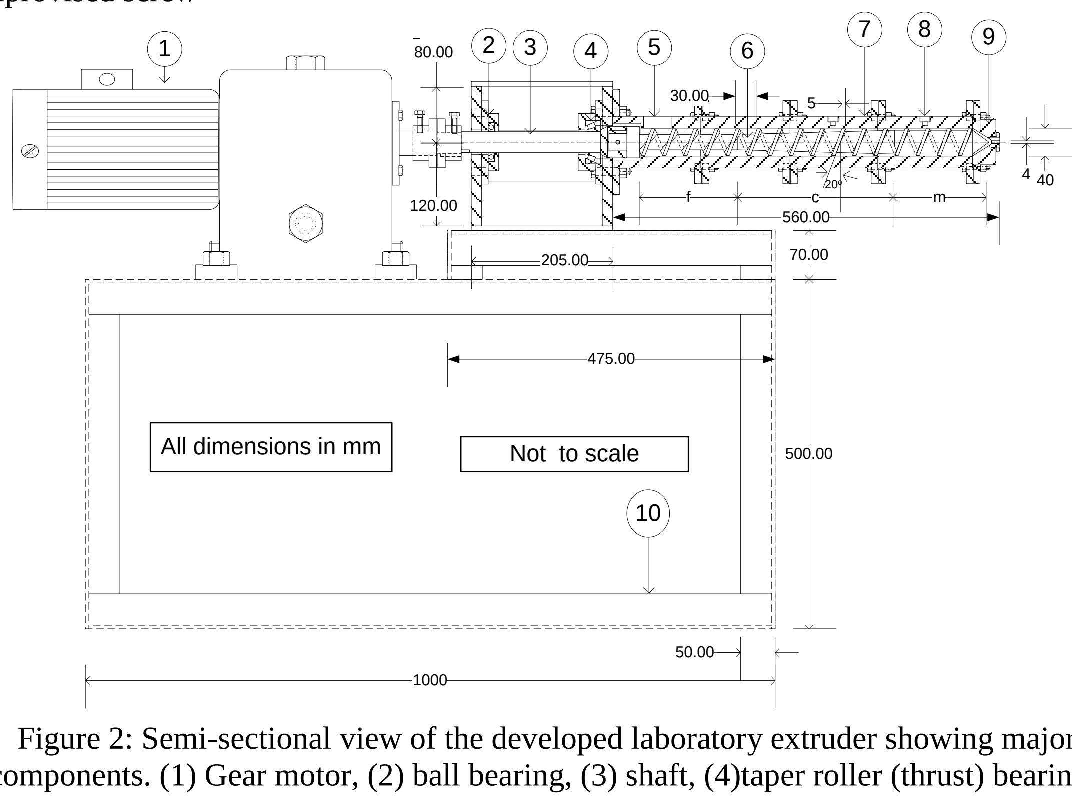

Figure 2: Semi-sectional view of the developed laboratory extruder showing major components. (1) Gear motor, (2) ball bearing, (3) shaft, (4)taper roller (thrust) bearing , (5)inlet opening that receives improvised screw feeder, (6) screw, (7) barrel (8) thermocouple port, (9) die assembly, (10) stand.

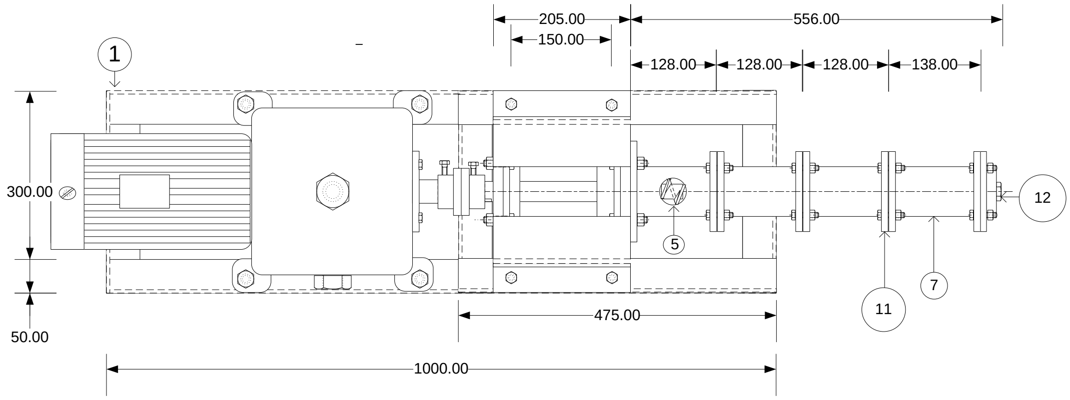

Figure 3: Plan view of the developed laboratory extruder showing major components. (11) flange, (12) die.

feeder (separate design). Deep flights in this section conveyed the feed ingredients down the extruder channel. As the material moves through the transition (or compression) section to metering section, it was thoroughly worked into a dough, well cooked and elevated in temperature (121-177 °C) obviously due to increasing pressure and friction in this section generated because of restrictions created by increasing the root diameter from 20 to 33 mm spanning 225 mm of the screw. As the dough passes through the die (a specially designed orifice which gives the already plasticized dough a definite shape), the pressure is rapidly released, allowing a large fraction of the super-heated vapor to flash off, hence “puffing” the dough. Cooling results in thermosetting and a slight decrease in the size of the puffed dough.

Heating into a plasticized dough was achieved through a combination of the thermal energy sources generated by viscous dissipation and transferred through the barrel wall by electrical heating elements resulting in an increase in temperature and its associated phase changes (e.g., melting of solid material or evaporation of moisture. The heating element may be switched on or off depending on the attainment of preset temperatures recorded and monitored on the control panel.

2.6 Performance Testing

The extruder fabricated was tested on its ability to produce expanded products from blends of cassava and soybean flours. This was done by:

i. Studying the influence of input variables on the machine performance (or system parameters), namely: product temperature (PT), machine throughput (MT), residence time (RT), and specific mechanical energy (SME); and
ii. Carrying out assessment of extrudates quality characteristics, namely: product moisture (PM), expansion ratio (ER) and trypsin inhibitor reduction (TIR).

2.6.1 Materials

One year old sweet local variety of cassava (*Manihot esculenta* Crantz) roots popularly known as Okoyawo among the local farmers and processors around Ogbomoso, Nigeria and soybean were sourced from the university farm. The cassava roots were processed into flour as described by Badrie and Mellowes (1991). Whole soybean seeds were dried and partially defatted to an oil content of 8.15 % using hexane as solvent and dried. Both the cassava (CF) and partially defatted soybean flours (PDSF) were milled by a plate attrition mill to break up lumps and made to pass through a 500 μm British standard sieve and packed separately in high density polyethylene (HDPE) bags and kept frozen in a freezer until further use. All chemicals used were of analytical grade.

The chemical composition of CF and PDSF were analyzed for moisture, crude protein (N × 6.25), total fat, crude fiber and ash content using AOAC (1995) standard methods 925.10, 920.87, 920.39, 925.08 and 923.03 respectively. Carbohydrate content was determined by difference 100 − (% moisture + % protein + % fat + % ash). Atwater energy conversion factors 17 kJ/g (4 kcal/g), 37 kJ/g (9 kcal/g) and 17 kJ/g (4 kcal/g) were used to calculate the energy contribution of protein, fat and carbohydrate, respectively (AOAC 1995). Chemical composition of raw material is as shown in Table 2.

2.6.2 Extrusion experiments

The volumetric feed rate was fixed at 500 cm^3/s using an improvised vertical screw dispenser (separate design). The independent variables in the experiments were: feed moisture (FM), amount

Table 3: Chemical composition of raw materials (g/100g)

Parameter	CF	PDSF
Moisture	9.00	7.33
Crude fat	0.27	8.15
Crude protein (N x 6.25)	1.95	46.11
Crude fibre	2.86	2.19
Ash	1.75	5.03
Carbohydrates(by difference)	84.17	31.19
Energy (kJ/g) (Atwater factor)	1569.74	1615.59

of soybean (AS), barrel temperature (BT) i.e. temperature at the metering section, die diameter (DD) and screw speed (SS), at three levels by varying one factor at a time while keeping others constant as shown in Table 4. CF and PDSF were mixed and adjusted to predetermined moisture content levels by the addition of calculated amounts of water sprayed and admixed into each sample (w/w) according to the experimental plan (Table 4). Thereafter, each of the samples was sealed in HDPE bag and kept in a refrigerator for 24 hours for equilibration and later brought out to room temperature for at least 8 hours for the sample to attain room temperature. The moisture content of the blends was ascertained before extrusion by drying the samples to a constant weight in a hot air-convection oven at 105 ^{o}C (AOAC 1995). Table 4 presents all the experimental runs of extrusion. Extrudates were collected, cooled and dried at 50 °C for 2 days and packed in HDPE bags and stored in a refrigerator at 4°C until further analyses.

2.6.3 System parameters

System parameters namely: product temperature (PT), residence time (RT), machine throughput (MT) and specific mechanical energy (SME) of the CSEs were determined following the methods of Ojo *et al*. (2014), Nwabueze and Iwe (2006), Oke *et al*. (2013) and Su (2007), respectively.

2.6.4 Characterization of the extrudates

The cassava and soybean extrudates (CSEs) obtained were characterized by defining the product in terms of moisture (% d.b.), expansion ratio and trypsin inhibitors reduction (%) by methods of AOAC (1995); Shirani and Ganesharanee (2009) and Kakade *et al*. (1974), respectively. Values obtained are as recorded in Table 4.

3. RESULTS AND DISCUSSION

3.1 Cost Estimate of the Extruder Developed

The direct cost of fabrication of the machine was roughly ₦650,000.00 or US $ 4,000 at ₦150 /dollars in year 2014 when fabrication was done. The equipment was fabricated in modest local workshops at Ogbomoso and Ilorin, Nigeria. This includes the direct cost of components bought, cost of materials and parts fabricated and cost of machining and non-machining jobs performed. The machine is low cost compared with the counterpart cost of imported extruders. Even if this cost profile quadrupled to ₦2.0 million (or US$6,000 currently in 2018 at the exchange rate of ₦350/dollar) was still far cheaper than any imported machine at the lowest cost range of £2,000 as estimated by Senanayake and Clarke (1999) for a twin-screw extruder of similar capacity. It is also much more affordable when compared to the cost of US$20,000 required for the importation of Brabendar extruder of similar capacity.

3.2 System Parameters

Table 4 summarises the overall results of the system parameters of the laboratory single-screw extruder using cassava and soybean blend samples at three different levels of each of input variables. These system parameters are measures of the system's technical performance capability and have significant effects on macromolecular degradation of biopolymers (Lazou and Krokida 2010). As expected, water and oil act as plasticizers in the extruder and cause decrease in melt viscosity and mechanical energy dissipation that is friction between extruder barrel and screw walls and thus, reduction in the PT, MT and SME but increase in RT. (Ilo *et al.* 1996). Similar reports have been made about rising product temperature in the extrusion of starchy raw materials (Jin *et al.* 1994; Meng *et al.* 2010).It is evident that the extruder performed satisfactorily in raising the PT (121 – 175 ^{o}C) and held the food melt for RT between 49.67 and 72.11 s which are adequate enough in changing the rheological properties of extruded melts, and in turn affects the degree of expansion of starchy materials (Iwe *et al*., 2001; Meng *et al*., 2010).

SME encompasses extruder system parameters such as screw speed, amperage/torque and MT in its calculation (Su, 2007). High SME was observed at lower BT, FM, DD and SS. These input parameters at low levels offer higher resistance to MT and cause the extruder to draw higher power. Chevanan *et al.* (2008) and Oke *et al.* (2013) reported similar findings. At low BT and FM, there was need for more mechanical power input to overcome resistance offered against material transport coupled with the likely higher die pressure of extrusion as indicated in equation 5. The values of SME as recorded in Table 4 validate the fact that the extruder performed to its billing that extrusion is an energy efficient process.

3.3 Extrudate Characteristics

The moisture contents of CSEs ranged between 8.88% and 13.33% (d.b.) as recorded in Table 4, indicating acceptable moisture levels that would enhance the shelf-stability of the extrudates. These values fall within the range reported for rice/legume blends by Asare *et al.* (2004). This indicated ability of the extruder to produce shelf-stable products that will be safe for an extended period of time if well packaged. Expansion is an important characteristic of extrudates intended as snack and ready-to-eat products by the food industries. Expansion ratio describes the degree of puffing undergone by the melt as it exits the extruder die as extrudates (Baladran-Quintana *et al.* 1998). All treatments resulted in a reasonable degree of expansion (1.82 – 2.98) as recorded in Table 4. Although the ER decreased as the concentration of FM, AS and BT increased (Table 4), it can be inferred that the machine performed fairly well as a medium–to–high shear extruder that can be used in the production of snacks, ready-to-eat cereals, pet foods, fish flour, fingers, e.t.c.

Table 4: Effects of extrusion conditions on product characteristics and system parameters[a]

Run no.	Input variables[b]					System parameters[c]				Extrudate characteristics[d]		
	FM	AS	BT	DD	SS	PT	RT	MT	SME	PM	ER	TIR
1	16	20	145	5	180	150	49.67	10.42	0.0623	8.88	2.98	63.14
2	20	20	145	5	180	147	57.68	9.16	0.0532	9.67	2.69	72.95
3	24	20	145	5	180	145	60.95	8.68	0.0521	13.13	2.43	83.77
4	20	10	145	5	180	148	50.10	9.42	0.0503	10.11	2.75	67.82
5	20	30	145	5	180	145	68.15	9.01	0.0480	9.28	2.53	69.34
6	20	20	120	5	180	121	53.73	10.79	0.0588	11.71	2.14	65.34
7	20	20	170	5	180	175	68.12	8.95	0.0447	9.20	2.74	87.93
8	20	20	145	4	180	161	72.11	8.86	0.0676	9.11	2.72	79.31
9	20	20	145	6	180	141	52.34	10.35	0.0456	12.07	1.82	61.07
10	20	20	145	5	160	155	70.43	8.87	0.0542	9.34	2.68	80.11
11	20	20	145	5	200	148	57.38	11.17	0.0649	11.97	1.95	63.21

[a]All data presented are average of duplicate.
[b]FM, feed moisture (g water/100g); AS, amount of soybean (g soyabean/100g); BT = barrel temperature (^{o}C); DD, die diameter (mm); SS, screw speed (rpm).
[c] PT, product temperature (^{o}C); RT, residence time (seconds); MT, machine throughput (kg/h); SME, specific mechanical energy (kJ/kg).
[d] PM, product moisture (%); ER, expansion ratio; TIR, trypsin inhibitors reduction (%).

Low anti-trypsin activity was recorded for extrudates under all experimental conditions especially at low levels of all the input variables, which indicated that high temperature and high mechanical stress developed during extrusion processing inactivated substances responsible for these factors. Reported reduction values after the extrusion of beans (Noguchi 1986) have usually been 95%, at extrusion temperature range of 120 – 150^{o}C, which was also achieved with the extruder developed, though at higher temperature. Temperatures recorded in these experiments reached 175^{o}C, which was more severe and destroyed the trypsin inhibitors to the expected level. Despite the high thermal stability of trypsin inhibitors, the combination of high heat and high humidity in the extrusion process considerably reduced their inhibitory activity in the CSEs (61.07 – 87.93%; Table 4). These results confirm those recorded by Alonso *et al.* (2000) and Anton *et al.* (2009).

4. CONCLUSIONS

A laboratory extruder was designed and fabricated from engineering materials that are easily sourced locally at a low cost. The unit was tested and found capable of producing expanded extrudates from cassava-soy blends at a mass throughput very close to theoretical value at reasonably low energy cost typical of extrusion processing although with some heating from band heaters mounted on the barrels. Control devices to vary machine four variables apart from feed variables to satisfy multivariable criteria of extrusion process were provided on the control panel. Being made in Nigeria conjures up many economic and technical benefits for this machine especially by its ethos of promoting self-reliance. Therefore, the extruder is considered to be relevant for technological environment of DCs of which Nigeria is a typical example. The simple laboratory scale single-screw extruder workstation is capable of opening up a new vista in product and research development in the country where there is vast supply of bio-resources that are begging to be exploited to meet nutritional needs of the populace and/or in times of emergencies.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Tractor mounted mulcher blade structural analysis using finite element method

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ABSTRACT

The maximum stress and deformation due to impact in the mulcher blade during field operation is the major concerns in the design considerations. The blade works under varied forces due to power, vibration, and torque, impact effect of soil parts (stones and stumps). To determine the impact-induced maximum stress and deformation, Solid Works software was used for both design of four 3D Model blades and Finite Element Analysis (FEA). FEA was carried out to investigate the failure of the four designed blades under worst case scenario, and tested at same conditions. Simulations were run at six treatment levels on blades with 0°, 60°, 120° and 150° lifting angles. Results were compared against the average measured stress and deformation. From the simulation effects, maximum stress and deformation on the blade with 120° lifting angle were 18.95 MPa and 0.0041 mm respectively. All stress and deformation values were within the acceptable limit for the design intent and material specifications of the mulcher blade. Maximum stress on the blade with 150° lifting angle were 74.29 MPa and 0.0175376 mm accordingly. The stress distributions were above the yield stress (62.04 MPa) of the specified blade material, the blade was the worst in terms of failure due to fatigue.

Keywords: Mulcher Blade, Stress, Deformation, Finite element method, Nigeria

1. INTRODUCTION

The oil produced from one tree constitutes only 10% of the total biomass, leaving 90% available during oil palm tree felling for replanting or further land development activities (Wicke et al., 2011). Currently, these felled palm trees are being shredded and left in the field for mulching/soil regeneration purposes. Tractor mounted mulcher machine is used in mulching crop residues in oil palm plantation field. It comprises of 0° blade lifting angle mounted on three point linkages and driven by the tractor power-take-off (PTO) shaft. During mulching operations various factors affect its energy requirements. These factors can include soil conditions, operational conditions and blade geometry. It has a capacity for cutting of oil palm fronds, mixing topsoil and preparing oil palm fields prior to replanting directly. It has more mulching capacity than forestry mulchers (Abdullah and Sulaiman, 2013). The blades work under forces because of power, torque, vibration and impact effect of soil parts after reaching higher side. Blades have to be reliable in field performance against operating forces. Predicting stress distributions and deformation is important for the designers, manufacturers and end users (Shinde *et al.*, 2011).

Improvement in computers and computational techniques has led to the development of a new generation of highly efficient programs for simulating real situations. Numerical techniques, especially finite element method (FEM), help to analyze the soil–blade interaction with the development of a suitable constitutive (stress-deformation) relation for specific working condition. FEM predicts information about the failure zone, stress and deformation, acting forces on blades for agricultural equipment without limitation on the geometry of blades (Armin *et al.*, 2014).

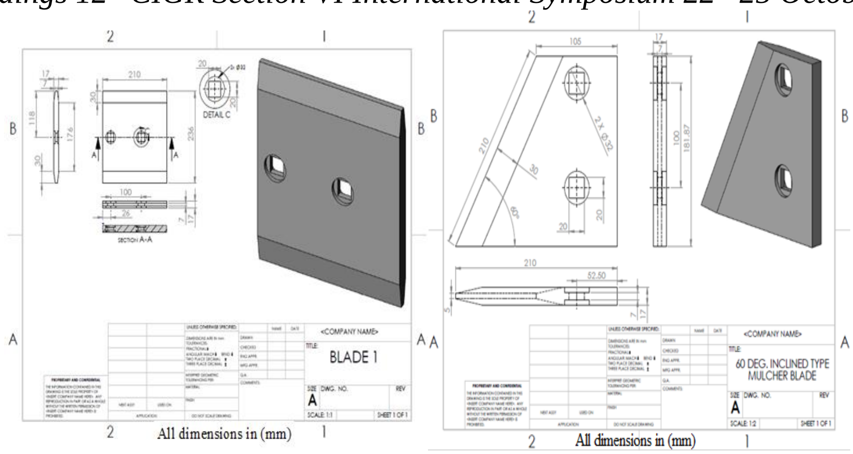
The maximum stress and deformation due to impact in the mulcher blade during field operation is the major concern in the design considerations. It is obvious that the toughness of material is connected to its ductility, ultimate strength and the capacity of structure to endure an impact load which relies upon toughness of material used (Shigley, 2011).
Estimation of maximum stress and deformation of mulching blade geometry effects on soil physical properties is important. Unless the correct blade geometry combination is chosen for mulching implement, the long term effects of soil mulching by tractor mounted mulcher may result in poor soil structure. Incorrect blade geometry may also result in unnecessary waste in machinery input energy (Masiyandima, 1995).

The FE model with the finest mesh generated the most accurate results with dependent on factors such as geometry, type and size of mesh element and loading condition. Effect of parameters such as geometry and size of mulcher blades were considered (Shigley, 2011).
The objectives of this research were to study the effects of blade geometry (operating lifting angles) on soil forces and compare the results using the finite element method for four different blade lifting angles.

2. MATERIALS AND METHODS

Several meshing patterns were performed to verify convergence. Large number of equilibrium iterations were required for convergence, the calculations were mostly long (normally lasting numerous hours on a computer with Intel core i3 4 GHz processor and 3.2 GB of RAM). Thus for computational efficiency and to make a balance between computational effort and accuracy, each model was meshed with higher density near the contact areas, and only the models that can be considered converged are shown in this study.

Three different blades were developed (with different lifting angles of 60^o, 120^o, and 150^o) with the original blade (0^o) as control and developed with CAD methods (Figure 1 and 2) and analyzed by 3D modeling. Geometrical parameters were used at initial stage as a basis for 3D modeling which were related to commercially available mulcher tools using 3D CAD software.



v- Figure 1: Orthographic and 3D Model Mulcher Blade with 0^o (Original Mulcher Blade from Howard) and 60^o Lifting Angle

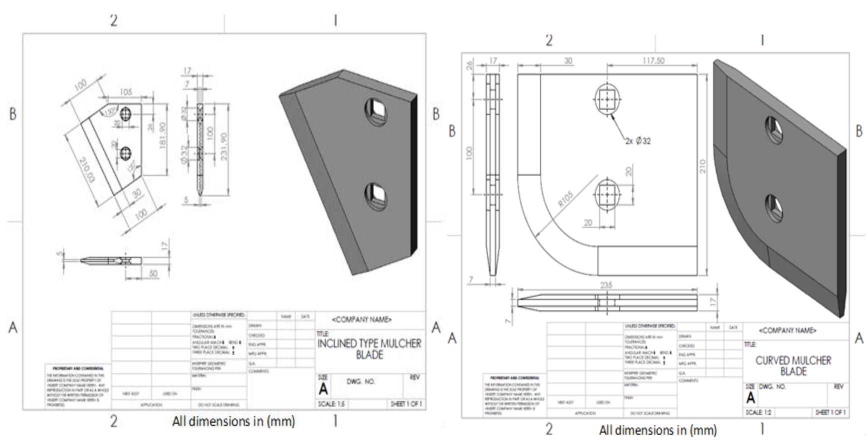


Figure 2: Orthographic and 3D Model Mulcher Blade with 120^o and 150^o Lifting Angle

The mulcher blade properties (Steel) were obtained from the database of Howard Company production system. The material properties (two steel sizes AISI 1040 and AISI 1148) were used for the design and production of three mulcher blades and soil properties were considered based on the blade material properties as shown in
Table 1. The Steel material used is available in Malaysia and easy to access and cheap. The structural analysis was carried out to check the stress distribution and displacement on the new blades and the original blade from the Howard Company. To compare with the original blade, both original and new blades were modeled and analyzed using FEM. The blades were simulated before field testing and black cotton soil was considered as a reference soil with shear strength of 1350 x 10^3 N/m^2.

Table 1: Properties of steel materials for analysis

Material Properties	Values
Yield Strength	$6.204 x 10^8$ N/m^2
Tensile Strength	$7.23826 x 10^8$ N/m^2
Elastic Modulus	$2.1 x 10^{11}$ N/m^2
Poison's ratio	0.28
Mass density	7700 kg/m^3
Shear Modulus	$7.9 x 10^{10}$ N/m^2
Thermal Expansion	$1.3 x 10^{-5}$/Kelvin

A three-dimensional based finite element model was analyzed in Solid Works 2014 SP5 software to assess the effect of mesh density on material property and the resulting influence on the predicted stress distribution. The same loading conditions were used in all models.

2.1 Boundary and Loading Conditions

Fixed support constraints (boundary conditions) were applied into the holes located on the meshed geometric models as represented the point of attachment to the blade carrier. Loads (forces) were applied to the cutting edges of the blades to investigate the stresses and deformation and its effect on the blade material. These loads were derived from using the Mckyes and Ali's model for calculating soil forces Amin *et al.*, 2014. Mckyes and Ali's model was adopted in the determination of anticipated soil reaction forces on the blades.

The highest stress/deformation level was observed in the element which was at the tip of the opening and was of a particular interest during the whole simulation. At the beginning all bonding forces were active and this element (to be referred to as the tip element) is adjacent to the tip of blade. As the blade started to move, stresses went through the elastic phase until the solid line representing the yielding condition was reached.

Simulations were run at the six treatment levels from the laboratory test on four design tractor mounted mulcher blades with different lifting angles (0^o, 60^o, 120^o and 150^o). Results were compared against the average measured stress and deformation. Overall, the simulations were able to capture the trends in the stress loading. The stress at points on the front and back of the blades were also monitored and also showed good convergence. Each simulation took approximately 2.2 hours to run on a Solid Works 2014 SP5 software.

3. RESULTS AND DISCUSSION

3.1 Mesh Convergence Analysis for Designed Mulcher Blades

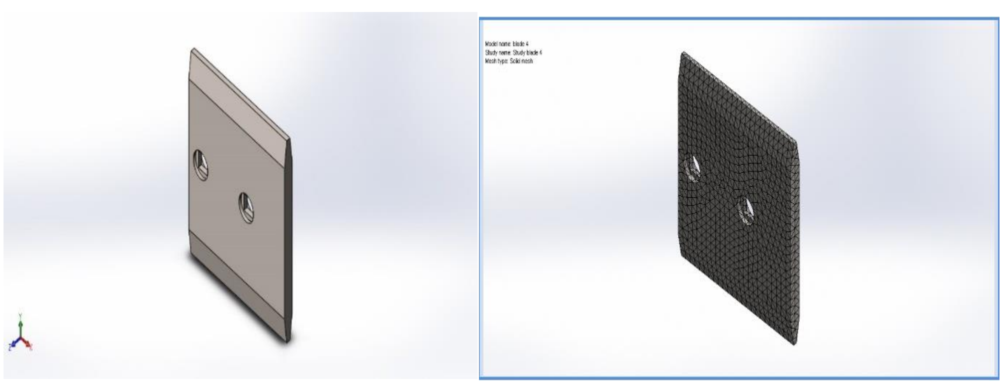
Significant variations were observed in the modulus distributions between the mesh densities of the four blades. Better results in different analysis with Solid Works software on mesh convergence study was explained on the four design tractor mounted mulcher blades.

3.2 Mesh Convergence Test Analysis for Blade With 0º Lifting Angle

The Table 2 presents result of convergence test analysis carried out on blade with 0º lifting angle. The test results revealed that by adding the number of elements, maximum stress increased sharply and then gradually remained stable. The analysis began with 8157 elements and rose until 302869 elements as it reached its finest stage as presented in the geometric and mesh models in Figure. In the initial test, maximum stress was 36.50 MPa, which increased up until 44.85 MPa in the final test at 302869 elements as shown in (mesh density distribution in the domain of the blade). Figure 54 shows the maximum stress at 181683 elements which discontinued its sharp increase at 42.43 MPa and maintained its very little escalation until the final point as graphically shown. Also from the calculations of stress change, the result showed that it was below 10%, therefore the result gave a good convergence.

Table 2: Convergence test analysis for blade with 0º lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	8157	36.50	0.0174206
2	14126	37.78	0.0174505
3	23157	39.13	0.0174739
4	55778	40.46	0.0174841
5	181683	42.43	0.0175012
6	302869	44.85	0.0175085



vi- Figure 3: Geometric model and meshing density for blade with 0º lifting angle

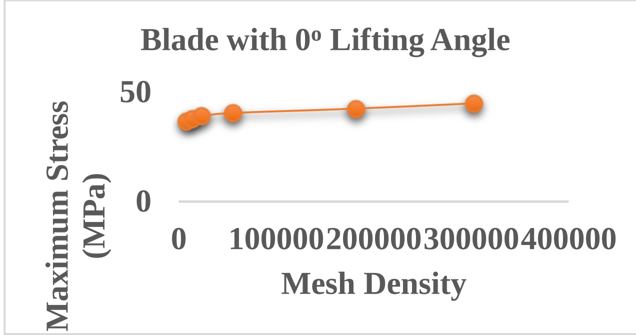


Figure 5: Mesh density distribution in the domain for blade with 0^{o} lifting angle

3.2.1 Maximum Stress and Deformation for Blade With 0º Lifting Angle

Table 2 presents the maximum stress and maximum deformation simulation results of the blade with 0^{o} lifting angle. Maximum stress of 44.85 MPa was obtained at bottom of the blade which is indicated in red colour as shown in Figure5. The stress at the tip of the blade had a low value of 1.000 MPa. The maximum deformation was found to be 0.0175 mm as shown in **Error! Reference source not found.**5. The stress results were compared with the yield point (62.04 MPa) of the blade material and established that the maximum stress did not exceed the yield point, which simply mean that deformation did not affect failure on the blade with 0^{o} lifting angle.

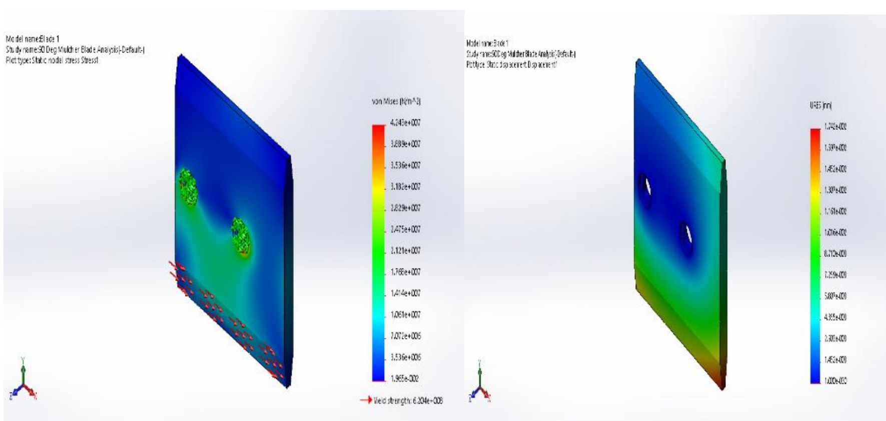


Figure 5: Maximum stress and maximum deformation for blade with 0^{o} lifting angle

At the inner bolt holes, large amount of stress were traced which proposed that bolts that can endure stresses above 24.75 MPa can be used to tighten the blade to the mulcher's blade carrier in order to resist estimated stresses.

3.3 Mesh Convergence Test Analysis for Blade with 60º Lifting Angle

Table 5: Convergence test analysis for blade with 60o lifting angle. Increasing the number of elements, maximum stress increased abruptly and then approximately remains steady. The mesh convergence analysis started with 4618 elements and increased until 177041 elements where it reached its finest stage as shown in **Error! Reference source not**

found.6. The maximum stresses at 105763 elements, for the first and peak test, were 17.68 MPa and 20.41MPa, respectively. As shown at 177041 elements, maximum stress stopped its sharp increase at 19.99 MPa and kept slightly rising until the last point as shown in Figure7. Also from the calculations of stress equation change, the result indicated that it was less than 10%, therefore the solution gave a good convergence.

Table 5: Convergence test analysis for blade with 60^o lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	4618	17.68	0.00572141
2	8312	18.04	0.00571822
3	14560	18.38	0.00572305
4	33171	18.64	0.00572872
5	105763	20.41	0.00573255
6	177041	19.99	0.00573563

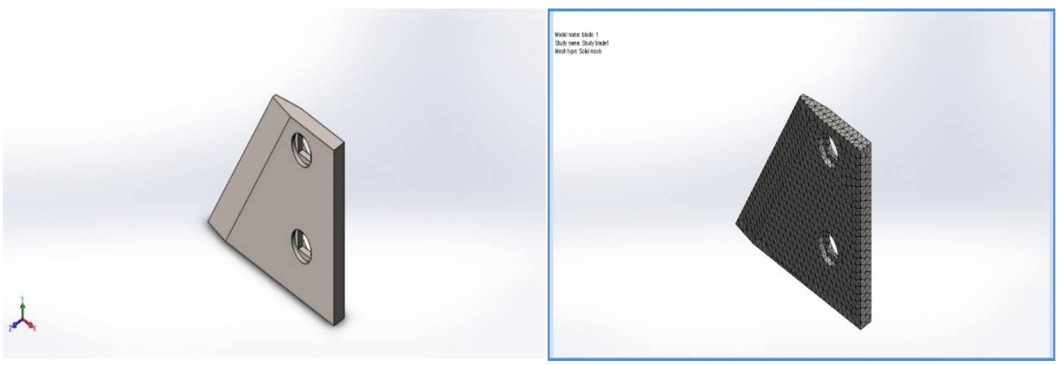


Figure 6: Geometric model and meshing density for blade with 60^o lifting angle

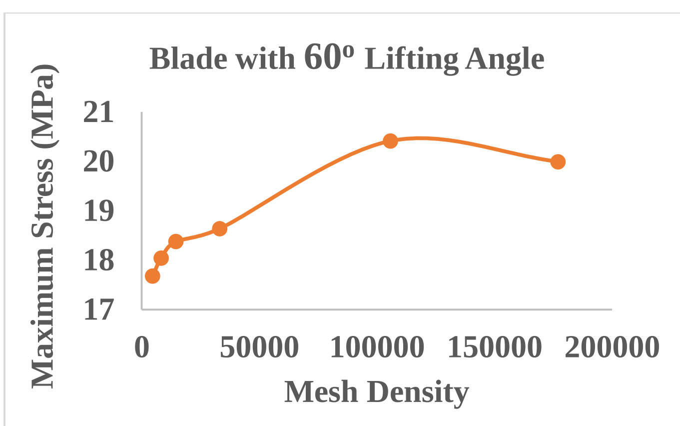


Figure 7: Mesh density distribution in the domain for blade with 60^o lifting angle

3.3.1 Maximum Stress and Deformation for Blade With 60º Lifting Angle

Table 54 shows the simulation result for maximum stress and maximum deformation on the blade with 60º lifting angle. Maximum equivalent stress of 20.41 MPa at the top of the blade was obtained which is indicated in red colour in Figure8 and a maximum total deformation of 0.0057 mm was obtained as presented. The stress results were equated with the yield point (62.04 MPa) of the blade material and found that the maximum stress did not exceed the yield point, which implied that deformation did not cause failure on the blade with 60º lifting angle.

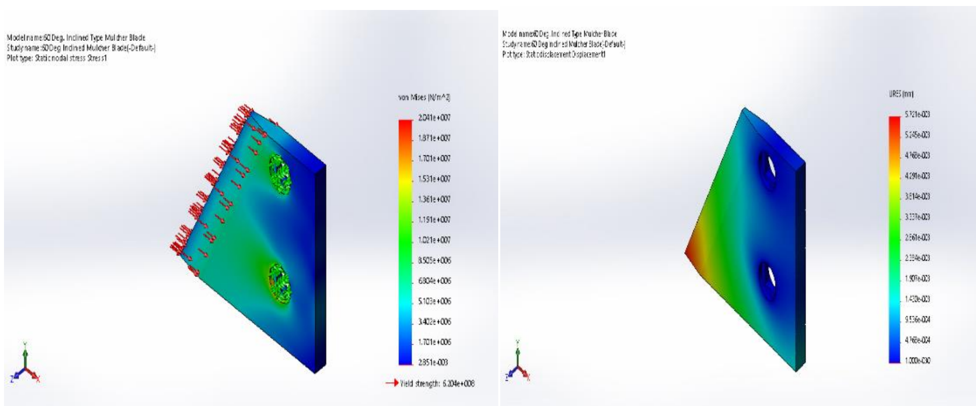


Figure 8: Maximum stress and deformation for blade with 60º lifting angle

Higher stress values were located at the inner bolt holes, which suggest that bolts that can withstand stresses above 11.91 MPa would be used to tighten the blade to the Mulcher's blade carrier in order to withstand anticipated stresses.

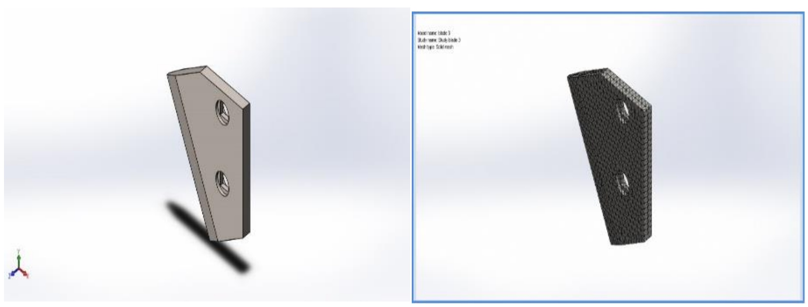
3.4 Mesh Convergence Test Analysis for Blade with 120º Lifting Angle

The analysis of convergence test was carried out on blade with 120º lifting angle and the results are presented in

Table5. The test result shows that by increasing the number of elements, maximum stress increased sharply and then suddenly remained constant. The analysis began with 4733 elements and increased until 197861 elements as it reached its optimum stage as shown in Figure9. In the first test, maximum stress is 16.55 MPa, which increased up until 18.46 MPa in the finishing test at 112116 elements. As revealed at 197861 elements, maximum stress discontinued its sharp increase at 18.92 MPa and maintained its very little escalation until the final point as shown in Figure 210. Similarly, the calculations of stress change recorded that it was lower than 10%. Therefore the outcome gave a good convergence.

Table 5: Convergence test analysis for blade with 120^o lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	4733	16.55	0.0040438
2	9261	16.65	0.00404526
3	15613	17.34	0.00404775
4	35076	17.44	0.00404968
5	112116	18.46	0.00405174
6	197861	18.92	0.00405284



vii- Figure 9: Geometric model and mesh density for blade with 120^o lifting angle

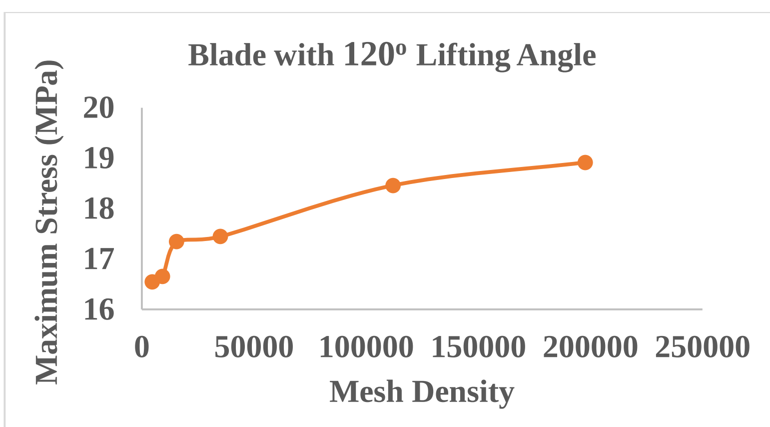
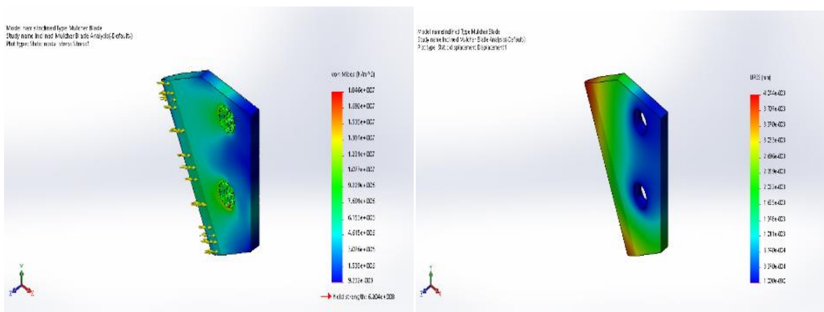


Figure 20: Mesh density distribution in the domain for blade with 120^o lifting angle

3.4.1 Maximum Stress and Deformation For Blade with 120^o Lifting Angle

Table5 shows the Finite Element Analysis (FEA) of the geometric model, maximum stress and maximum deformation of the blade with 120^o lifting angle. From the simulation effects, maximum stress on the blade with 120^o lifting angle was 18.95 MPa as shown in Figure31 which is indicated in red colour at the tip of the blade. The stress distributions were below the yield stress (62.04 MPa) of the stated blade material. Larger stress results were sited at the inner bolt holes, which suggest that bolts that can resist stresses above 6.26 MPa is recommended to tight the blade to the mulcher's blade carrier in order to sustain predicted stresses. The stress at the dorsal of the blade had a low value represented with a blue colour.



viii- Figure31: Maximum stress and maximum deformation for blade with 120^o lifting angle

The maximum deformation results for the blade with 120^o lifting angle was 0.0041 mm as indicated in **Error! Reference source not found.**1. All deformation values were within the acceptable limit for the design intent and material specifications of the mulcher blade. The maximum deformation of the blade at the mid-section was due to the high amount of force the blade was required to be overcome during operation.

3.5 Mesh Convergence Test Analysis for Blade with 150^o Lifting Angle

Convergence test was performed on the blade with 150^o lifting angle and the analysis are presented in

Table6. The test effects show that by increasing the number of elements, maximum stress increased sharply and then abruptly remained stable. The analysis started with 7034 elements and increased until 292180 elements as it reached its optimum stage as shown in Figure 4 the geometry and mesh models. In the first test, maximum stress was 66.87 MPa, which increased up until 73.35 MPa in the finishing test at 175532 elements. The maximum stress at 292180 elements discontinued its sharp increase at 73.35 MPa and maintained its very little escalation until the final point as shown in Figure 53. Similarly, the calculations of stress change on convergence test shows that it was lower than 10%, therefore the outcome gave a good convergence.

Table 6: Convergence test analysis for blade with 150º lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	7034	66.87	0.0174249
2	13990	67.80	0.0174424
3	23030	69.38	0.0174807
4	53166	71.60	0.0175034
5	175532	73.35	0.0175301
6	292180	74.29	0.0175376

ix-

Figure 42: Geometric model and meshing density for blade with 150º lifting angle

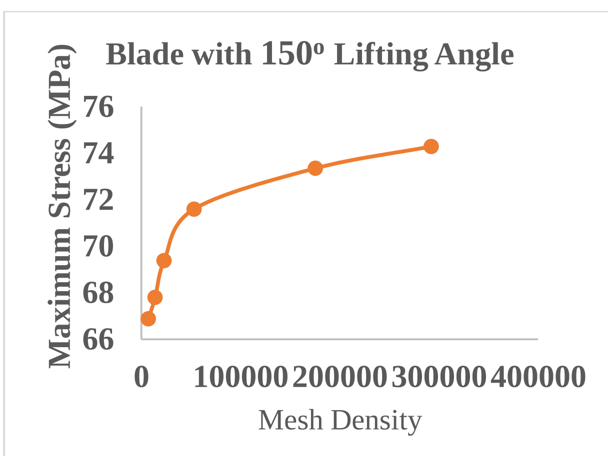


Figure 53: Mesh density distribution in the domain for blade with 150º lifting angle

3.5.1 Maximum Stress and Deformation for Blade with 150º Lifting Angle

Table6 presents the FEA of the geometric model, maximum stress and maximum deformation of the blade with 150º lifting angle. From the simulation effects, maximum stress on the blade with 150º lifting angle was 74.29 MPa as shown in Figure 154 which is indicated with red colour at the tip of the blade. The stress distributions were above the yield stress (62.04 MPa) of the specified blade material, the blade was the worst in terms of failure due to fatigue. Larger stress results were sited at the inner bolt holes, which suggest that bolts that can resist stresses above 32.26 MPa are recommended to tight the blade to the mulcher's blade carrier in order to sustain predicted stresses. The stress at the top of the blade represented with a blue colour had a low value. Maximum deformation result for the blade with 150º lifting angle was 0.0175 mm as indicated in **Error! Reference source not found.**.

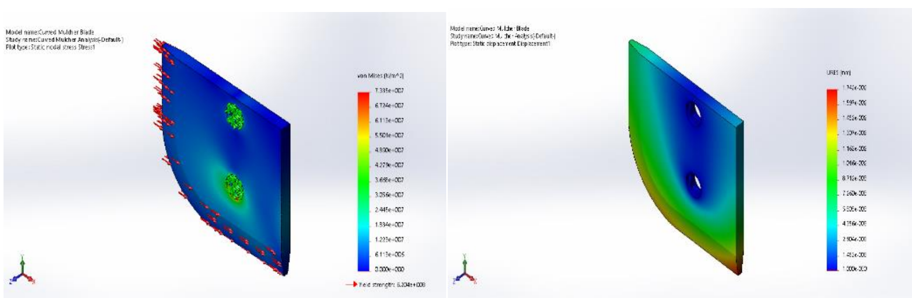


Figure 15: Maximum stress and maximum deformation for blade with 150º lifting angle

The blade geometry, material properties, bolt placements and blade thickness played a significant roles which accounted for the stress and deformation differences in the blade concepts. (Bosrotsi et al.), (2017) reported that blades with higher stress and deformation values have shorter design life (high rate of wear and fatigue). From Tables 1- 6, the results indicate that the blade with 120º lifting angle gave minimal stress and deformation values than the other blades with 0º, 60º and 150º lifting angles. Hence, the blade with 120º lifting angle was recommended over the other blades.

4. CONCLUSION

Based on the research conducted on simulating the blades of tractor mounted mulcher for mulching oil palm fronds prior to replanting period, the following conclusions can be drawn. Minimum stress and deformation requirement for finite element analysis were achieved by blade with 120º lifting angle. The worst performing blade was the one with 150º lifting angle.

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Determination of Some Physical Properties of *Thevetia Peruviana* Dried Fruit in Relation to Agro-Processing Equipment

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ABSTRACT

Thevetia Peruviana J. (Apocynaceae) is an evergreen tropical shrub or small tree that bears yellow or orange-yellow trumpet like flowers, it is funnel shaped with spectral spirally twisted and its fruit is deep green in colour encasing a large kernel. *Thevetia Peruviana* is very rich in oil with the oil content in the kernel being as high as 62.14 % (w/w) while other part of the fruit bears negligible amount of oil. Some Physical properties of *Thevetia Peruviana* dried fruit were investigated in this study. These properties include length, width, thickness, sphericity, surface area, density, bulk density, moisture content, angle of repose, volume and porosity. The results showed that the average length, width and thickness of *Thevetia Peruviana* dried fruit were 29.62 mm, 16 mm and 14.20 mm respectively. The geometric mean diameter, sphericity, surface area, mass, volume, density, moisture content, bulk density and porosity were 18.39 mm, 0.62 mm, 1.2 2mm^2, 0.041 g, 31.5cm^3, 0.0013 g/cm^3, 11.35 %, 0.74 g/cm^3 and 0.85 % respectively. The average coefficient of static friction over three structural surfaces (metal, plastic, plywood) was 0.38 at moisture content of 5.4 % (db); the average angle of repose on the three surfaces were 15^o, 12.8^o and 13.2^o respectively. These properties are necessary for the design of equipment for processing, sorting, separating and transporting of the fruits and kernel of the bio-fuel plant.

Keywords: Thevetia Peruviana, Moisture Content, Bio-fuel, Density, Porosity, Angle of repose, Nigeria

1. INTROUCTION

Bio-energy has become the major alternative solution to the global energy considering the environmental and sustainability challenges in order to fulfill the current energy demand. (Pattanaik *et al.*, 2017). Among the several other bio-energy alternatives, research on non-petroleum based, non-polluting, renewable biofuels has been the priorities. Biodiesel is one of the most important in the category of biofuels. For production of biodiesel, the feedstock plays a vital role and has been chosen according to quality, availability in each region or country, physico-chemical properties and its production cost. The main non-edible plant species which are potential biodiesel sources are *Jatropha curcas* (ratanjyot), *Pongamia pinnata* (karanj), *Calophyllum inophyllum* (nagchampa, polanga), *Ricinus communis* (castor), *Argemone mexicana* (Mexican prickly poppy), *Cerbera odollam* (sea mango), *Putranjiva roxburghii* (Lucky bean tree), *Sapindus mukorossi* (soapnut), *Hevea brasiliensis* (rubber tree), *Melia azedarach* (syringa), *Salvia chinensis* (jojoba), *Madhuca indica* (mahua), *Schleichera triguga* (kusum), and *Thevetia peruviana* (yellow oleander), and so on (Pattanaik *et al.*, 2017) . They are easily available in many parts of the world and are relatively cheap. Among other plant species *Thevetia Peruviana* is quite popular source for biodiesel in Asian and African countries.

Thevetia Peruviana J. (Apocynaceae) is an evergreen tropical shrub or small tree that bears yellow or orange-yellow trumpet like flowers funnel shaped with spectral spirally twisted and its fruit is deep green in colour encasing a large kernel. The leaves are specially arranged linearly about 130 to 150 mm in length. It contains a milky sap containing a compound called thevetin used as heart stimulant but in its natural form, the sap is extremely poisonous, as are all parts of the plant (Aboyeji and Olofintoye, 2011). *Thevetia Peruviana* requires well drained, moderately fertile soil moisture for cultivation. It is tolerant to heat, drought and seaside conditions according to Pattanaik *et al*. (2017). The seeds, leaves, fruits and roots of *Thevetia Peruviana* are considered as potential sources of biologically active compounds, such as insecticides, rodenticide, fungicide and bactericides (Theurkar *et al.,* 2014). The plants toxins have been tested in experiments for its use as biological pest control such as insecticides for toxins. The seed oil can also be used to make paint.

Thevetia Peruviana is very rich in oil content. The kernel oil content is as high as 62.14 % (w/w) while other part of the fruit bears negligible amount of oil (Sahoo *et al*., 2009). The oil can be used for making biofuels, paints, insecticides, cosmetics; residue (de-oiled cake) which is a rich source of protein (30-37 %) can be used for animal feed formulation (Thilagavathi *et al.*, 2010). In the study conducted by Ibiyemi *et al.* (2002) it was reported that *Thevetia Peruviana* kernel contains about 30 – 35 % protein and the kernel fraction in the fruit of the nut is only 16.14 %. The cake derived after oil extraction can be added to the soil as manure and the hard kernel coat (endocarp) derived after nut cracking can be processed to particle board for making furniture or turned to briquette and used as heat source.

Thevetia dried fruit and kernel undergo a series of unit operations before reaching the final step of oil extraction. The knowledge of physical properties of the fruit and kernel of *Thevetia Peruviana* are needed in developing designs, fabricating particular equipment and structures for these unit operations like handling, transport, processing, storage and also for assessing the behavior of the product quality (Sahay and Singh, 1996). The size, shape and angle of repose of fruit and kernel can be used to determine the lower size limit of the conveyors, such as belt conveyor, bucket elevator, screw conveyor and hopper; cleaning, grading, while bulk density and moisture content are used in determining the size and shape of storage bin and drying process respectively (Sahoo *et al. (2009)*.Hence the need to study the physical properties of the fruit.

The aim of this study was to investigate some physical properties of *Thevetia* dried fruit in order to provide useful data for the design and fabrication of its processing equipment. The parameters studied include moisture content; size, mass, geometric mean diameter, sphericity, surface area, bulk density, true density, porosity and angle of repose.

2. MATERIALS AND METHODS

2.1 The Materials/Instrument Used for Sample Collection and Preparation

The following are the relevant materials and instrument used to carry out the physical properties of *Thevetia Peruviana* dried fruit:

- *Thevetia Peruviana* dried fruit,
- Digital Weighing Scale,
- Measuring Cylinder,
- Inclined Plane,
- Slotted weights,
- Digital Venier Caliper,
- Calibrated bucket and
- Laboratory oven.

2.2 Sample Collection and Preparation

Dried Thevetia Peruviana dried fruit were handpicked along the female hostel of Kwara State polytechnic, Ilorin and were kept at room temperature in a cool dry place before the experiments were conducted. All experiments were performed in the laboratory within the room temperature range of 28°-32°C. The *Thevetia Peruviana* dried fruit used for the experiment were defect free.

2.3 Determination of Physical Properties

The following were determined under the physical properties of *Thevetia Peruviana* dried fruit.

2.3.1 Determination of Mass

The mass of the kernel was determined by using a digital weighing scale (Elmakarus, El-5K02) with accuracy of 0.001g. 100 dried fruit of *Thevetia Peruviana* were randomly selected and placed on the digital weighing scale then recorded carefully.

2.3.2 Determination of Size, Shape and Sphericity

The axial/dimensions which are length, width and thickness were measured using a digital venier caliper (Mituitoyo, Model Absolute Digimatic, Japan reading up to 0.01mm). The geometric means diameter (D_m) in mm and sphericity were computed from the values obtained for the dimensions of the *Thevetia Peruviana* dried fruit using the following expression given by (Fadele, 2011 and Mohsenin, 1986) in equation 1 and 2 below respectively.

$$D_m = (abc)^{1\backslash 3} \qquad (1)$$

Where;

a = the length of the dimension along the longest axis in mm
b = the width of the dimension along longest axis perpendicular to a in mm
c = the thickness, dimension along the longest axis perpendicular to both a and b in mm.

$$\Phi = \frac{(abc)^{1/3}}{a} \qquad (2)$$

Where;

a = the length of the dimension along the longest axis in mm
b = the width of the dimension along longest axis perpendicular to a in mm
c = the thickness, dimension along the longest axis perpendicular to both a and b in mm.
Φ = sphericity

2.3.3 Surface Area

The surface area was determined using equation 3 according to Mc Cabe *et al.* (2006)

$$S = \Pi Dg^2 \qquad (3)$$

Where,

Dg = the geometric means diameter of the dried fruit

2.3.4 True Density and Bulk Density

The true density of dried fruit is defined as the ratio of the mass of a sample of the dried fruit to the volume occupied by the same sample. A weighed quantity of *Thevitia Peruviana* dried fruit was poured into a 100 cm^3 fractionally graduated cylinder containing 50 cm^3 of distilled water. The volume of water displaced by the dried fruit was noted. The true density was calculated as expressed by (Aderinlewo *et al.*, 2011) as shown in equation 4

$$\text{True Density} = \frac{M_s}{V_w} \qquad (4)$$

Where,

M_s = mass of sample, g
V_w= volume of water displaced, cm^3

In order to determine the bulk density at given moisture content, a cylinder container of 0.3m height and 0.2 m diameter was filled with *Thevita Peruviana* dried fruit from a height of 0.15 m from surface of the container, and the top was leveled. No separate or additional manual compaction was done. The digital weighing scale was used for weighing, and the bulk density was defined as the ratio of the mass of the bulk dried fruit to the volume of the container. It can be determined using this equation 5 below as expressed by (Mahbobeh *et al.*, 2011)

$$\text{Bulk Density} = \frac{m_s}{v_o} \qquad (5)$$

Where,
M_s = mass of sample, g
V_o = volume occupied, cm^3

2.3.5 Porosity
This is the ratio of the volume of internal pores in the dried fruit sample to its bulk volume and it was determined using the following relationship below in equation 6 according to Mohsenin (1986); Aderinlewo *et al.* (2011) (Mohsenin, 1986; Aderinlewo *et al*., 2011)

$$\text{Porosity} = 1 - \frac{\textit{Bulk Density}}{\textit{True Density}} \times 100 \qquad (6)$$

2.3.6 Volume
The volume of the dried fruit was determined using a water displacement method. A known mass of the *Thevetia* dried fruit was put in a known measuring cylinder filled with water and the final volume was taken and recorded using equation 7 as given by (Anyakoha, 2016).

$$V\left(cm^3\right) = V_f - V_i$$

Where V=Volume of Sample
V_f = final Volume of water with Sample
V_i = initial Volume of water without Sample

2.3.7 Moisture Content Determination
The moisture content of *Thevetia Peruviana* dried fruit was determined using the oven drying method. The laboratory oven used was (New Age with model No.NL9023A). A known mass of *Thevetia Peruviana* dried fruit was place in the oven at a regulated temperature of 85^{o}C for 24 hours and weighed at every 1 hour until a constant weight is achieved. This was done in order to account for the moisture loss in the dried fruit (Sahoo *et al*., 2009). The differences in the mass was used to calculate the moisture content using equation 8

$$MC(w.b) = \frac{M_b - M_a}{M_b - M_c} \times 100 \qquad (8)$$

Where MC (wb) is moisture content (wet basis) of the sample,
M_b = weight of can plus sample weight before heating (kg)
M_a = weight of can plus sample weight after heating (kg)
M_c = weight of can (kg)

2.4 Determination of Angle of Repose and Co-efficient of Static Friction

The angle of repose is the horizontal at which the material will stand when piled. This was determined by using a topless and bottomless cylinder of 30 cm diameter and 50 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 70 cm and was filled with *Thevetia Peruviana* dried fruit. The cylinder was then raised slowly until it formed a cone on the circular plate. The height of the cone was measured and the angle of repose (θ) was calculated using the equation used by (Mahbobeh *et al.*, 2011) in equation 9.

$$\Theta = \tan^{-1}\left(\frac{2H}{D}\right) \qquad (9)$$

Where;

H is the height of the cone (mm)

D is the diameter of the cone (mm).

Θ is the angle of repose (^{0})

The co-efficient of static friction was determined on three different surfaces: metal, plywood and plastic surfaces. For this measurement, the material was placed on the surface and gradually raised by the screw. Vertical and horizontal height values were read from the ruler when the material started sliding over the surface. The tangent value of the angle was used to evaluate the coefficient of static friction. The co-efficient of static friction on the various surfaces was calculated using equation 10 used by (Mahbobeh *et al.*, 2011).

$$U = \tan^{-1} Q \qquad (10)$$

Where,

U = the coefficient of friction

3. RESULTS AND DISCUSSION

The physical properties of *Thevetia Peruviana* dried fruits are presented in table 1. Physical properties under investigation include the major diameter (mm), intermediate diameter (mm), minor diameter (mm), geometric mean diameter (mm), sphericity, surface area, mass, moisture content, volume, porosity, bulk density, angle of repose and coefficient of static friction were studied. The values from table 1 were also represented in graphical illustration for ease of interpretation as shown in figure 1 below. Table 1 revealed mean value for length, breadth, thickness, geometric mean, sphericity, surface area, mass, volume, density, moisture content, bulk density and porosity were 29.62 mm, 16.00 mm, 14.20 mm, 18.39 mm, 0.62, 1.22 mm^2, 0.041 g, 31.40 cm^3, 0.0013 g/cm^3, 11.35 (%), 0.74 g/cm^3, 0.85 % respectively. The mean values for the length, breadth, thickness and the geometric mean diameter would be useful in the design of sieves, sorters, cleaning machine and any other handling processing equipment; as reported by Mohsenin (1986) that length, breadth and thickness, geometric mean diameter are required in determining aperture sizes and other parameters in machine designing, which was also highlighted by (Omobuwajo *et al*., 1999).

The sphericity of the *Thevetia Peruviana* kernel was 0.62. The Sphericity is an expression of the shape of a solid relative to that of a sphere of the same volume. The value is closer to the corresponding value of 0.68 as reported for *Jatropha* (Sirisomboon *et al*., 2007) and (Faleye *et al.,* 2013) for cowpea varieties. Bal and Mishra (1988) and Dutta *et al.,* (1988) have considered the grain as spherical when the sphericity value is more than 0.7. The determined sphericity value indicates that *Thevetia* fruit should not be treated as an equivalent sphere for calculation of the surface area. Garnayak *et al*. (2008) reported similar results for *Jatropha* seed. This information is useful in the design of hoppers, separators and conveyors.

Bulk and true densities are essential in knowing the weight of the crop per unit volume and are useful in handling operations. They are also useful in the design of silos, storage bins and design of specific gravity separators. The porosity or the percentage of voids of grains is useful in airflow, heat flow and drying studies such as determining the Reynolds number in pneumatic and hydraulic handling of grains, and in calculating thermal diffusivity in drying.

Table 1: Summary of the Average Physical Properties of *Thevetia Peruviana* Dried Fruit

Parameters	Mean	Maximum	Minimum	STDev
100- Kernel sample				
Length (mm)	29.62	33.22	21.93	3.35
Breadth (mm)	16.00	18.51	9.42	3.11
Thickness (mm)	14.20	16.36	.35	2.79
Geometric Mean Diameter (mm)	1.39	21.47	9.72	3.65
Sphericty (mm)	0.62	0.68	0.31	0.08
Surface Area (mm)	1.22	1.44	0.31	0.26
Mass(Kg)	0.041	0.025	0.020	0.05
Volume(cm^3)	31.40	35.00	30.00	2.21
Density (Kg/cm^3)	0.0013	0.0083	0.0007	0.00
Bulk Density (g/cm^3)	0.74	0.76	0.72	0.02
Porosity (%)	0.85	0.93	0.71	0.10

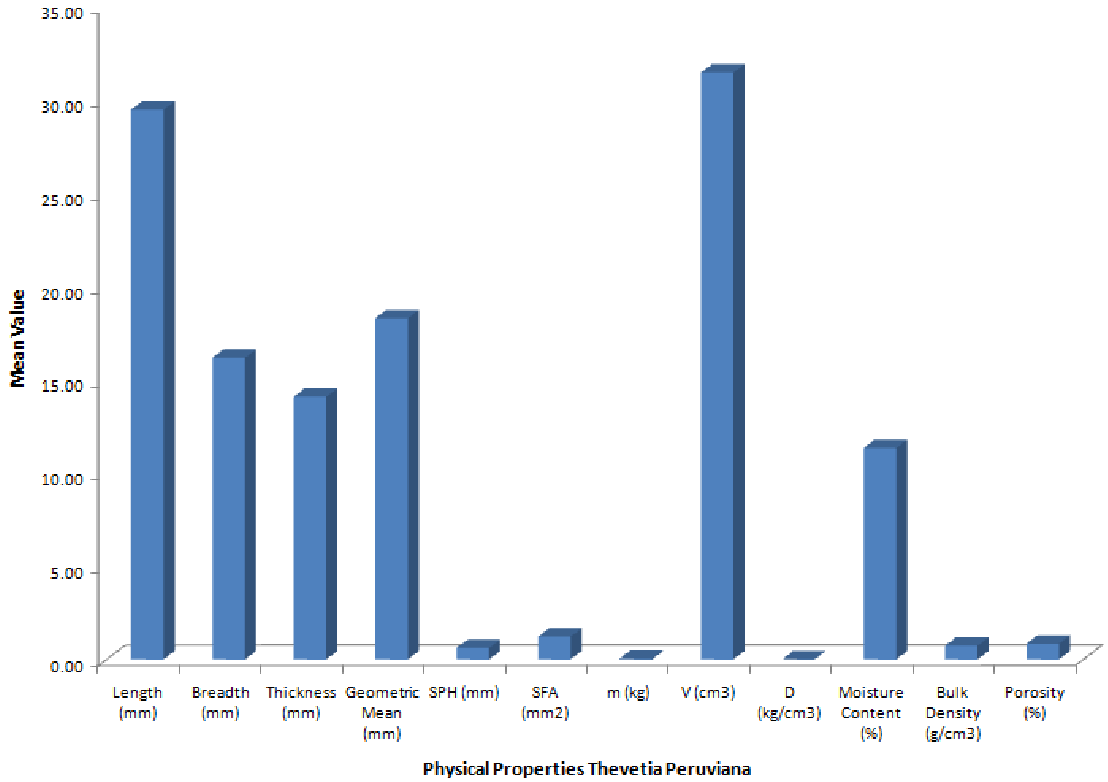

Figure 1: Physical Properties of *Thevetia Peruviana* Dried Fruit

Table 2 and figure 2 revealed the summary of angle of repose conducted on the *Thevetia Peruviana* dried fruit. This was carried out on three different surfaces: metal, plastic and plywood. The metallic surface had the highest value (15°) when compared with the plastic (12.8°) and plywood surfaces (13.2°). The angle of repose of the *Thevetia* dried fruit is lower than that of Prosopis Africana seed, similar results were also reported by Balogun *et al*. (2015) and Garnayak *et al*. (2008) for Jatropha. The values obtained can be used to design for the hopper of processing equipments.

Table 2: Angle of Repose of Thevetia Peruviana Dried Fruit

Angle of Repose	Metal	Plastic	Plywood
Mean	15	12.8	13.2
Maximum	15	15	15
Minimum	15	10	10
STDev	0	1.8	2.5

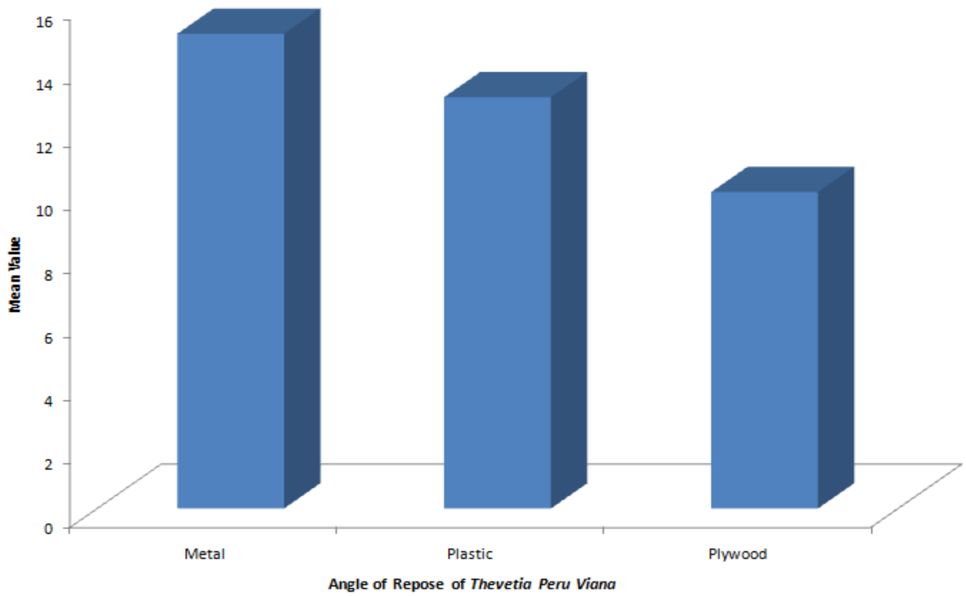

Figure 2: Angle of Repose of *Thevetia Peruviana* Dried Fruit

Table 3: Coefficient of Static Friction of *Thevetia Peruviana* Dried fruit

Coefficient of Static Friction	Metal	Plastic	Plywood
Mean	0.38	0.38	0.38
Maximum	0.97	0.97	0.97
Minimum	0.18	0.18	0.18
STDev	0.39	0.39	0.39

The coefficient of static friction for the *Thevetia* dried fruit ranges from 0.18° to 0.97° when the dried fruit was randomly selected for the experiment. This is presented in Table 3 and Figure 3 for the graphical illustration. The values obtained will be useful in the design of nut cracking machine, sorters, and separation unit of processing equipments.

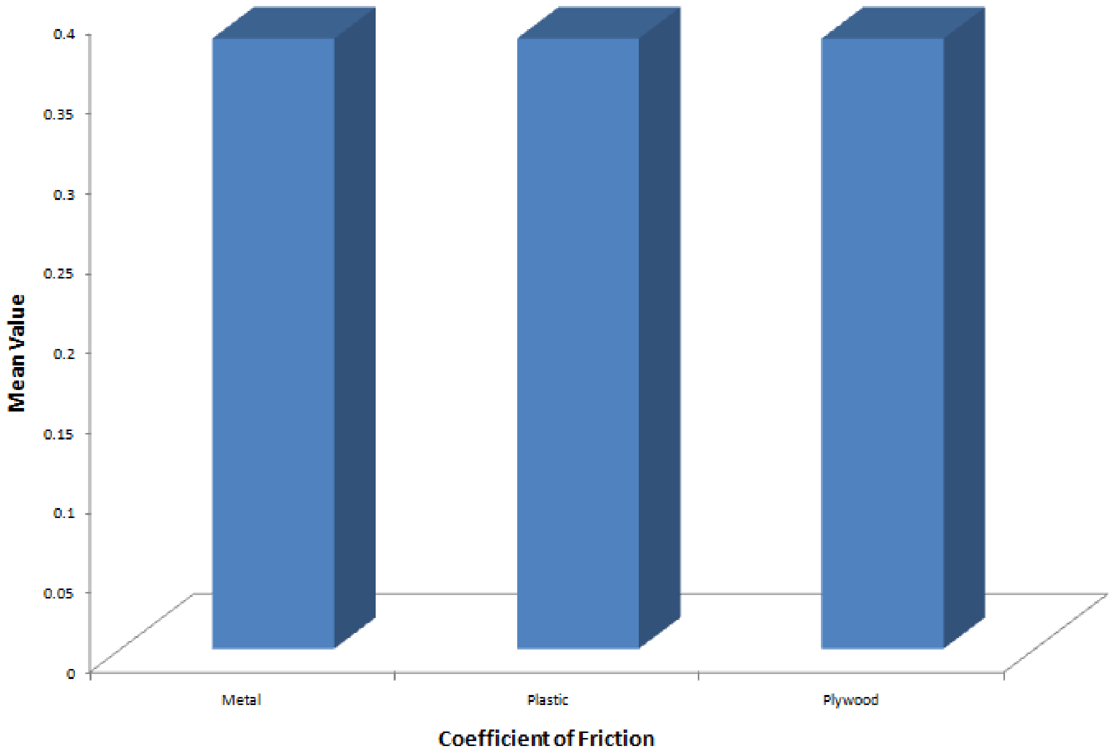

Figure 3: Coefficient of Static friction of Thevetia Peruviana Dried Fruit

4. CONCLUSIONS

The search for alternative source of energy and the utilization of non-conventional and non-edible feedstocks for biodiesel production in which *Thevetia Peruviana* (yellow oleander) is one of the promising non-edible feedstock which fulfils all the criteria for sustainable biodiesel production, thus the result of investigated physical properties of the fruit carried out with serve as a data/information in the design and fabrication of equipment required for its processing. \

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Ergonomic Evaluation of Manual Peeling of Cassava in Ten States in Southern Nigeria

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ABSTRACT

Manual peeling lends itself to human manipulation than mechanical peeling, and sometimes perfects mechanical peeling. An assessment of manual cassava peeling practices was conducted to identify the inherent problems in the manual peeling task and generate information that may be useful in the ergonomic design of efficient peeling workstation for women peelers. Randomly selected 100 human subjects were evaluated in ten states of Nigeria. Twenty-seven anthropometric data were measured during peeling operation, following standard procedures. The predominantly women peelers' age ranged between 18 and 67 (average 45.07±10.15). Heart rate was measured with automatic sphygmanometer following standard methods before and after peeling task. The average working heart rate and oxygen consumption of the peelers during peeling were *HR* = 78.85±4.80 beats/min (SD 4.8) and $12.83 \leq \boldsymbol{V_{O2}} \leq 15.33$ lit/min, respectively. Hence energy expenditure was lower than other types of jobs. Facility layout was observed to be haphazard; working posture was mainly sitting. The sitting posture adopted is fraught with the risk of musculoskeletal disorders due to the repetitive task, stretching, bending, twisting and static work involved. Hazards in the cassava peeling job included finger-cut, fatigue and back pain. Maximum output per peeler was 280kg per 8-hour day. Results of heart rate during peeling revealed low energy expenditure, suggesting peeling task is a light activity whose inherent job hazards can easily be mitigated through ergonomic interventions, which when employed with the anthropometric and human kinetic parameters, could result in better peeling workstation design for the predominantly women peeler population.

Keywords: Women, Cassava peeling, Anthropometric, Ergonomic evaluation, Musculoskeletal disorder, Heart rate, Energy expenditure

1. INTRODUCTION

Manual peeling of cassava predominates since no more efficient mechanical peeler has been built for the use of smallholders (Adetan *et al*, 2006). It is estimated that cassava roots are processed and eaten by 500 million people a day in Africa where it is a staple for 40% of the population (NetGenCassava, 2013). Peeling of roots and tubers has traditionally been done manually from time immemorial. This may continue for long time because of the irregular shape of the root and tuber crops that make them not easily amenable to mechanical methods of peeling. Another reason must have been that it lends itself to human manipulation. Even where the mechanical mean of peeling is applied, the imperfection in bark removal is often perfected by manual means. This is an indication that manual peeling approach can do it more perfectly with less waste than may be recorded with machines.

Peeling is often done by women who are mostly involved in meal preparations in many cultures.. Women are often employed to do peeling jobs while men are rarely involved. In cassava processing enterprises, women population involved in peeling are also involved in subsequent unit operations such as washing, soaking, decanting, pulverizing, pulping, dewatering, mashing, drying, frying, cooling and packaging. Men are often engaged in cassava grating and pressing (Samuel, 2010). Cassava peeling activity seems straightforward and non-hazardous at domestic scale but could lead to considerable stress with potential accidents and injury when large-scale peeling operations are required for commercial operations. Workstation set-up for peeling in typical cassava processing enterprises has implications – on health, productivity (quality and quantity) and, of course, the remuneration. The women involved in peeling are perceived to be low-paid due to low productivity and non-standard way of doing the job, resulting in poverty.

In the light of the above, research to improve peeling activity is justified to help the cassava processing industry improve processing efficiency and reduce poverty. Implicitly, human physiological parameters such as anthropometric data, collected during peeling activities or other unit operations, could be suitable for the ergonomic design of facilities in the cassava processing industry. This study aimed to measure the human physiological parameters that interplay and influence the efficiency of manual peeling operations carried out by humans, especially women. The purpose is to be better able to design peeling workstation for the predominantly women peelers and improve their health, income, and general livelihoods.

2. METHODOLOGY

The study was done in ten cassava processing factories selected from ten out of the 36 states of Nigeria – one processing center per state was selected by purposive sampling. The study states and cassava processing sites were located at Oyo (7 22N, 3 58E), Delta (5 30N, 5 41E), Edo (6 12N, 6 38E), Ekiti (7 38N, 5 12E), Imo (5 29N, 7 0E), Kwara (8 30N, 4 35E), Ogun (7 3N, 3 19E), Ondo (7 15N, 5 5E), Osun (7 48N, 4 37E) and Rivers (4 40N, 7 10E). Questionnaires and focus group discussions (FGD) were used to elicit information

from randomly selected ten women subjects (women cassava-peelers) on the status of cassava peeling practices at each processing location (total of 100 subjects for the ten processing centers from the ten states). The 100 subjects selected for the peeling experiment did not have any physical deformity or handicap. Gender, age and other socio-economic parameters of the respondents were recorded. The method of peeling, posture taken during peeling, workstation set-up, common injury and accidents that were characteristic of each processing location were elicited.
Triplicate measurements of twenty-seven anthropometric data were taken on each of the subjects following standard anthropometric protocol (Pheasant, 2003). These included age, weight, height, eye height (standing/sitting), forward grip reach (sitting/standing), sitting height, buttock-popliteal length, buttock-knee length, knee length and thigh clearance. Others were forearm-to-forearm breadth, knuckle height, elbow grip length, hip breadth (sitting), hand length (at index), hand breadth, hand thickness, grip span and lumbar height. The instrument used included weighing scale, measuring tape, vernier caliper (giant) and stadiometer. Based on the weight and height anthropometric data of the Subjects, the Body Mass Index (BMI) and Body Surface Area (BSA) were calculated. The total daily production and daily work rate and net working heart rate, mean and standard deviation were computed as well.

At the beginning of the peeling exercise, 25kg of roots was allocated randomly to each peeler, after sorting them into sizes to ensure what was allocated to each subject was relatively uniform, ensuring that each batch was procured from the same farm and peeled within one day of harvesting. Sorting was also done to eliminate those not economical (too small). The selected women cassava-peelers were earlier trained to peel normally (not shaving) by using a knife. The peeling activity or segment was done between 9am and 11am, 12noon and 2pm, 3pm and 5pm. The women cassava-peelers were made to rest for at least 30 minutes after arriving for the experimental work, and then resting heart rate was taken before the commencement of the first segment of peeling. Working heart rate data was collected for two hours of work, and the subject was allowed to rest for at least 30 minutes before next peeling segment. Working heart rate activity was measured, and quantity peeled was weighed after each segment of work.

The heart auscultation with a non-invasive automatic sphygmomanometer (SE-7000 full digital blood pressure monitor) was used following standard procedure to measure the heart rates of subjects at the start and end of peeling activity. Pressure cuff was wrapped around the upper left arm of the subject at about the same height as the heart. The device was switched on and the cuff rapidly inflated and subsequently deflated while readings (the systolic; the diastolic; the pulse rate) were displayed on the monitor. The subjects were measured in a quiet, seated posture. Three replications of each measurement were taken and the average recorded.

The technique developed by Rosenblat (Bedny & Meister, 1997; Bedny & Seglin, 1997) was used to calculate energy expenditure through oxygen consumption. In a dynamic work, heart rate correlates with energy expenditure. Using the method for calculating the average heart rate during work ($\boldsymbol{HR_w}$)

$$\boldsymbol{HR_w} = \frac{\boldsymbol{H_1T_1 + H_2T_2 + \cdots + H_nT_n}}{\boldsymbol{T_s}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where,

$\boldsymbol{H_1, H_2, \ldots H_n}$ are the heart rates of the first, second, and so forth, operation;

$\boldsymbol{T_1, T_2, \ldots T_n}$ are the performance times of the first, second, and so forth, operation;

$\boldsymbol{T_s} = \boldsymbol{T_1 + T_2 + \cdots + T_n}$ is the overall duration of the actual work performance during the shift. Applying Rosenblat equation to the peeling task, peeling is noted to be a single (unit) operation which may be performed at different times of the day with probably differing physiological demands due to various ambient environmental factors. Hence daily peeling activity is broken into three segments of two hours each (9-11am, 12-2pm, and 3-5pm), separated by two one-hour rest durations (not less than 30 minutes), (11am-12pm and 2-3pm).

Therefore, (1) modified, becomes

$$HR_w = \frac{H_1T_1 + H_2T_2 + H_3T_3}{T_1 + T_2 + T_3} \quad \text{----------------------------(2)}$$

If $T_1 = T_2 = T_3 = 2$ hours, then (2) gives $HR_w = \frac{T_1 (H_1 + H_2 + H_3)}{3T_1}$

$$HR_w = \frac{(H_1 + H_2 + H_3)}{3} \quad \text{----------------------------(3)}$$

(3) is noted to be the same as calculating the average heart rates during peeling activity. For this peeling operation, therefore, the formula for calculating means holds for calculating heart rate, and this was employed in the data analysis. The work rate was calculated by dividing the quantity peeled by the time expended, while the corresponding net heart rate was calculated by subtracting the resting heart rate from the working heart rate.

Using Scot and Christie's (2004) predictive equation of

$$y = 0.26x - 6.42 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(4)}$$

Where y = predicted oxygen consumption $\boldsymbol{V_{O2}}$ ml/kg/min, and x = measured heart rate $\boldsymbol{HR_w}$ in beat/min, established by regression in an experiment assessing physiological responses of forestry stackers on the field. With this, a noninvasive, indirect measure of energy expenditure can be determined. This was employed in the computation of the oxygen uptake from the heart rates measured in the peeling activity. It is generally accepted that the energy expenditure for extended work periods should ideally not exceed 21 kJ min^{-1} (Ayoub & Mital, 1989).

BMI was calculated from

$$BMI = \frac{weight\ (kg)}{Height^2\ (m^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(5)}$$

BSA is also calculated from Mosteller formula

$$BSA = \sqrt{\frac{(Height\ (cm)\ x\ weight\ (cm)}{3600)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(6)}$$

as reported by Jeje *et al* (2014) and Nupo *et al* (2013) for each group of the subjects per state. Data analysis was done using SPSS software (version 20) to calculate the minimum, maximum, mean, standard deviation, 5th, 50th, and 95th percentiles.

3. RESULTS AND DISCUSSION

3.1 Anthropometric Characteristics of Women Cassava Peelers in Nigeria

Table 1 shows discrete statistics of the anthropometric data of the 100 subjects. This includes the physical features and the dimensions of body segments relevant to cassava peeling activity. The results are similar to the results obtained in the previous study of a *gari*-frying population of the Southwest Nigeria (Samuel *et al*., 2015). The similarity may be due to the labour-use pattern as previously observed in cassava processing operations whereby the same population that begins the first set of processing steps such as peeling continues the subsequent processing steps. The only exceptions are for grating, dewatering and pressing where a different category of labor is required (Aiyelegun *et al*., 2017). While women dominate peeling, men are often in the majority for grating and dewatering (Aiyelegun *et al*., 2017). The average age of cassava peelers is 45.1 years while the mean height and body-mass were 1.5m and 61.9kg, respectively. Also, 95% of the Subjects were below the age, body-mass and height of 60.05years, 79.81kg and 1.62m, respectively. Similarly, the average Body Surface Area (BSA) The mean Body Mass Index (BMI) also known as the weight-to-height ratio was 22.37 ± 2.04kg/m^2. The value falls within the normal weight category between 18.5-24.9 range for the normal category. Therefore, the energy expenditure could be reliably evaluated for the group.

Table 1: Anthropometric Data of Cassava Peelers (n=100)

Parameter	Mean	Min	Max	CV	Percentile		
					5th	**50th**	**95th**
Age (yrs)	45.07 ± 10.15	18.00	67.00	0.23	37.95	42.00	60.05
Body Mass (kg)	61.9 ± 12.29	39.00	71.50	0.12	50.92	55.50	65.54
Height	154.2 ± 5.03	141.00	180.00	0.04	153.09	157.00	166.15
Shoulder Height (sitting)	54.7 ± 1.84	49.35	59.50	0.03	53.69	54.95	57.40
Eye height (standing)	144.47 ± 5.22	132.00	160.00	0.04	141.72	145.00	151.98
Eye height (sitting)	66.62 ± 2.94	58.40	75.70	0.04	64.63	66.75	70.92
Forward grip reach (standing)	68.26 ± 3.08	59.50	75.50	0.05	66.34	68.00	72.80
Forward grip reach (sitting)	67.10 ± 2.72	60.40	75.10	0.04	65.44	67.15	71.10
Sitting height	77.92 ± 3.07	60.80	87.40	0.04	76.25	78.20	82.45
Butttock-popliteal length	48.83 ± 2.57	40.90	56.70	0.05	47.46	48.95	52.57
Butttock-to-knee length	57.4± 2.84	50.40	66.80	0.05	55.89	57.80	61.66

Popliteal height (sitting)	39.97 ± 2.91	34.30	59.40	0.07	38.40	39.30	44.35
Knee height (sitting)	50.47 ± 2.26	40.92	58.40	0.04	49.12	50.75	53.83
Thigh clearance	13.13 ± 1.88	7.40	18.20	0.14	11.71	13.15	15.96
Forearm-to forearm breadth	42.43 ± 4.24	29.24	59.81	0.10	39.80	42.23	48.68
Waist depth	26.16 ± 10.15	20.70	34.20	0.09	24.74	26.24	29.56
Elbow rest height sitting	17.38 ± 1.99	12.20	23.60	0.11	15.99	17.20	20.29
Knucke height	68.42 ± 2.88	60.00	75.00	0.04	66.99	68.45	72.56
Elbow grip length	34.81 ± 1.46	31.00	38.80	0.04	33.93	34.85	36.96
Hip breadth (sitting)	30.79 ± 2.91	23.63	41.34	0.09	28.81	30.71	35.07
Hand length	10.39 ± 0.73	8.04	12.34	0.07	9.84	10.40	11.43
Hand breadth at thumb	9.37 ± 0.44	8.30	10.65	0.05	9.03	9.38	9.99
Hand breadth at knucles	6.91 ± 0.50	5.45	9.10	0.07	6.52	6.85	7.66
Hand thickness	4.21 ± 0.36	3.20	5.20	0.09	3.90	4.21	4.74
Grip span	2.94 ± 0.27	2.35	3.90	0.09	2.67	2.91	3.32
Hand length @ index	17.33 ± 0.83	15.00	20.00	0.05	16.82	17.45	18.56
Lumbar height	16.39 ± 2.37	10.50	22.60	0.14	14.89	16.65	19.96
BMI	22.37 ± 2.04	17.47	28.15	0.09	20.85	22.07	25.56
BSA	1.55 ± 0.06	1.27	2.15	0.00	1.47	1.55	1.74

While there was a wider variation in age, body mass, and BMI (cv≥0.2), the range is narrower for the rest of the anthropometry data (CV was 0.04-0.14). A similar study by Oduma and Oluka, (2017) using seventeen common female anthropometric data for agricultural workers in Southeast Nigeria for similar range of age group of between 20 and 60 years revealed similar anthropometric data range. There was, however, a wider range observed for the elbow, hip, hand length, hand breadth and popliteal height in that study. This implies that the current data could be a good representation of Anthropometric information for women involved in agriculture or cassava processing activities in Nigeria.

However, analysis of variance comparing differences in anthropometric data among States showed that out of the 27 anthropometric parameters of the Subjects measured, only five parameters (body mass, forearm-to-forearm breadth, waist depth, hand breadth at the knuckle and lumber height) were significantly different ($p<0.05$) among the States. The differences in body mass resulted in differences in BMI and BSA. Women cassava peelers from Kwara State had the least average body mass (51.0 kg), forearm-to-forearm breadth (38.89cm), hand breadth at the knuckles (6.62cm), lumbar height (13.48cm) and BSA (1.45 m^2). On the other hand, cassava peelers from Osun State had the highest average body mass (91.1kg), forearm-to-forearm breadth (50.03cm), waist depth(28.89cm), BMI (37.11 kg/m^2) and BSA (1.90m^2). On the other hands, women cassava peelers from Edo and Ekiti States had the highest handbreadth at knuckle (7.54cm) and lumbar height (17.47cm) while women cassava peelers from Imo and Oyo States had the least waist depth (24.78cm) and BMI (23.06 Kg/m^2). These data seem to suggest that women cassava peelers from Osun State are likely to be more obese than women from the other sampled States.

Anthropometric data collected in the present study were compared with those collected in four regions in Nigeria and India whose age range is fairly similar to provide a good reference upon which the data could be compared.in order to see the variation. Findings confirm variation among regions selected regions of both countries as indicated in Table 2. For example, findings show variation between the weight in the present study and that of India in all its regions, while data collected in other regions in Nigeria is comparatively closer to that in the present study.

Table 2: Comparison of Anthropometric Data in Selected Regions of India and Nigeria

Parameter	Present Study	India				[5]Nigeria			
		N. E. India [1]Meghalaya	[4]Eastern India	[2]Ladakh Region of India	[3]Hyderabad	Abia	Anambra	Ebonyi	Enugu
Age Range	18-67	19-51	18-75	18-60	25-45	20-60			
Body Mass (kg)	61.9 ± 12.29	47± 7.1	NA	49.4±3.4	47.13±7.76	57.2	64	67.1	76.2
Height	154.2 ± 5.03	150.8±4.9	NA	149.8±3.1	153.06±4.92	162.75	163.95	165.8	167.9
Shoulder Height (sitting)	54.7 ± 1.84	NA	NA	NA	NA	50.1	55.4	50.8	51.3
Eye height (standing)	144.47 ± 5.22	NA	NA	NA	141.98±3.21	150.55	155.2	155.1	160.5
Eye height (sitting)	66.62 ± 2.94	NA	NA	60.3±5.6	67.72±2.98	65.4	65.8	64.9	63.4
Forward grip reach (standing)	68.26 ± 3.08	NA	NA	70.4±3.5	63.93±2.92	75.15	71.18	68.7	68.2
Forward grip reach (sitting)	67.10 ± 2.72	NA	NA	NA	NA	NA	NA	NA	NA
Sitting height	77.92 ± 3.07	78.4±4.5	NA	69.5±5.9	78.11±3.33	73.75	71.33	74.2	68.3
Buttock-popliteal length	48.83 ± 2.57	42.3±2.7	NA	40.8±3.4	NA	45.3	46.85	46.2	45.7
Buttock-to-knee length	57.4± 2.84	51.3±2.7	NA	49.2±3	NA	53.95	57.1	46.4	50.7
Popliteal height (sitting)	39.97 ± 2.91	39.4±2.5	NA	33.6±4.3	41.16±1.29	46.45	46.25	481	43
Knee height (sitting)	50.47 ± 2.26	42.8±2.5	NA	NA	44.86±2.21	52.1	54.6	53	44.6
Thigh clearance	13.13 ± 1.88	NA	NA	NA	NA	11.25	12.15	12.1	13.1
Forearm-to forearm breadth	42.43 ± 4.24	NA	NA	NA	NA	NA	NA	NA	NA

Waist depth	26.16 ± 10.15	NA	NA	NA	NA	NA	NA	NA	NA
Elbow rest height sitting	17.38 ± 1.99	22.7±2.9	NA	15.2±1.3	20.59±1.29	22.25	22.5	23.7	24.4
Knuckle height	68.42 ± 2.88	NA	NA	NA	NA	61.65	65.65	64.3	59.7
Elbow grip length	34.81 ± 1.46	30.3±1.6	NA	25.9±2.5	NA	36.45	36.65	31.8	37.4
Hip breadth (sitting)	30.79 ± 2.91	30.5±1.9	NA	34.1±1.6	NA	29.8	31.1	39.4	67
Hand length	10.39 ± 0.73	16.1±0.8	16.09 ± 0.70	15.7±0.9	17.01±1.21	18.15	19.8	18.3	18.9
Hand breadth at thumb	9.37 ± 0.44	9.2±0.6	NA	NA	8.54±0.95	7.2	7.35	6.8	7.6
Hand breadth at knuckles	6.91 ± 0.50	NA	7.30 ± 0.35	NA	NA	NA	NA	NA	NA
Hand thickness	4.21 ± 0.36	NA	2.58 ±0.18	NA	NA	NA	NA	NA	NA
Grip span	2.94 ± 0.27	3.6±0.3	4.80 ± 0.29	NA	NA	4	5.05	4.8	5.4
Hand length @ index	17.33 ± 0.83	NA	NA	NA	NA	NA	NA	NA	NA
Lumbar height	16.39 ± 2.37	NA	NA	NA	NA	NA	NA	NA	NA

[1]Agrawal *et al* (2010)
[2]Diwit *et al* (2014)
[3]Premkumari *et al* (2016}
[4]Kar *et al* (2003)
[5]Oduma and Oluka, (2017)

3.2 Work Flow and Human Kinetic Parameters during Peeling

Table 3 shows the means of the peeling operation parameters for the women peelers (n=100) in all ten states studied for three-time segments. Average peeling output was 74.39kg for a six-hour operation. Peeling output (kg peeled roots), and consequently work rate (kg peeled roots per min), tend to be higher in the morning than the rest of the day. Similarly, resting and working heart rate were slower in the morning and higher during the remainder of the day.

Table 3: Work Flow and Kinetic Parameters within Three-time Segments *(n=100)*

Time Segments	Quantity (Kg)	Work Rate (kg/min)	Resting HR (beats/min)	Working HR (beats/min)	Net HR (beats/min)	Working * V_{O2} (lit/min)
9.00-11:00am	77.55±5.38	0.65±0.05	69.27±4.50	76.98±5.13	7.71±2.42	12.26≤ ≤14.93
12.00-2.00pm	72.79±5.23	0.61±0.04	69.63±4.45	80.33±4.58	10.70±3.22	13.28≤ ≤15.66
3.00-5.00pm	72.83±5.28	0.61±0.05	69.95±4.14	79.24±4.06	9.29±2.41	13.13≤ ≤15.23
Mean	74.39±5.74	0.62±0.05	69.62±4.36	78.85±4.80	9.23±2.97	12.83≤ ≤15.33

*Computed using equation (4)

It can then be concluded that greater energy is expended in the midday while least energy is expended in the early day with higher productivity. Irrespective of the time of the day, working heat rate was greater than resting heart rate with an average net heart rate increase of 9.23±2.97 beats/min between resting and cassava peeling activity.
Apart from resting heart rate, significant differences ($p<0.05$) were observed among the time segments on the quantity of peeled cassava, work rate, working heart rate and net heart rate.
Significant differences were observed among the states on working heart rate and resting heart rate. For all the three time segments, cassava peelers in Ekiti had the least resting heart beat (67 b/m) and working heart beat (74-76 b/m). On the other hand, Oyo and Ondo States, Edo and Imo States, and Edo and Osun States had the highest working heart rates of 79 b/m, 83 b/m and 82 b/m during morning (9.00 and 11.00 am), afternoon (12.00 and 2.00 pm) and evening (3.00 and 5.00 pm) peeling segments respectively. While cassava peelers from Oyo state had the highest work rates in the morning (0.663kg/min) and afternoon (0.639 kg/min), peelers from Delta had the highest (0.640kg/min) in the evening peeling segments. The least working rates were observed in Kwara state (0.630kg/min) in the morning, Edo state (0.5790kg/min) in the afternoon and Ondo state (0.5820 kg/min) in the evening peeling segments.

Working heart rate values are less than 100 beats/min, the threshold which necessitates rest period for workers. The oxygen uptake of the cassava peelers at work was lower in the morning and increased in during the remainder of the day. However, the largest oxygen uptake was 14.21 l/min. The working heart beat compares with the values obtained by Oduma and Oluka (2017) for female agricultural workers in Southeast Nigeria. The heart rate values (< 100 beats/min) suggest that peeling activity is a light task and could be engaged in continuously with different rest periods depending on individuals. Again, the repetitiveness of the job under a sedentary condition, calls for rest within the 8-hour workday, to reduce fatigue and to result in musculoskeletal disorder that could emanate. This working heart rate is directly related to the oxygen uptake, which is an indication of energy expenditure. In this case, the mean heart rate and oxygen uptake in cassava peeling is only about half of the results of findings of Scot and Bend (2004) on forestry stackers. Men have significantly lower resting heart rates than for women. Lower resting heart rates have been reported in athletes (Shin *et al*., 1997; Fagard *et al*., 1999) and in those in the general population who participate in leisure-time sports (Jensen-Urstad *et al*., 1998).

3.3 Posture at the Workstation during Cassava Peeling Activity

The cassava processing sites were observed to have a different layout of the facility in their respective workstations (Figure 1). The common arrangement is to heap the fresh roots at one side or center, and the women peelers sit close-by while picking the roots one-by-one by hand or with a knife and placing the roots after peeling at the opposite side of the heap of unpeeled roots. Most subjects take sitting posture, while a few stand (Fig. 1a). When seated, cassava peelers sometimes stretch, bend or twist to reach the unpeeled roots and discharge the peeled roots. Where the cassava roots are loaded inside a bowl before peeling, discharging the content of the bowl and filling the bowl with unpeeled roots when full often necessitate occasional movements and muscle stretch. This also slows down job flow and could reduce work rate. In general, no standard seat was observed in cassava processing sites as some cassava peelers even seat on the bare floor, a low stool or other sitting objects.that are almost at the height with the unpeeled roots (Figure 1b, c & d).

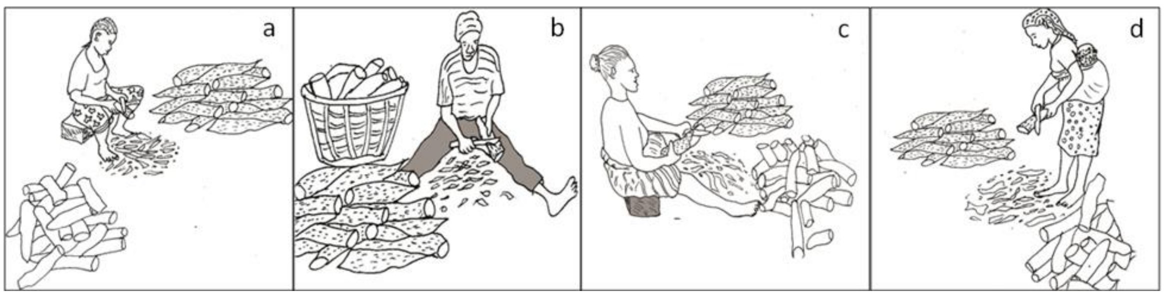

Figure 1: Sitting Postures at Cassava Peeling Sites

Depending on the sitting posture, the knee angle (between the thigh and leg) varies (Fig 1b, c & d) but is usually less than right-angle as opposed to proper sitting posture on a seat that maintains a neutral posture of the trunk. The prolonged static sitting posture at the processing sites was observed as a potential ergonomic risk for musculoskeletal disorders. This engenders fatigue and pains on the musculoskeletal system, thereby reducing the efficiency and productivity of the cassava peeler. This is compounded by the low seat often used, which results in early tiredness and slow of work. This situation requires ergonomic intervention since it is a major constraint to task demand and job flow. Hence there is a need to design more suitable workstation for cassava peeling in the cassava processing industry.
Focus group discussions with the women cassava peelers (FGD) established that accidents and injuries are prevalent in the peeling activity. The most rampant for the novice peeler is finger cut and, generally, pain in the wrist, forearm and shoulder. Knives used are observed to vary from one location to the other. In general, most knife designs put the hand of the peeler at a disadvantaged position while the awkward sitting posture creates ergonomic risks. This risk can be mitigated through redesigning of more appropriate type of knife for cassava peeling. Both the design of the workstation and the tools for cassava peeling must take into consideration physical characteristics of the workers in order to increase productivity and minimize job hazards.

4. CONCLUSION

This study has established that manual cassava peeing is a light task, owing to low energy expenditure calculated from heart rate and oxygen uptake of a human subject during cassava peeling operation. By implication, peeling activity can be engaged-in continuously. However, some ergonomic interventions are needed to prevent the identified ergonomic risks. We, therefore, recommend the use of the participatory approach to implement ergonomic interventions to design more proper ergonomic workstation including proper tools, backrests, and knives for cassava peeling operation to overcome inherent ergonomic risks and increase productivity in the cassava processing industry.

5. ACKNOWLEDGEMENT

This research was undertaken as part of, and funded by, the CGIAR Research Program on Roots, Tubers and Bananas (RTB) and supported by CGIAR Fund Donors.

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Effect of Pre-Treatment and Temperature on the Physical and Functional Properties of Cocoyam Flour

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ABSTRACT

Cocoyam (*Colocasia esculenta*) is a perishable tuber crop used as a staple food among rural dwellers in Nigeria. Processing cocoyam into flour is one of the ways to overcome the problem of high perishability thereby increasing its availability and uses. This study investigated the effect of pretreatment and temperature on the quality of cocoyam flour produced from dried cocoyam slices. Cocoyam slices were pretreated by soaking in 1 % sodium metabisulphite solution (SS) for 10 minutes; steam blanching (SBS) for 2 minutes and a combination of soaking in metabisulphite solution and steam blanching (S&BS) while a portion was left un-pretreated (US) to serve as control. The samples were dried in thin layers in a laboratory oven at temperatures of 50, 60 and 70 ^oC and constant air velocity of 2 m/s. The samples were milled into flour, some physical and functional properties of the flour were determined using AOAC standard and the data obtained was then subjected to analysis of variance. Moisture content of cocoyam flour ranged from 5.43 to 11.5%.The loose and tapped bulk density ranged from 0.44 to 0.61 g/cm^3 and 0.87 to 0.94 g/cm^3 respectively. The particle size raged from 1.53 to 1.7 µm while the angle of repose was between 26.38 and 43.13^o. The method of pretreatment and temperature had significant effect ($P<0.05$) on the moisture content and water absorption capacity of cocoyam flour. However, the pretreatment method only but not temperature had significant ($P<0.05$) effect on fineness modulus, average grain size, bulk density, angle of repose and coefficient of static friction. In conclusion, this study showed that pretreated cocoyam flour samples were significantly different in terms of physical and functional properties from un-pretreated cocoyam flour.

Keywords: Cocoyam, flour, drying temperature, pre-treatment, functional properties, physical properties

1. INTRODUCTION

Roots and tubers which include cassava, yam, cocoyam and sweet potatoes are plants whose edible portions are underground corms and they are generally high in carbohydrate content (Akanbi *et al.,* 2004). Cocoyam (*Colocasia esculent*) belongs to the family Araceae (Akanbi *et al.,* 2004). It is largely cultivated because of its underground corms and cormels (Okpala, 2015; Hahn, 1984). The moisture content of cocoyam at harvest ranges from 63 to 85% (Akanbi *et al.,* 2004). However, it consists of a broader compliment of nutrients when compared to most tuber crops (Akanbi *et al.,* 2004). Nutritionally, cocoyam has broader compliments of vitamins and nutrients than most root and tuber crops and it is a good source of dietary carbohydrates, proteins, vitamins A and C, thiamine, niacin, calcium, phosphorus and iron (Ngoddy and Ihekoronye, 1985). It is however rich in fat in which linoleic acid is the most abundant among the fatty acids (Ngoddy and Ihkoronye, 1985). Cocoyam corms have been reported to contain high contents of potassium and magnesium but they are low in calories (Onwueme, 1994). In spite of its high nutritive value and potential in meeting dietary needs of the populace, it is still underutilized due to its high perishability; and it is regarded as a poor man's food (Olayiwola *et al.,* 2012).

The major drawback in the utilization potentials of this crop is its high moisture content which results in huge postharvest losses. This has led to problems of storage as well as dehydration prior to subsequent processing. There have therefore been a lot of efforts to elongate the shelf life of cocoyam so as to raise it from being food for the poor to a sought after product (Ngoddy and Ihekronye, 1985; Okoye *et al.,* 2009). This can only be achieved if in addition to its consumption at household level, it is also processed to other products; mostly cocoyam flour for other uses. This will in turn enhance food security and value addition for household consumption as well as its potential for export purposes.

The main quality attributes of cocoyam flour are its colour and texture (Akissoe *et al.,* 2003; Hounhouigan *et al.,* 2003). The flesh of cocoyam (*Colocassia esculenta*) is usually white, but according to Akissoe *et al.* (2003) the colour of processed cocoyam flour ranges from creamy white to dark brown. The susceptibility of the flesh of cocoyam to enzymatic browning reaction is the major cause of the darkening which is also an issue of concern in its utilization potential. According to (Olayiwola *et al.,* 2012) the use of onion extract to reduce the occurrence of enzymatic browning reaction in cocoyam flesh is a common practice among rural processors. But its use has been discouraged due to its organoleptic impact. Results from earlier studies on tuber crops (Njintang *et al.,* 2001) have suggested that applications of pre-treatments such as dipping in anti-browning solution, refrigeration, blanching, among others could help reduce or abate this problem. Njintang and Mbofung, (2003) also stressed that the use of two or more pretreatment may be more effective and give a product of higher quality.

The need to widen the scope of information on food processing and preservation has been established by FAO (2006) and the effect of pretreatments on the dehydration of some tuber crops such as yam, potatoes, and cassava dried artificially in heated mechanical air-drying systems have been reported (Das *et al.,* 2001). There is a dearth of information on the influence of pretreatments and temperature on quality of cocoyam flour. Thus, there is need to establish appropriate processing condition for obtaining high quality stable product from cocoyam corms.

Processing of agricultural produce into flour is perhaps the best way of creating a product that is not only functionally good, but also remain for an extended period without spoilage. Flour related products are mostly the staple diet of most countries; hence the availability of flour has often been a major economic issue (Adeleke and Odedeji, 2010). Incorporation of flours from tuber crops into various products together with other cereal flour has been reported (Pangloli *et al.*, 2000). There have been several attempts to use flour from tuber source in different food products such as butter cookies, pretzels, cakes, hotcake mixes, and instant porridges, and as a composite with wheat in the production of noodles and bread (Truong, 1992; Amante, 1993; Collado and Corke, 1996). These products have specific quality requirements, and quality standards for flour from tuber source should be devised for each end use. Therefore, the objective of this study was to investigate the effect of pretreatment and drying temperature on quality characteristics of flour produced from dried cocoyam slices.

2. MATERIALS AND METHOD

Fresh and mature cocoyam corms were obtained from Ilera farm, Ifetedo, Osun State, south western Nigeria. The corms were washed using potable water to remove dirt and other impurities. Thereafter, it was peeled and carefully sliced across the vertical dimension to a thickness of approximately 5 mm. The thickness of the slices was checked using a digital vernier caliper. The samples were then divided into four batches: three for pretreatments and the last as control (untreated).In other to reduce the rate of occurrence of enzymatic browning reaction, Petreatment by sulphiting was carried out using the method described by Adeyemi and Oladiji (2009) with slight modifications. The sliced cocoyam corms were dipped in 1% sodium metabisulphite ($Na_2S_2O_5$) solution for ten minutes, drained and spread in thin layers**.** However, pretreatment by blanching was carried out a using the method described by Aked, (2002). Sliced cocoyam corms were blanched for two minutes to inactivate polyphenol oxidase (the enzyme responsible for the occurrence of browning reaction). Pretreatments using a combination of blanching and soaking was carried out by dipping the cocoyam slices in 1% sodium metabisulphite ($Na_2S_2O_5$) solution for ten minutes, steam blanched for 2 min, drained and spread in thin layers. Figure 1 shows the flow chart for cocoyam flour production. The samples were then dried in a laboratory oven (SM 9023 Surgifriend Uniscope, England) at drying temperatures of 50,60 and 70 ^oC until equilibrium was attained. The dried corms were milled into flour and the physical and quality properties were investigated.

2.1 Determination of quality parameters of cocoyam flour

The results obtained for the quality Parameters are as follow

(a) Moisture content

The moisture content of cocoyam flour was determined using AOAC (2000) standard at 106 ºC for 4 h in a hot air oven (SM 9023 Surgifriend Uniscope, England). Equation 1 was used to compute the moisture content values with w_i and w_f representing the initial weight of sample and weight of dry matter respectively and $M.C_{(db)}$ is the moisture content dry basis.

$$M.C_{(db)} = \frac{w_i - w_f}{w_f} \times 100 \quad (1)$$

(b) Particle size

Particle Size of cocoyam flour was determined using the method of Idowu *et al.* (1996). Test sieves of various apertures (90 µm, 75 µm and 50 µm) as these seieve dimensions were reported as being ideal for the particle size of most flour samples (Idowu *et al.* 1996). The sieve were arranged in ascending order and mounted on the test sieve shaker. As recommended by Idowu *et al.* (1996), 30 g of cocoyam flour was put in the top sieve and covered with the lid. The shaker operated for 30 min to ensure that the particles are thoroughly sifted after which the sieves were removed. The amount of cocoyam flour retained on every test sieve was weighed.

The percentage retention of each sieve was calculated. Mean values were calculated after four replications. The percentage retention was then used to determine the fineness modulus (FM) which is the average size of the particles in the flour expressed as an index number and average grain size (D) using equations 2 and 3.(Adeleke and Adedeji, 2010). The uniformity index was however calculated using the method described by Igbeka, (2013) and Olaosebikan *et al*., (2016).

$$FM = \sum \frac{W * N}{100} \quad (2)$$

$$D = 0.135(1.366)^{FM} \quad (3)$$

Where: W is the weight (g) of sample retained per sieve and N represents the mesh number.

(c) Water absorption capacity

This parameter was used to measure the capability of the flour to retain water. The method of Abbey and Ibeh (1988) was adopted for determining water absorption capacity. One gram of the flour was mixed with distilled water in a centrifuge tube, made up to 10 ml dispersion and allowed to rest at ambient temperature for 30 min. The sample was centrifuged at 3000 rpm in a centrifuge (0502-1 Hospibrand, USA) for 30 minutes so as to ensure thorough sedimentation and also to make decantation process easier. The mean water absorption capacity was obtained after four replications in (g/g) using equation 4.

$$Wac = \frac{final\ weight - initial\ weight}{initial\ weight} \times 100 \quad (4)$$

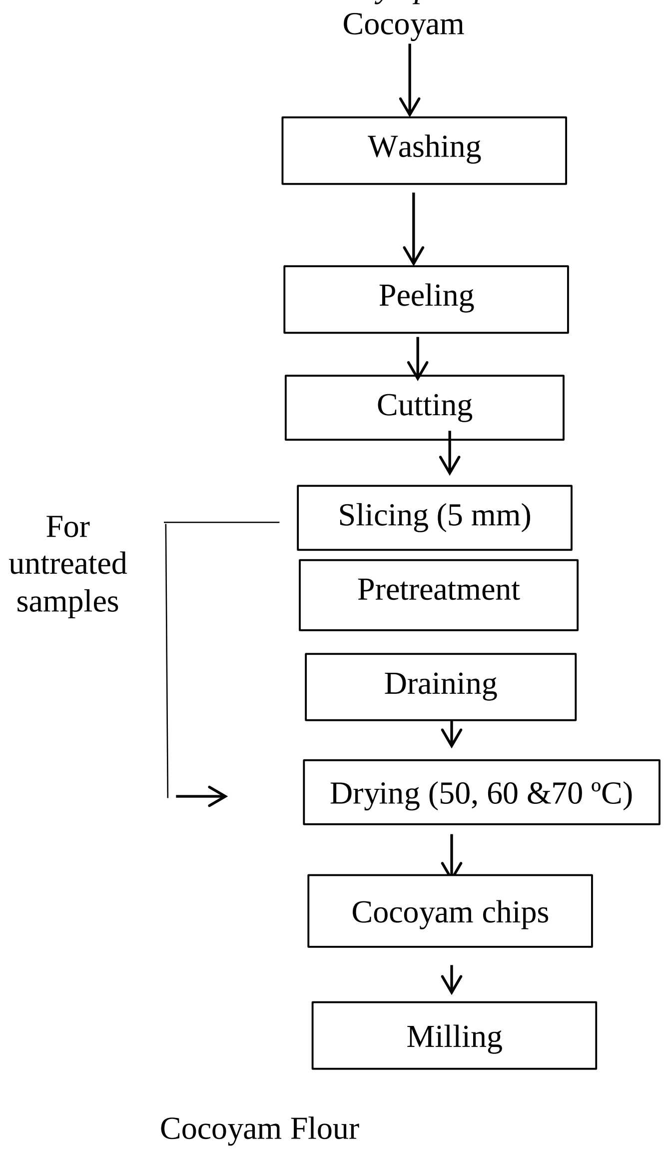

Figure 1: Flow chart for production of cocoyam chips

(d) Gelatinization temperature:

The sequence of changes that occur when starch granules in the presence of water and heat form a paste is known as starch gelatinization and the temperature at which this occurs is known as gelatinization temperature. The method of Okpala *et al*., (2013) was adopted with slight modification for the determination of gelatinization temperature. Twenty five (25) grams of the flour was dissolved in distilled water in a beaker and made up to 100ml dispersion. The mixture was placed on heating mantle and stirred as heating progressed until gelatinization was visually noticed. The temperature of the mixture when hydration and swelling of the starch granule began was recorded as gelling temperature of cocoyam flour.

(e) Bulk density

The method of Njintang *et al.*, (2001) was used to determine the bulk density of the flour samples. Fifty (50) grams of the sample was weighed, placed in a100ml graduated cylinder and the initial volume was recorded. The cylinder was tapped repeatedly for 100 times to a constant volume and the final volume was recorded. The tapped bulk density was calculated as the mass of the sample divided by the volume at the end of tapping. The loose bulk density on the other hand was determined using the initial mass of the sample that filled the cylinder before tapping was done divided by the volume.

(f) Static coefficient of friction (μ) and angle of repose

The coefficients of friction of cocoyam flour against unpolished wood, surface was determined using the Inclined Plane Apparatus. About 5g of cocoyam flour was poured on the test surface which was horizontally glued on the tilting table. The table was gently raised and the angle of inclination to the horizontal at which the sample started sliding was measured with the protractor attached to the apparatus. According to Mohsenin, (1978), the tangent of the angle (equation 5) was reported as the coefficient of friction).

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$$\mu = \tan\theta \tag{5}$$

The method of (Chen and Lu (2004)) was used to determine the angle of repose of cocoyam flour. A cylindrical paper carton with both ends opened was filled with cocoyam flour on a flat surface and was gradually lifted to a distance of about 20 cm until a conical heap of the flour was formed on the flat surface. The emptying angle was calculated from the height and base radius of the heap. The process was carried out 3 times for every sample. The angle of repose (θ) was calculated from the ratio of the height (H_c) to the base radius (D_c) of the heap formed using equation (6).

$$\theta = \tan^{-1}\left(\frac{2H_c}{D_c}\right) \tag{6}$$

2.2 Data analysis

The experimental design was completely randomized block design with two factors and 12 treatments. The data obtained from the study was subjected to analysis of variance (ANOVA) procedure of Steel and Torrie (1980) using windows version of graph pas prism software to test the differences between the mean values obtained for both varied factors (temperature and pretreatment) and Duncan multiple test was used to separate significantly differing means.

3. RESULTS AND DISCUSSION

The results obtained for moisture content, loose and tapped bulk densities, angle of repose, coefficient of static friction, gelatinization, and particle size for cocoyam flour samples are as follows:

3.1 Moisture content

The moisture content of cocoyam flour (Table 1) ranged from 6.6 to to11.15% (dry basis, db) for un-pretreated samples, 5.88- 10.2% for sulphited, 5.97-10.63% for blanched samples and 5.43-9.67% for S&B samples. Un- pretreated samples generally had the highest moisture content values. The moisture content of cocoyam flour also reduced with increasing drying temperature as expected. Amandikwa, (2012) reported the final moisture content of 6.5-13.2% (wet basis, wb) for tannia flour, which was close to the range obtained in the study. Owuamanan, (2010) also reported final moisture content of tannia flour to be within a similar range (8.55-10.62%, wb).

Table 1: Moisture content for cocoyam flour samples

Drying temperature	Sample	MC (%) db	SD
70	control	6.6^{bc}	0.36
60	control	8.59^{abc}	0.34
50	control	11.15^{a}	0.22
70	Sulphited	5.88^{b}	0.23
60	Sulphited	7.55^{abc}	0.25
50	Sulphited	10.20^{ab}	0.95
70	Blanched	5.97^{b}	0.05
60	Blanched	7.05^{bc}	0.75
50	Blanched	10.63^{abc}	0.21
70	S&BS	5.43^{abc}	0.12
60	S&BS	6.49^{bc}	0.17
50	S&BS	9.67^{abc}	0.39

Means with the same letters are not significantly different at $P<0.05$

The moisture content values of flour samples were significantly different ($p \leq 0.05$) for most of the flour samples. However, moisture content for untreated samples was significantly higher ($P < 0.05$) than those of pretreated samples, with S&B samples having the lowest moisture content values. This shows that application of pretreatment aids moisture loss and thus improves drying. The result obtained is in agreement with the reports of Arijono *et al*., (2013) for yam flour. However, higher values moisture content (20.31 - 20.99 % w.b.) were reported by Eje, (2016) for sundried cassava flour.

As presented in Table 2, the combined effect of the method of pretreatment and drying temperature on moisture content was not significant ($P > 0.05$) but the effect of the individual factors at the same significant level were significant.

Table 2. ANOVA for moisture content for cocoyam flour

Source of Variation	SS	Df	MS	F	P-value	F crit
Pretreatment	7.591	3	2.530	7.194	0.0041	3.490
Temperature	82.116	2	41.058	116.727	1.37E-08	3.885
P*T	0.952	6	0.159	0.451	0.8308	2.996
Error	4.221	12	0.352			
Total	94.880	23				

3.2 Loose and tapped bulk densities of cocoyam flour

The tapped bulk density values were generally higher than loose bulk densities by about 43.56%, 44.74%, 44.37% and 43.37% in untreated samples, sulphited samples blanched samples and S&B samples, respectively. As presented in Table 3, the loose bulk density for cocoyam flour samples ranged from 0.46 to 0.57 g/cm^3 for untreated samples, 0.56 to 0.67 g/cm^3 for sulphited sample, 0.44 to 0.61 g/cm^3 for blanched sample and 0.45 to 0.61 g/cm^3 for B&S sample. However, the tapped bulk density ranged from 0.87 to 0.93 g/cm^3 for untreated sample, 0.88 to 0.94 g/cm^3 for sulphited sample, 0.9 to 0.92 g/cm^3 for blanched samples and 0.89 to 0.94 g/cm^3 for sulphited and blanched samples. Generally, lower values of both loose and tapped bulk densities were recorded for samples dried at higher temperatures while higher values were recorded for samples dried at lower temperatures and the lowest values occurring in untreated samples. This trend may be attributed to the higher final moisture content of samples dried at lower temperatures relative to those dried at higher temperatures (Subhash and Hathan, 2014).

Table 3. Tapped bulk density (TBD) and loose bulk density (LBD) of cocoyam flour

Temp(^{O}C)	Sample	TBD (g/cm^3)	SD	LBD (g/cm^3)	SD
70	Control	0.87^f	0.06	0.46^b	0.15
	Sulphited	0.91^c	0.01	0.44^b	0.04
	Blanched	0.88^{ef}	0.06	0.47^b	0.14
	S&B	0.89^{de}	0.03	0.45^b	0.01
60	Control	0.89^{de}	0.24	0.49^b	0.49
	Sulphited	0.90^{cd}	0	0.47^b	0.02
	Blanched	0.89^{cd}	0.01	0.47^b	0.02
	S&B	0.90^{cd}	0.02	0.49^a	0.02
50	Control	0.93^b	0.01	0.57^a	0.01
	Sulphited	0.92^b	0.01	0.61^a	0.03
	Blanched	0.94^a	0	0.56^a	0.07
	S&B	0.94^a	0.11	0.61^a	0.02

Means with the same letters are not significantly different at P<0.05

At 95 % confidence interval, only the temperature had a significant effect on the loose bulk density (Table 4). Hence, application of pretreatment to cocoyam slices does not have a significant influence on the loose bulk density of cocoyam flour. While both the method of pretreatment and the interaction between temperature and pretreatment did not. The result obtained is in agreement with the reports of Adegunwa *et al*., (2010) for sweet potato flour. However both the method of pretreatment and temperature had a significant effect on the tapped bulk density of cocoyam flour and so also did the interaction between temperature and pretreatment. This implies that application of pretreatment and altering drying temperature can alter the tapped density of cocoyam flour. The result obtained is in agreement with the report of Onimawo and Egbekun, 1998.

Table 4: ANOVA for Tapped bulk density (TBD) and loose bulk density (LBD) of cocoyam flour

Factor	**LBD**			**Factors**	**TBD**		
	F	P-value	F crit		F	P-value	F crit
Temperature	0.3024	0.8231	3.4903	**Temperature**	4.535	0.024	3.490
Pretreatment	50.5138	0.0000	3.8853	**Pretreatment**	96.340	0.000	3.885
T*P	1.0150	0.4601	2.9961	**T*P**	4.424	0.014	2.996

3.3 Coefficient of static friction and angle of repose of cocoyam flour

The coefficient of static friction of cocoyam flour on plywood surface was found to increase in samples dried at lower temperatures with values ranging from 0.80 to 0.95 (Table 1) and reduced in samples dried at higher temperature with values ranging from 0.44 to 0.8. This may be due to higher moisture of samples dried at lower temperature and thus might increase its susceptibility to caking. It may also be due to the increase in the cohesive and adhesive forces within the molecules of the samples with increasing moisture content (Njitang *et al.,* 2001). Subhash and Hathan, (2014) reported the coefficient of friction of beet root flour to range from 0.71- 0.78 on plywood surface which was quite close to the range obtained for cocoyam flour in this study.

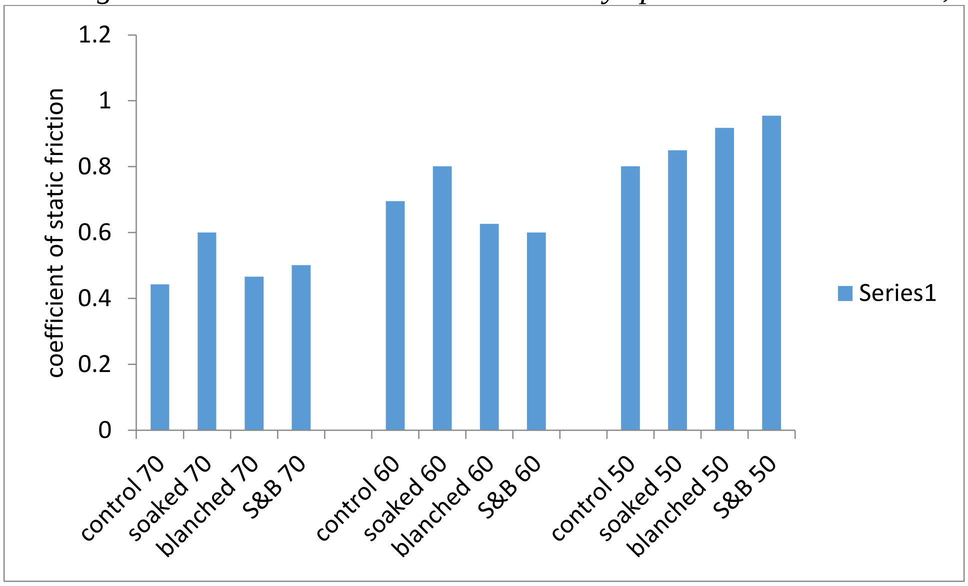

Figure 1: Bar chart showing coefficients of static friction for cocoyam flour

As presented in Table 5, analysis of variance (ANOVA) shows that, both drying temperature and method of pretreatment had a significant effect ($p<0.05$) on the coefficient of static friction. However, the interaction between temperature and pretreatment had a significant effect on the coefficient of friction of the flour.

Table 5: ANOVA result for coefficient of static friction (**COSF**) and angle of repose (**AOR**) of cocoyam flour

Factors	**COSF**			**Factors**	**AOR**		
	F	p-value	F crit		F	P-value	F crit
Temperature	4.15	0.0312	3.49	Temperature	0.1675	0.9163	3.4903
Pretreatment	87.643	6.9E-08	3.885	Pretreatment	7.1643	0.009	3.8853
T*P	3.302	0.0371	2.996	T*P	0.2496	0.9502	2.9961

The effect of temperature on the angle of repose of cocoyam flour is presented in Table 6. The angle of repose of cocoyam flour was found to be higher in samples dried at a lower drying temperature. The values ranged from 26. 38 to 29.88 ^{o}C in samples dried at 70 ^{o}C as compared to 30.75 to 38.25 ^{o} and 38.75 to 43.13 ^{o} in samples dried at 60 and 50 ^{o}C, respectively.

Table 6: Angle of repose of cocoyam flour

T(°C)	Sample	Angle of Repose (°)	SD
70	Control	29.88^{de}	1.5
	Sulphited	26.38^{e}	2.1
	Blanched	28.50^{de}	1.2
	S&B	27.25^{e}	0.4
60	Control	35.13^{bc}	0.9
	Sulphited	32.25^{cd}	0.4
	Blanched	38.25^{ab}	0.4
	S&B	30.75^{cd}	0.4
50	Control	38.75^{ab}	1.1
	Sulphited	41.63^{a}	0.2
	Blanched	39.6^{ab}	0.2
	S&B	43.13^{a}	0.9

Means with the same letters are not significantly different at $P<0.05$

As presented in in Table 1, moisture content of cocoyam flour varied with drying temperature and pretreatment and this is the possible cause of the increasing trend of angle of repose in samples dried at lower drying temperature as samples dried at lower temperatures tend to contain more moisture and the surface layer of moisture surrounding the particle hold them together by the surface tension (Fagbemi and Olaofe, 1998). Subhash and Hathan (2014) stated that the angle of repose for beet root flour was between 54.19 and 55.23 ^{o}. Abbey and Ibeh (1988) reported a decrease in angle of repose with increasing moisture content for cowpea flour. Hence, cocoyam flour contained lower moisture compared to beet root flour.

3.4 Water absorption capacity of cocoyam flour

Results obtained for water absorption capacity for cocoyam flour samples is presented in Table 7. Samples dried at a higher drying temperature had the highest water absorption capacity with the highest value of 3.1 g/g for in sulphited samples dried at 70 ^{o}C while the lowest value 1.69 g /g occured in sulphited and blanched samples dried at 50 ^{O}C. Generally, at all drying temperatures, the highest water absorption capacity was recorded for sulphited samples followed by untreated samples.

Table 7: Water absorption capacity (WAC) of cocoyam flour

T(° C)	Sample	WAC (g/g)	SD
70	Control	2.50[a]	0.07
	Sulphited	3.10[a]	0.04
	Blanched	2.60[a]	0.07
	S&B	2.90[a]	0.01
60	Control	2.60[a]	0.01
	Sulphited	2.90[a]	0.08
	Blanched	2.70[a]	0.01
	S&B	2.80[a]	0.03
50	Control	1.69[b]	0.06
	Sulphited	1.85[b]	0.04
	Blanched	1.72[b]	0.01
	S&B	1.75[b]	0.02

Means with the same letters are not significantly different at $P<0.05$

The trend in the water absorption capacity may be attributed to the degree of influence caused by the presence of disintegration of native starch granule (Njitang *et al.*, 2001) which may have led to the reduction in ability to absorb or retain water. The water absorption capacity obtained in this study compared well with those obtained for *tannia* flour which ranged from 1.5- to 3.7 g/g (Amandikwa, 2012), 2.08-2.42g/g (Owuamam *et al.,* 2010).

Table 8: ANOVA result for water absorption capacity (WAC) and Gelatinization temperature **(GT)** for cocoyam flour

Factors	**GT**			**Factors**	**WAC**		
	F	P-value	F crit		F	P-value	F crit
Temperature	3.061	0.0494	3.49	**Temperature**	0.1675	0.9163	3.4903
Pretreatment	36.096	8.38E-06	3.885	**Pretreatment**	7.1643	0.009	3.8853
T*P	1.566	0.2393	2.996	**T*P**	0.2496	0.9502	2.9961

As shown in Table 8, water absorption capacity of the flours differed significantly ($p<0.05$) with sulphited samples dried at 70 °C having the highest (3.1 g/g) while sulphited and blanched samples (S&B) dried at 50 °C had the least (1.75 g/g). The drying temperature had a significant effect on the water absorption capacity while the method of pretreatment and the interaction between temperature and pretreatment did not. However, sulphited samples gave the highest values of water absorption capacity at all drying temperatures, followed by the untreated samples, and then blanched samples while sulphited and blanched samples gave the lowest values.

3.5 Gelatinization temperature of cocoyam flour

Cocoyam flour dried at 70 °C had the lowest gelling temperatures which ranged from 69.78 to 73.39 °C, followed by those dried at 60 °C with temperatures ranging from 70.13 to 74.44 °C. The highest gelling temperature was recorded in samples dried at 50 °C with temperatures ranging from 76.64 to 79.15 °C as presented in Figure 2. Adegunwa *et al.*, (2010) reported lower gelatinization temperature range (50.20 - 50.25) for sweet potato flour.

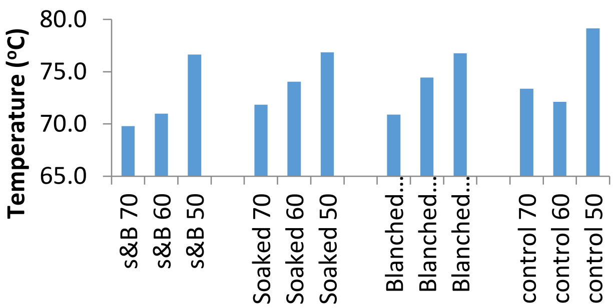

Figure 2. Gelatinization temperature of cocoyam flour

However, gelatinization temperature obtained for cocoyam flour was within the range reported by Owuamanam *et al.*, (2010) which ranged from 63 to 73 °C for tannia flour obtained from tannia slices oven-dried at 70 °C. There was significant difference ($p>0.05$) in gelling temperature of cocoyam between the four methods of pretreatment as determined at 95% confidence interval. The three drying temperature levels also gave a distinctive difference in gelling temperature and this may be due to their moisture content. However, as presented in Table 8, interaction between the two factors (temperature and pretreatment) had no significant effect on the gelatinization temperature.

3.6 Particle size of cocoyam flour

The result of fineness modulus and particle size analysis showed that the untreated sample, blanched sample and S&B samples dried at 50 °C had the highest amount of coarse particles fraction with average grain sizes of 0.167, 0.170 and 0.165 mm, respectively, While the opposite was observed for samples dried at 70 °C (Table 9). It was observed that all the values obtained for each sieve after sieve analysis are significantly different ($p<0.05$). This implies that samples dried at 70 °C comprised of more small particles (less than 0.155 mm) than samples dried at 60 and 50 °C. This may be as a result of the ease of milling of samples with lower moisture content. This trend can be further understood by classifying the percentage of the sample that is made up of fine particles, coarse and medium sized particles (Table 11). This parameter is referred to as the uniformity index of the sample. The presence of relatively large particles of samples dried at 50 ^oC could be attributed to the fact that they are less brittle. This toughness may be because of a relatively higher moisture content of the corms which could result in inefficient milling (Sanni *et al.*, 2006).

Table 9 Fineness modulus and average grain size for cocoyam flour

Temperature	**Sample**	**Fineness modulus**	**Average grain size (μm)**
70	control	0.40	1.53
60	control	0.44	1.55
50	control	0.68	1.67
70	Sulphited	0.38	1.52
60	Sulphited	0.47	1.56
50	Sulphited	0.62	1.64
70	Blanched	0.41	1.53
60	Blanched	0.54	1.60
50	Blanched	0.71	1.70
70	S&BS	0.42	1.54
60	S&BS	0.54	1.60
50	S&BS	0.70	1.65

The range of values obtained for fineness modulus were much more lower than those reported for *gari* with an average value of 4.69 and so also was the average grain size which ranged from (0.7-0.53) mm (Olaosebikan *et al*., 2016).

The uniformity index was quite different from the reports obtained for *gari* as cocoyam flour had more of fine particles than medium and coarse particles (Olaosebikan *et al*., 2016). It has been established that the degree of flour fineness in a milling operation depends on the type and efficiency of the applied machine (Oladunmoye *et al.,* 2010). The small grain size and moisture content of wheat before milling improves milling efficiency and resulted in fine particles. According to Oladunmoye *et al.* (2010), particle size of about 180 μm is suitable for flour intended for baking bread, biscuits and other pastry products. From the current findings, cocoyam flour particle size distribution was within the range expected for food use such as bread and cookie baking. The particle size distribution of flour could be very important for specific applications. Bearing these factors in mind, samples dried at 60 ^oC and 50 ^oC could be best raw materials for products where lower water binding capacity and smooth textures are not as important.

Table 11 Uniformity index for cocoyam expresses in percentage

Texture	**Sample**			
	Control	**Sulphited**	**Blanched**	**S&B**
70 oC Fine (%)	70	70	70	70
Medium (%)	20	30	20	20
Coarse (%)	10	0	10	10
60 oC				
Fine (%)	60	60	60	60
Medium (%)	20	30	30	30
Coarse (%)	20	10	10	10
50 oC				
Fine (%)	50	50	50	50
Medium (%)	30	40	30	30
Coarse (%)	20	10	20	20

4. CONCLUSIONS

Cocoyam slices were made to undergo different pretreatment methods, dried at varying temperature and milled into flour. The effect of temperature and pretreatment on the physical and functional properties of the cocoyam flour obtained was determined. The average moisture content and gelatinization temperature of pretreated samples were lower than un-pretreated samples and were significantly influenced by both factors considered (Temperature and pretreatment). The loose bulk density, tapped bulk density and average grain size of cocoyam flour increased with increasing moisture content and were significantly influenced by only pretreatment method. However the coefficient of static friction and angle of repose increased with increasing moisture content. All S&BS appeared whiter than all other samples. The lowest moisture content, highest water absorption capacity and the lowest gelatinization temperature value was also obtained for S&BS dried at 70^{O}C. Therefore based on these results, a combination of soaking and blanching pretreatment can be recommended for cocoyam processing and the temperature of 70^{o}C can be recommended for drying cocoyam slices.

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6. NOMENCLATURES

FM: fineness modulus
db: dry basis
MCDB: moisture content dry basis
D : average grain size
Wac: water absorption capacity
μ: coefficient of static friction
Ө : angle of repose
ANOVA: analysis of variance
wb: wet basis
mc: moisture content

Development of an Improved Rotary Dewatered Cassava Mash Sifter

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ABSTRACT

Cassava mash sifting, which is an essential process, has been seen as cog in the wheel of gari processing. Hence, this research work aims at developing a rotary cassava mash sifter that will be faster, user-friendly and more convenient for farmers so as to solve the challenges of high product loss (due to spillage or breakage in the sieve), time consumption and unfriendly gender sitting posture resulting in back aches and pains being experienced in the use of traditional raffia sieve to sift cassava mash.The cassava mash sifter consists of hopper, sifting unit (concave cover, sifting mechanism and sieve), frame, mash outlet and chaff outlet. The overall floor dimension of the machine is 1470 mm × 500 mm × 1560 mm. The machine was operated by a 5.5 hp internal combustion petrol engine via belt-pulley transmission system. A performance test was carried out on the machine using dewatered cassava mash at 40.0 % moisture content (wet basis).The rotational speed of the sifting mechanism was 467.0 rpm. Results showed that the machine has an average sifting capacity and sifting efficiency of 176.37 kg/hr and 92.30 %, respectively compared to raffia sieve, which has a respective average sifting capacity and sifting efficiency of 45.35 kg/hr and 55.17 %. The machine was observed to perform efficiently, hence recommended for the small and medium scale cassava processors.

Keywords: Development, improved, rotary, cassava mash, sifter

1. INTRODUCTION

The application of novel post-harvest handling, processing, packaging and storage techniques is of critical importance for successful large-scale production and utilization of cassava roots and products. Successful application of post-harvest technologies will contribute towards maintaining product quality and safety as well as reducing incidence of postharvest losses and, thereby, improve food security (Opara, 2013). Cassava is usually sold as a processed product in form of gari, farinha, fufu, and flour (Ahiakwo *et al*.,2015). The traditional processing of cassava is a labour demanding operation while women and children are the major producers (Agbetoye, 2003). The processing method comprises the combination of the following activities: peeling, boiling, steaming, slicing, grating, soaking, fermenting, pounding, frying, pressing, sifting and drying.

Sifting is a necessary operation. It does not only reduce the lump into fine particles (undersize) which pass through the sieve, but also separates the coarse unwanted particles (oversize) which are discarded after each batch of sieving. Sifting operation causes a great challenge in gari production. To date large percentage of cassava mash lumps is still been sifted manually by rubbing hands on local sieve called 'raffia sieve' (Ajav and Akogun, 2015). The raffia sieve is cheap but needs frequent replaced; has high product loss (due to spillage or breakage of sieve); time consuming and demands an unfriendly gender sitting posture resulting in back aches and pains and hazardous. Jackson and Oladipupo (2013) reported that it takes about three men one hour to sift 1 kg of dewatered cassava mash. Due to this shortcoming of traditional method of sifting, there is need to develop a mechanical means of sifting of cassava mash by simulating the traditional method (Smith *et al*., 1994).Mechanical sieve has been developed by previous researchers to mimic the traditional process of sifting cassava mash. Odigboh and Ahmed (1984) developed a prototype machine for pulverizing and sifting gari mash with a sifting capacity of 125 kg/hr. However, it was reported that it might not be technically suitable for peasant family unit processors, indicating that the machine was complex. Igoni (2000) constructed a continuous flow rotary sieve for dewatered cassava mash. It sieves gari at moisture content of 47.6%. The machine has sifting efficiency of 48.6%, which is not enough for effective operation. Jimoh and Oladipo (2000) also developed a reciprocating sifter which is electrically operated. The machine has a sifting capacity and operating efficiency of 8.0 kg/hr and 61 % respectively. However, the machine could not be used in rural areas where there is no electricity supply. Agbetoye and Oyedele (2007) developed a mash sifter using reciprocating action to shake the cassava cake lumps and pulverize it to allow smaller particles to pass through the apertures of the sieve. Although, this concept is better than the traditional method, some of the limitations are that the trays are uncovered and the quality of the final product is affected because of contamination by foreign particles. In addition, the primary beneficiaries most of whom are small scale processors are unable to effectively utilize and maintain the machines. Sanni *et al*. (2008) developed a rotary pulverizer for cassava cake for gari production.Two different sieve sizes (5 mm and 7 mm) were considered. The efficiency obtained was 81.2 % for 5-mm sieve and 69.0 % for 7-mm sieve. The throughput capacity for 5-mm sieve was 350 kg/hr while 227.71 kg/hr was obtained for 7-mm sieve. The uniformity coefficient of the sifted mash using the 5-mm sieve (1.72) gave a product that compared favourably with that of raffia sieve.Ikejiofor and Oti (2012) evaluated the performance of a combined cassava mash pulverizer/sifter developed by National Root Crops Research Institute (NRCRI). The sifter has a sifting capacity and sifting efficiency of 167.52 kg/hr and 91.2 %, respectively which ar ze high, but effect of sieve aperture on the performance of the machine was considered, since only one sieve aperture (4 mm) was used. Kudabo *et al*. (2012) developed a motorized cassava mash sifter, which was powered by an electric motor with an output capacity of 136.2 kg/hr and 93.3 % sifting efficiency at a sifting speed of 410 rpm. The results obtained from evaluating the machine was silent about the size of the sieve aperture used. Moreover, it was recommended that the receiving outlets should be folded to help gather the sifted materials effectively.Adetunji *et al.* (2013) developed an improved gari sifting machine with a sifting efficiency of 92.5 %.Jackson and Oladipo (2013) evaluated the sifting efficiency of a dewatered cassava mash at different operating speeds developed at National Centre for Agricultural Mechanization (NCAM). The efficiency got was 86.5 % at an operating speed of 650 rpm. Ajav and Akogun (2015) developed a combined dewatered cassava mash lump pulverizingand sifting machine to determine the effect of moisture content, operating speed and mash quantity on the performance of the machine. The results of the analysis revealed that sifting capacity for 5 mm aperture sieve ranged from 56.2 to 97.4 kg/hr, while output capacity for 3 mm aperture sieve ranged from 45.10 to 87.8 kg/hr. Sanni, *et al*. (2016) developed a motorized rotary sifter to pulverize pressed cassava cake and sift out fibre-free cassava meal for gari and cassava flour production.The material recovery efficiency of the machine ranged from 4.79 to 41.30%. The optimum throughput capacity and material recovery efficiency of the machine were231.79 kg/h and 92.98%respectively compared to 56.29 kg/h and 100% for the manual method. The results show that the motorized rotary sifter performs better than the popular manual method in terms of throughput even though there was a slight decrease in material recovery efficiency. In view of these constraints, cassava sifting has been seen as a critical stage in gari processing. Hence, this research work aims at developing an improved rotary cassava mash sifter that will be faster, user-friendly and more convenient for farmers than the existing ones.

2. MATERIALS AND METHODS

The research work was in three stages namely the pre-design experimentation; design, fabrication and machine assembly; and machine testing and evaluation stages.

2.1 Description of the cassava mash sifter

Figures 1, 2 and 3 show the various views of the machine.

2.1.1 The Hopper

This was made of stainless steel sheet with the following dimensions 300 x 300 mm at the top and 170 mm x 170 mm at the bottom with a height of 258 mm. The dimension at the base of the hopper to the concave cover was 170 mm x 100 mm.

2.1.2 The concave cover

The concave cover which is semi-circular in shape was fabricated using stainless steel with length and width of 910 mm × 390 mm respectively. The concave cover will cover the sifting unit so as to prevent splashed cassava mash from being thrown out.

2.1.3 The sifting unit

The sifting unit consists of a solid shaft made of stainless steel, which is 1075 mm in length and 25 mm in diameter. There are 10 mm thick stainless rods alternatively arranged on the shaft to which wire brushes are attached. The stainless rods pulverize the cassava mash lumps by breaking them into smaller particles while the brushes scrape off the mash which may be stocked to the sieve apertures. Also, there are spikes made of stainless steel in-between the first two brushes. These spikes assist in breaking the cassava mash lumps into smaller particles.

2.1.4 The sieve
The sieve which was concave in shape was constructed with gauge 1.5 mm thick stainless steel with a dimension of 890 mm × 680 mm. The sieve aperture was 4.0 mm in diameter. There is a rubber seal in between the concave cover and the concave sieve that prevent cassava mash from escaping from the sifting chamber.

2.1.5 The sifted mash outlet
The sifted cassava mash outlet is made of stainless steel of gauge 1.5 mm with the dimension of 890 mm × 690 mm × 400 mm. It tapers from height 200 mm downward. The outlet is directly below the concave sieve. It is through this place that the sifted cassava mash is collected.

2.1.6 The Residue Outlet (Chute)
This is made of stainless steel sheet of gauge 1.5 mm. It is welded to the main frame at the other end of the sieve where the residue from the cassava mash passes through into the collecting trough. This is 390 × 240 mm in dimension.

2.1.7 The Frame
The frame is made of angle iron (50 mm by 50 mm in size) with length, width and height of 1015 mm, 500 mm and 920 mm respectively.

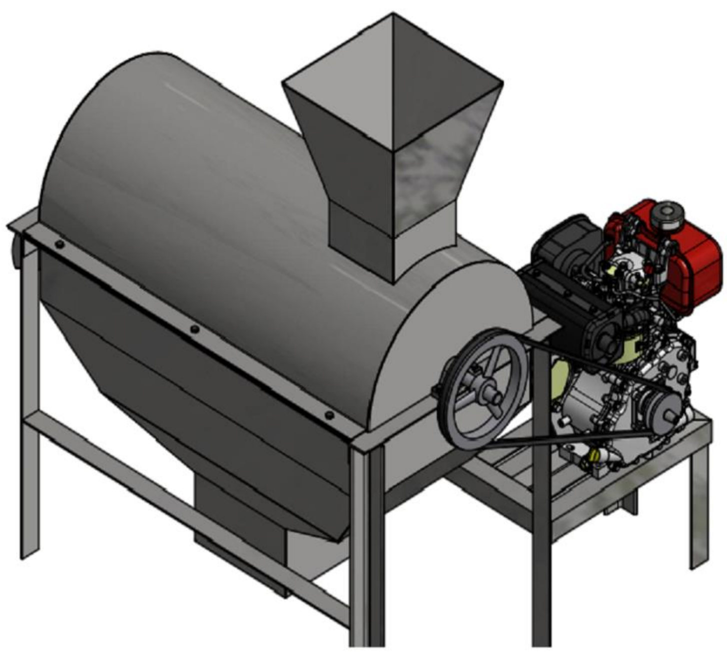
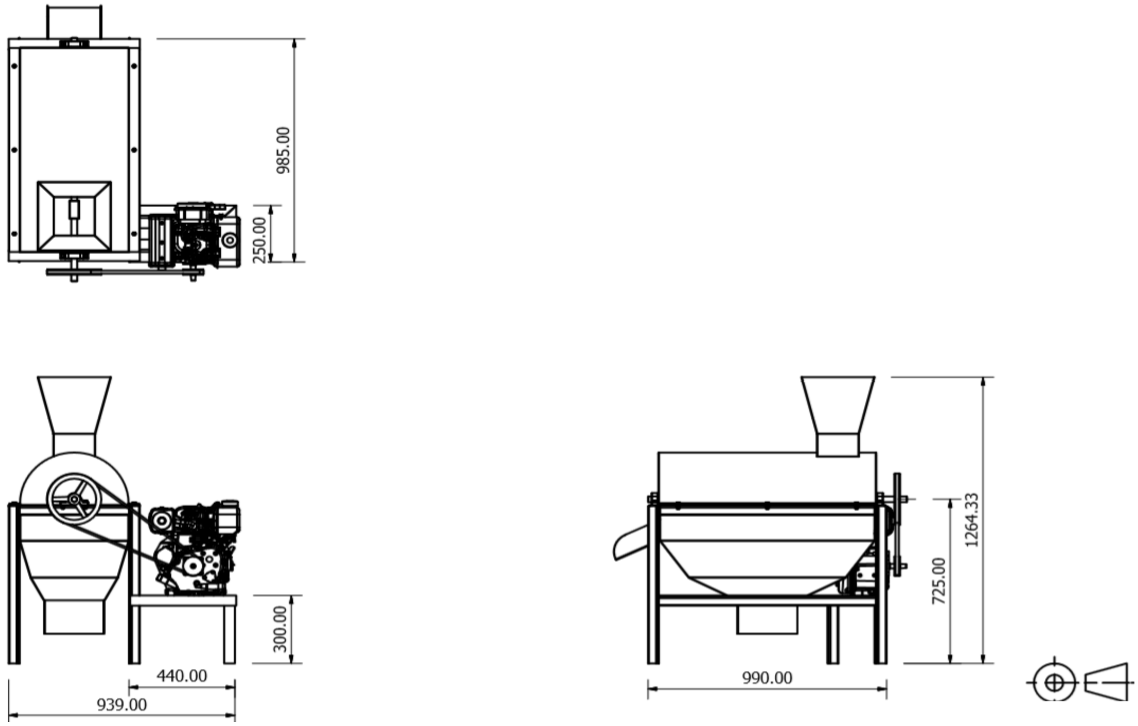
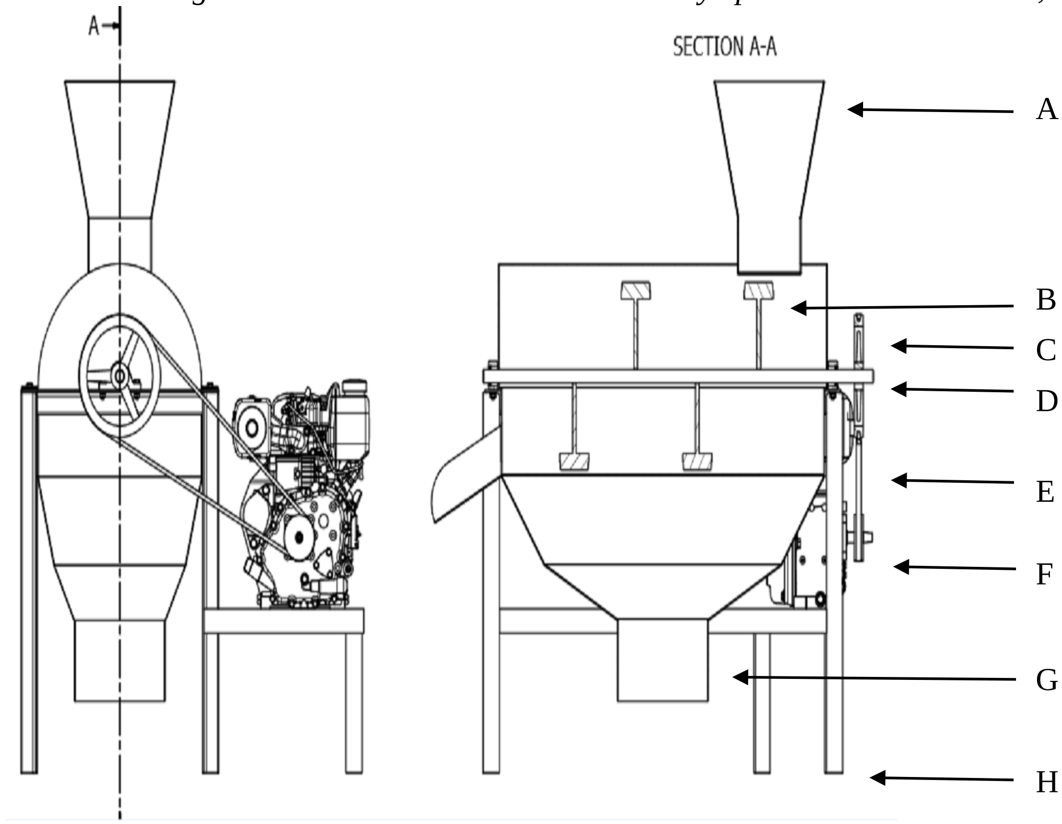


Figure 1: Isometric view of the cassava mash sifter



x- Figure 2 Orthographic view of cassava mash sifter



A – Hopper; B – Spikes with brushes; C – Machine pulley; D – V-belt; E – V-belt: F – Engine pulley; G - Mash outlet; H - Frame

Figure 3 Sectional view of cassava mash sifter (Labeled)

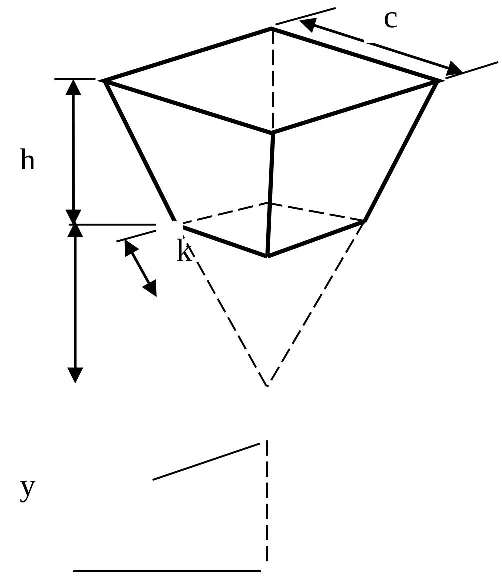
2.2 Pre-design Stage

The pre-design stage involved the characterization of the physical and mechanical properties of cassava mashwhich aided the design of the equipment. Cassava tubers obtained from the Teaching and Research Farm of Oyo State College of Agriculture and Technology, Igboora were processed into mash (that is, peeled, washed, grated, fermented and dewatered). Thereafter, some physical and mechanical properties of the mash related to the equipment design were determined in the laboratory. These include: moisture content (wet basis), bulk density, particle size, and static angle of repose. Each property was replicated thrice and the average value was determined.

2.3 Design analysis

The sifting equipment was thereafter designed using relevant engineering principles, theories and equations. The design of the hopper, shaft, transmission unit and power requirements is as stated below.

2.3.1 Design for hopper



$$\text{Volume of big pyramid} \; = \frac{1}{3}\mathrm{c}^2\,(h+y)$$

Where,

h = 0.258 m, c = 0.3 m, k = 0.17 m

Comparing small and big pyramids using similar triangle formula, the height (y) of the small pyramid can be obtained by $y = \frac{hk}{c-k}$

(1)

$$y = \frac{0.258 \times 0.17}{0.30 - 0.17} = 0.337384615 \text{ m}$$

$$\text{Volume of big pyramid}$$
$$= \frac{1}{3} \times 0.3^2\,(0.258 + 0.337384615)$$
$$= 0.01786\, m^3$$

$$\text{Volume of small pyramid} = \frac{1}{3}\mathrm{k}^2\ \mathrm{y}$$
$$= \frac{1}{3} \times 0.17^2 \times 0.337384615$$
$$= 0.00325\, m^3$$

$$\text{Volume of frustum} \quad = \text{Voume of hopper} = 0.01786 - 0.00325$$
$$= 0.01461\, m^3$$

2.3.2 Design for power transmission shaft

The required diameter for a solid shaft having combined bending and torsional loads is obtained from ASME code equation (Hall, *et al*., 1980) as

$$D^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (2)$$

For a rotating shaft with gradually applied load, the bending fatigue factor K_b= 1.5; torsional fatigue factor K_t = 1.0; Allowable combined shear stress for bending and torsion S_s = 40 MPa for steel shaft with keyway; torsional moment M_t = 55.59 Nm; bending moment M_b = 52.41 Nm (calculated) and D = Diameter of solid shaft (m).
The bending load is due to the weight of pulley (20.012 N), the summation of tensions on the belt acting vertically downward (24.94 N), weight of the solid shaft (41.202 N), weight of spikes and brushes (19.299 N) and weight of cassava mash (196.20 N).
Total load = 41.202 + 19.299 +196.20 + 20.012 +24.94 = 301.65 N
Calculated bending moment = 52.41 Nm.

$$D^3 = \frac{16}{3.142 \times 40 \times 10^6}\sqrt{(1.5 \times 52.41)^2 + (1.0 \times 55.59)^2}$$

$$D = 23.03\ mm$$

The calculated diameter is less than the least chosen diameter (25 mm). Therefore, strength criterion is satisfied.

2.3.3 Determination of Machine's Speed

The machine's speed was selected using the equation for speed ratio as shown in the equation below
:

$$D_e N_e = D_m N_m \qquad (3)$$

Where,

D_e = Diameter of engine pulley (m) = 91.2 mm
N_e = Rotational speed of engine (rpm) = 1300 rpm
D_m = Diameter of machine pulley (m) = 254 mm
N_m = Rotational speed of machine (rpm) (cassava mash sifter)

$$N_m = \frac{91.2 \times 1300}{254}$$

$$= 467\ rpm$$

2.3.4 Power Required to sift, P_t

The power required to sift the cassava mash (P_t) is the summation of the power required to drive the sifting mechanism (P_d) and the kinetic power as a result of the impact of spikes and brushes on the mash (P_i) as shown in the equation below:

$$P_t = P_d + P_i, \qquad (4)$$

but

$$P_d = M_d . gV \qquad (5)$$

$$P_i = 3.99433 M_p R N^2 gV \qquad (6)$$

Where,

M_d= total mass of shaft with spikes and brushes (kg) = 6.17 kg
V = shaft linear velocity = 7.86 ms^{-2}
R = shaft radius = 12.5 mm

N = angular velocity = 10 rps

$P_d = 6.17 \times 9.81 \times 7.86 = 475.75\ W$

$P_i = 3.99433 \times 20 \times 0.001 \times 10^2 \times 9.81 \times 7.86 = 615.98\ W$

$P_t = 475.75 + 615.98 = 1091.73\ W$

Considering a factor of safety of 2,

The design total power requirement for sifting $= 1091.73 \times 2 = 2183.46$ W

$= 2.93\ hp$

The calculated power requirement was 2.93 hp, therefore 5.5 hp petrol engine selected is adequate.

2.2.6 Belt selection

The minimum centre distance,

$C_d = \frac{D_e + D_m}{2} + D_e$ (7)= $\frac{91.2+254}{2} + 91.2$

$=$ 263.8 mm

To take care of bigger pulley, a – 500 mm centre distance is chosen.

The pitch length of the belt

$L = 2C_d + 1.57\frac{(D_e+D_m)}{2} + \frac{(D_m-D_e)^2}{4C_d}$(8)

$$L = (2 \times 500) + \frac{1.57(91.2 + 254)}{2} + \frac{(254 - 100)^2}{4 \times 500}$$

$$L = 1403.50\ mm$$

Angle of contact between the belt and the big (machine) pulley

According to Hall *et al*, (1980), the angle of contact (wrap) between the belt and the big (machine) pulley is given by

$$\propto_1 = 180 + 2\mathrm{Sin}^{-1}\frac{R - r}{C} \quad (9)$$

Where, r = radius of small pulley = 45.6 mm

R = radius of big pulley = 127 mm

C = centre distance = 500 mm

$\propto_1$= angle of contact between the belt and the small pulley (rad)

$\propto_2$= angle of contact between the belt and the big pulley (rad)

$$= 180 + 2\mathrm{Sin}^{-1}\frac{127 - 45.6}{500}$$

$$\propto_1 = 3.45\ rad$$

Angle of contactbetween the belt and the small (engine) pulley

$$\propto_2 = 180 - 2\mathrm{Sin}^{-1}\frac{R - r}{C} \quad (10)$$

$$= 180 - 2\mathrm{Sin}^{-1}\frac{127 - 45.6}{500}$$

$$\propto_2 = 2.83\ rad$$

Determination of Linear Velocity of Belt

Linear velocity of belt is given by

$V = \omega r = \frac{\pi d N}{60}$ (11)

Where,

V = linear velocity of belt (m/s)

ω = angular velocity of belt (rad)

r = radius of small pulley (m)

d = diameter of small pulley (m)

N = number of revolution of small pulley per minute

$$V = \frac{\pi \times 0.1 \times 1500}{60}$$

$= 7.855\, m/s$

$\approx 7.86\, m/s$

Determination of tension in the tight side

To obtain T_1 and T_2, the following equations are solved simultaneously:

$(T_1 - T_2)V = P_t$ (12)

and

$\frac{T_1 - mv^2}{T_2 - mv^2} = e^{\mu\alpha/\sin\theta/_2}$ (13)

Where,

T_1 = tension in the tight side

T_2 = tension in the slack side

$m = bt\rho$

Where,

b = belt width = 17 mm

t = belt thickness = 11 mm

ρ = belt density = 970 kg/m^3 for leather belt

$m = 17 \times 11 \times 10^{-3} \times 970 = 0.18139$

$m \approx 0.18\, kg/m$

θ = 40 deg. (most common angle of groove)

For big pulley,

$$e^{\mu\alpha_{1}/\sin\theta/_2} = e^{(0.15\times 3.45)/\sin 40/_2}$$

α_1 = 3.45, μ = 0.15, θ = 40 deg.

$$= e^{0.5175/_{0.3420}} = e^{1.513158} = 4.54$$

For small pulley,

$$e^{\mu\alpha_{2}/\sin\theta/_2} = e^{(0.15\times 2.83)/\sin 40/_2}$$

α_2 = 2.83, μ = 0.15, θ = 40 deg.

$$= e^{0.4245/_{0.3420}} = e^{1.241228} = 3.46$$

The pulley with smaller value governs the design. In this case, the smaller pulley governs the design.

$$\frac{T_1 - mv^2}{T_2 - mv^2} = 3.46$$

$$\frac{T_1 - (0.18 \times 7.86^2)}{T_2 - (0.18 \times 7.86^2)} = 3.46$$

$$3.46(T_2 - 11.12) = T_1 - 11.12$$
$$3.46T_2 - 38.4752 = T_1 - 11.12$$
$$3.46T_2 - T_1 = 27.3552$$

But $Power(kw) = (T_1 - T_2)V$

$$2.18 = (T_1 - T_2)7.86$$
$$T_1 - T_2 = 0.278$$
$$T_1 = 0.277 + T_2$$

Substituting the value of T_1 in the equation above

$$3.46T_2 - (0.277 + T_2) = 27.3552$$
$$2.46T_2 = 27.6322$$

$T_2 = 11.23\ N$

From,

$$T_1 = 0.277 + T_2$$
$$T_1 = 11.51\ N$$

2.4 Fabrication and assembly of the machine

The equipment was fabricated in the workshop of the Agricultural and Bio-Environmental Engineering Department, Oyo State College of Agriculture and Technology, Igboora, Nigeria. Marking out of materials was done using rule and scriber. Operations as cutting, drilling, welding and machining were done using essential equipment. The various components were thereafter assembled. The cassava mash sifter consists of hopper, sifting unit (concave cover, sifting mechanism and sieve), frame, mash outlet and chaff outlet as shown in Figures 1, 2 and 3. The overall floor dimension of the machine was 147.0 cm × 50 cm × 156.0 cm. The machine was operated by a 5.5 hp internal combustion petrol engine via belt-pulley transmission system. The engine was selected for its availability, durability, relatively cheapness and convenience to power the machine after design calculations. The machine required a total of about 2.18 kW power for its operation.

The materials used for the fabrication of the cassava mash sifter include25mm diameter stainless steel solid shaft, 250 mm pulley, belt, 25mm bearing/casing, 50 × 50 × 50 mm angle iron, galvanized steel plates, stainless steel plates, mild steel angle bar, synthetic brushes, stainless steel rods, 4-mm sieve, bolts and nuts. Table 1 showed the bill of quantity for the fabrication of the machine. The analysis of the material selection is shown in Table 2.

Table 1 Bill of quantity of the equipment

Material	Specification	Quantity	Unit cost (₦)	Total cost (₦)
Sheet metal (Stainless steel)	1.5 mm	1	24,000	24,000
Angle iron (mild steel)	50 ×50 mm	2	2,800	5,600
Belt	Reinforced leather	1	600	600
Pillow Bearing	[redacted]mm	2	3,000	6,000
Pulley (cast iron)	[redacted] mm	1	2,000	2,000
Shaft (stainless steel)	[redacted]mm	1	8,000	8,000
Spikes (stainless steel)	[redacted]mm	1	2,000	2,000
Brush (synthetic)		8	220	1,760
Electrode	Gauge 12 (packet)	1	2,300	2,300
Hacksaw blade		2	700	1,400
Bolt and nut	M 17	10	20	200
Bolt and nut	M 19	6	30	180
Paint (gallon)		½	2,300	2,300
Petrol engine	5.5 hp	1	30,000	30,000
Transportation				5,000
Machining				5,000
Welder’s workmanship				20,000
Total				**116,240**

2. 5 Operation of the Machine

When the prime mover (internal combustion petrol engine) is started, it propels the shaft by transferring power via the belt-pulley transmission system and cassava mash is introduced through the hopper. As the mash flows down by gravity into the sifting chamber the lumps are broken up by the spikes in between the first two brushes and further broken up by the spikes that carry the brushes and the cassava mash is finally rubbed on the sieve by brushes. The sifted mash thatwas less than the size as the sieve aperture passed through the sieve and came out from the sifted mash outlet while bigger ones which are the ungrated cassava root parts and fibres (residues) were retained on the sieve and then transfered to the residue outlet by the brushes which also seved as conveyors

Table 2 Material selection for fabrication of cassava mash sifter

S/N	Machine Component	Suitable Engineering Material	Criteria for selection	Material selected	Remark
1.	Hopper	Stainless steel, galvanized steel	Corrosion resistance, workability	Stainless steel	Prevent food poisoning and corrosion
2.	Frame	Mild steel angle iron	Strength and rigidity	Mild steel angle iron	Strong and Rigid
3.	Pulley	Cast iron, mild steel, wood, forged iron and aluminum	Strength, availability and cost effectiveness	Cast iron	Strong and readily available
4	Belt	Rubber, leather	Strength and flexibility	Rubber	Strong and Flexible
5.	Bearing	P205	Axial loading	Ball bearing	Accommodate axial loading
6.	Pulverizing / Sifting Chamber	Stainless steel, galvanized steel	Corrosion resistance, workability	Stainless steel	Prevent food poisoning and corrosion

2.6 Machine testing and evaluation stage

Freshly harvested cassava tubers was obtained at the Teaching and Research Farm of Oyo State College of Agriculture and Technology, Igboora.. The cassava tubers were peeled manually using knife, washed manually and grated using cassava grating machine. Obtained mash was

thereafter put in sacks and allowed to ferment. for three days (Akinoso and Olatunde, 2014). The cassava mash was dewatered to moisture content level of 40.0 % wet basis (Odigboh, 1981; Akande *et al*., 2004) using hydraulic press. The dewatered cassava mash was sieved with the cassava mash sifter with a sieve aperture of 4.0 at a machine speed of 467 rpm. The machine speed was selected using speed ratio as indicated in the design analysis. Each sample of cassava mash was weighed on the balance to 10 kg. This was poured into the sifting unit through the hopper. The machine was then operated until the cassava mash was completely sieved. The time taken for complete sieving was noted and recorded using a stop watch. The sifted mash and the chaff were weighed and recorded. These procedures were done in three replicates. These procedures were also carried out using raffia sieve to sieve the cassava mash, as a control to compare the performance of the machine at moisture content of 40.0 % (wet basis) being the most suitable moisture content for sieving cassava mash (Ajibola, et al., 1987). This was because sifted mash from raffia sieve is in conformity with the acceptable standard required by gari processors and consumers. At the end of the test analysis the following parameters were determined. Average throughput capacity**(**which represents the quantity of the mash fed into the machine per hour); Average sifting capacity (which represents the quantity of the mash sifted by the machine per hour); and average sifting efficiency (which represents the ratio of sifting capacity to throughput capacity expressed as a percentage). These were determined by the equations below:

$$Average\ throughput\ capacity = \frac{Weight\ of\ mash\ fed\ into\ the\ machine}{Time\ taken\ to\ comlete\ sifting} \quad (14)$$

$$Average\ sifting\ capacity = \frac{Weight\ of\ sifted\ mash}{Time\ taken\ to\ comlete\ sifting} \quad (15)$$

$$Average\ sifting\ efficiency\ (\%) = \frac{Average\ sifting\ capacity}{Average\ throughput\ capacity} \times 100\% \quad (16)$$

Experiments were also performed to compare bulk density, average grain size, fineness modulus and uniformity coefficient obtained both from rotary sifter and raffia sieve, since these are the important quality parameters to assess the quality of the sifted mash before garification.After sifting, a measuring cylinder of known volume was filled with sifted mash from rotary sifter and raffia sieve. Weight of the sifted mash was determined. The ratio of the weight of the material to the volume of the cylinder gave the bulk density of the sifted mash (Mohsenin, 1978). This experiment was replicated thrice and the average value was determined.The fineness modulus and average grain size of sifted mash were determined from a sieve analysis experiment carried out in accordance with American Associaion of State Highway and Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM) standards (Sanni, *et al*., 2008). A set of seven standard ASTM-E11 sieves with nominal openings of 4.75, 2.36, 2.00, 1.70 1.18, 0.85 and 0.50 mm and pan was used for the analysis. The sieve set containing a weighed sample (200.0g) of sifted mash was shaken for 10 minutes in an Endocott sieve shaker for proper distribution.The fineness modulus and average grain size for the materials from both the rotary sifter and raffia sieve were determined for comparison (Bowles, 1978; Henderson and Perry, 1980). The experiment was replicated thrice.

3. RESULTS AND DISCUSSION

Table 3 showed the summary of the results of the pre-design experiments.

Table 3 Design related physical properties of cassava mash

Property	**Value**
Moisture content (%, w.b.)	40.00 ±0.471
Bulk density (kgm^{-3})	1250.00 ±2.828
Angle of repose (º)	42.00 ± 0.943
Particle size analysis (mm)	0.45 ± 0.014

Results of the experiments were collated and the mean values were recorded below.The bulk densities after sifting were 517.2 kg/m^3 and 516.9 kg/m^3 for the 4-mm sieve and the raffia sieve, respectively. These results indicate that with 4-mm sieve in the machine, a sifted cassava mash of about the same bulk density with that of raffia sieve was obtained. This implied that using a 4-mm sieve on the machine gives the desired end product as that of the raffia sieve.Table 4 showed the sieve analysis data for the sifted cassava mash underflow using the rotary sifter and raffia sieve. The fineness modulus of sifted cassava mash from the sifter using 4-mm and that from the traditional raffia sieve were 2.08 and 2.17 respectively. The results show close values of fineness modulus for the 4-mm sieve and the raffia sieve, indicating that the fineness modulus of sifted mash from both were very similar. Table 5 indicates the respective fineness modulus of the retained particles on the raffia sieve and the sieve of the sifter (i.e. overflow) after sieving as 4.77 and 4.66. This shows that the retained particles on raffia sieve and the sieve of the rotary sifter are usually composed of fibres and unbroken lumps of cassava mash.From the results on Tables 4 and 5, it has shown that the 4-mm sieve on the sifter produced an underflow of sifted material similar in size and texture to that of raffia sieve but an overflow that was not well sifted.

Table 4 Sieve analysis of sifted mash (underflow) from rotary sifter and raffia sieve

Sieve (mm)	**Weight retained (kg)**		**Percentage retained (%)**		**Multiplying Modulus**	**Percentage retained × Multiplying Modulus**	
	4-mm sieve	**Raffia sieve**	**4-mm sieve**	**Raffia sieve**		**4-mm sieve**	**Raffia sieve**
4.75	2.65	2.10	1.33	1.05	7	9.31	7.35
2.36	13.31	14.56	6.66	7.28	6	39.96	43.68
2.00	7.38	10.97	3.69	5.49	5	18.45	27.45
1.70	8.79	10.85	4.40	5.43	4	17.60	21.72
1.18	32.55	33.96	16.28	16.98	3	48.84	50.94
0.85	41.23	37.81	20.62	18.91	2	41.24	37.82
0.50	64.47	55.27	32.24	27.64	1	32.24	27.64
Pan	29.62	34.48	14.81	17.24	0	0	0
					Total	207.64	216.6
					FM	2.08	2.17
					Average. size	0.44	0.47

Table 6 showed the performance indices of cassava mash sifter with 4-mm sieve.The machine has an average sifting capacity and sifting efficiency of 176.37 kg/hr and 92.30 %, respectively compared to raffia sieve, which has a respective average sifting capacity and sifting efficiency of 45.35 kg/hr and 55.17 % as shown in Table 7. This result indicated that the rotary sifter was almost four times faster than raffia sieve in sieving cassava mash. Also in terms of efficiency, the rotary sifter was almost twice more efficient than the raffia sieve. Based on these results, the machine could be used to sift at least 1.41 tons of cassava mash/8-h working day compared to 0.36 tons/8-h for raffia sieve. This was an indication that it performed far better than the traditional raffia sieve.

Table 5 Sieve Analysis of Retained Particles (Overflow) from Rotary Sifter and Raffia Sieve

Sieve (mm)	**Weight retained (kg)**		**Percentage retained (%)**		**Multiplying Modulus**	**Percentage retained × Multiplying Modulus**	
	4-mm sieve	**Raffia sieve**	**4-mm sieve**	**Raffia sieve**		**4-mm sieve**	**Raffia sieve**
4.75	58.95	62.85	29.48	31.43	7	206.36	220.01
2.36	49.76	53.28	24.88	26.64	6	149.28	159.84
2.00	12.48	9.88	6.24	4.94	5	31.20	24.70
1.70	10.32	8.96	5.16	4.48	4	20.64	17.92
1.18	16.86	14.84	8.43	7.42	3	25.29	22.26
0.85	22.75	19.78	11.38	9.89	2	22.76	19.78
0.50	21.14	24.83	10.57	12.42	1	10.57	12.42
Pan	7.74	5.58	3.87	2.79	0	0	0
					Total	466.10	476.93
					FM	4.66	4.77
					Average. Size	2.63	2.84

$$Fineness\ Modulus\ (FM) = \frac{\sum_1^7 (\%\ retained\ \times multiplying\ modulus)}{100}$$

$$Average\ size = 0.1041(2)^{FM}$$

(Source: Henderson and Perry, 1980)

Table 6 Performance Evaluation Indices of Cassava Mash Sifter with 4-mm sieve

Replicate	Moisture content (%, w.b.)	Machine speed (rpm)	Initial weight of mash (kg)	Sifted weight (kg)	Sifting time (min)	Throughput capacity (kg/hr)	Sifting capacity (kg/hr)	Sifting efficiency (%)
1	40.0	467.0	10.0	9.25	3.17	189.27	175.08	92.50
2	40.0	467.0	10.0	9.21	3.12	192.31	177.12	92.10
3	40.0	467.0	10.0	9.23	3.13	191.69	176.93	92.30
Mean				9.23	3.14	191.09	176.37	92.30
S.D.				0.0163	0.0216	1.3116	0.9202	0.1633

Table 7 Performance Evaluation Indices of Raffia sieve

Replicate	Moisture content (%, w.b.)	Initial weight of mash (kg)	Sifted weight (kg)	Sifting time (min)	Throughput capacity (kg/hr)	Sifting capacity (kg/hr)	Sifting efficiency (%)
1	40.0	2.00	1.08	1.42	84.51	45.63	53.99
2	40.0	2.00	1.13	1.50	80.00	45.20	56.50
3	40.0	2.00	1.10	1.46	82.19	45.21	55.01
Mean		2.00	1.10	1.46	82.23	45.35	55.17
S D			0.021	0.033	1.841	0.200	1.031

4. CONCLUSION

The 4-mm sieve produced sifted cassava mash of about the same bulk density with the one obtaineable using raffia sieve. This implied that the 4-mm sieve gives the desired end product as that of the raffia sieve. The 4-mm sieve on the sifter also produced an underflow of sifted material similar in size and texture to that of raffia sieve but an overflow that was not well sifted.

The rotary sifter was almost four times faster than raffia sieve in sieving cassava mash. Also in terms of efficiency, the rotary sifter was almost twice more efficient than the raffia sieve. Based on these results, the machine could be used to sift at least 1.41 tons of cassava mash/8-h working day compared to 0.36 tons/8-h for raffia sieve. This was an indication that it performed far better than the traditional raffia sieve.

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Biomass: A Review of Different Methods of Conversion of Biomass into Various Economic Resources

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ABSTRACT

Biomass takes the form of residual stalks, straw, leaves, roots, husk, nut or seed shells, waste wood and animal husbandry waste. Widely available, renewable and virtually free. Aside from being carbon neutral, the use of biomass for energy reduces dependency on the consumption of fossil fuel; hence, contributing to energy security and climate change mitigation. Biomass is still largely underutilized and left to rot or openly burned in the fields, especially in Nigeria that do not have strong regulatory instruments to control such pollutive practices. There are advantages in the use of biomass. Some benefits of biomass include; Production of particle board and straw board which is used for making doors, furniture and cabinets. In addition, Biogas production by anaerobic decay of organic materials from manure (human and animal waste). Gasification is also another resource of biomass involving the process of burning of biomass fuels (human, animal and agricultural wastes) at very high temperatures with a limited supply of oxygen so that the burning process is only partially completed and environmental friendly. Biomass Combustion as a result of biomass fuel (agricultural residue) has been used to burn biomass in a furnace or boiler to produce high pressure steam that passes into a steam turbine in order to produce electricity and also used to produce hot water for goods processing. Briquette has been used to provide an alternative to burning wood for heating and cooking. Agricultural residues has also been used to produce ruminant feeding, absorbent for industrial effluents treatment, grain storage structure and regulation and reduction of geothermal temperature of farm structures. The abundantly available agricultural and wood residues can efficiently be used for resolving energy problems to a significant extent by adopting proper measures.

Keywords: Biomass, Agricultural residues, resources, briquette, renewable energy

1. INTRODUCTION

Agriculture contributes 40% of Nigeria Gross Domestic Product (GDP) and employs about 70% of the working population (CIA, 2012). Since 70% of the population is employed in the agricultural sector, economic growth will almost be impossible to achieve without developing the sector. Furthermore, the importance of agriculture to the Nigerian economy is evident in the nation's natural endowments in production factors – extensive arable land, water, human resources, and economy growth (Tolulope and Chinonso, 2013). Apart from the normal land cultivation and rearing of animals practice, new trends have been discovered which is changing the status quo of agriculture as an industry. Biomass, today have become an alternative source of energy of which is a derivative of Agricultural activity. The importance of biomass should not be ignored as it is becoming a big sector in contributing to value added agriculture. The Production and contribution of biomass at present in Nigeria have been estimated to be about 8×10^2 MJ (Ikuponisi, 2013). This could increase when certain agricultural by-products are taken into account and the small and scattered agricultural holdings are generally harness together. Conversion of biomass wastes and residues to energy provides great environmental benefits by reducing the amount of air pollution, greenhouse gas emissions, and landfill use associated with their disposal, by promoting healthier forests, contributing to rural economies, and displacing the use of fossil fuels.

Biomass is any organic matter—wood, crops, seaweed, animal wastes—that can be used as an energy source. Biomass gets its energy from the sun. All organic matter contains stored energy from the sun. During a process called photosynthesis, sunlight gives plants the energy they need to convert water and carbon dioxide into oxygen and sugars. These sugars, called carbohydrates, supply plants and the animals that eat plants with energy. Biomass is a renewable energy source because its supplies are not limited. We use four types of biomass today—wood and agricultural products, solid waste, landfill gas and biogas, and alcohol fuels (like Ethanol or Biodiesel).

Biomass energy conversion can be considered very important as it can bring higher investment opportunity and increase in national income. Biomass energy conversion also improves waste management system (Production, collection, transfer, storage, treatment and utilization). Andre (2006) reported that Biomass conversion technologies currently deployed may play a key role in the future, including possible linkage to CO_2 capture and sequestration technology. As a result of this strive; special attention should be paid to production of bio fuels because this is likely to become the key emerging market for large-scale sustainable biomass use. Although, he alliterated that the actual role of bio-energy will depend on its competitiveness with fossil fuels and on agricultural policies worldwide, which seems realistic to expect that the current contribution of bio-energy per year will increase considerably making biomass a more important energy supply option than mineral oil today. He however concluded by saying that a key issue for bio-energy is that its use should be modernized to fit into a sustainable development path, especially in the production of electricity via advanced conversion concepts (i.e. gasification and state-of-the-art combustion and co- firing) and modern biomass which derived its fuel like methanol, hydrogen and ethanol from ligno-cellulosic biomass, which can reach competitive cost levels within 1–2 decades (partly depending on price developments with petroleum). Sugar cane based ethanol production already provides a competitive bio fuel production system in tropical regions and further improvements are possible. Flexible energy systems, in which biomass and fossil fuels can be used in combination, could be the backbone for a low risk, low cost and low carbon emission energy supply system for large scale supply of fuels and power and providing a framework for the evolution of large scale biomass raw material supply systems. The gasification route offers special possibilities to combine this with low cost CO_2 capture (and storage), resulting in concepts that are both flexible with respect to primary fuel input as well as product mix and with the possibility of achieving zero or even negative carbon emissions. Biomass market development, consistent policy support and international collaboration are essential to achieve this.

2. MATERIALS AND METHODS

Many researchers have developed various kinds of methods of biomass conversion into various economic uses in order to meet the need of man. The general methods of biomass waste conversions are physico, chemical, thermo chemical and bio chemical. Here, a number of studies have demonstrated the application of these conversions methods use for manufacturing or production of new products.

2.1 Physico chemical Conversion

The physio chemical technology involves various processes to improve physical and chemical properties of solid waste. The combustible fraction of this waste is converted into high energy fuel pellet or briquette which is use in the generation of fuel energy. According to Grover and Mishra (1996), briquetting is one of the several agglomeration techniques which are broadly characterized as densification technologies.

Agglomeration of residues is done with the purpose of making them more dense for their Use in energy production. Raw materials for briquetting includes waste from wood Industries, loose biomass and other combustible waste products. On the basis of Compacting, the briquetting technologies can be divided into:

1. High pressure compacting,
2. Medium pressure compacting with heating device,
3. Low pressure

Maih *et al* (1999) conducted a study on rice husk briquettes at Sylhet, Khulna and Dinaj Pur districts of Bangladish in order to identify the problems and prospects of using the briquettes as an alternative fuel for cooking. Rice is the staple food for the people of Bangladish. The total annual production of paddy is about 28million tonne (FAO, 1992) and about 20% of this (5.6million tonne) is rice husk. The study also concluded that to prevent environmental hazards caused by rapid deforestation activities, rice husk briquettes may be introduced as an alternative fuel which is smoke free, less hazardous, high calorific value and comparatively cheap.

Inegbenebor (2002) compressed fibrous agricultural and wood waste materials with suitable adhesive into briquettes in a compressing machine, which was designed and constructed for this purpose. Nine samples of fibrous waste materials were prepared into different categories: - (100% saw-dust, 100% rice-husk, and 50-50% rice-husk/sawdust), using starch as adhesive for category A, while category B employs gum Arabic as adhesive and category C used bentonite as adhesive. The results from water boiling test (WBT), involving comparison of the burning abilities of the solid fuel briquettes and fire wood of the same quantity (200 grams) in boiling 1.5liters of water. Results showed that the solid fuel briquettes bound with each of the three adhesives; boiled water within a period of 14 to 22 minutes. While, firewood boiled the same quantity of water within a period of 22 to 27 minutes. The open flame test showed that the solid fuel briquettes bound with starch burnt with bluish yellow flame with little black smoke. The solid fuel briquettes bound with gum Arabic and bentonite burnt with yellow flame with moderate black smoke.

Olorunnisola (2004) carried out, a study involving experimental production of briquettes from chopped rattan strands mixed with cassava starch paste. Samples of rattan strands of mixed species (*Laccosperma secundiforum and Eresmopatha macrocarpa*) were collected from a furniture workshop in Ibadan, Oyo State, Nigeria. The strands, having an average moisture content of 12% and an average dimension of 630 mm (length) by 4.0 mm (width) and 1.8 mm (thickness), were reduced to 25 mm (length) by 4.0 mm (width) and 1.8 mm (thickness) particles by manual shearing. They were subsequently mixed with cassava starch at six proportions by weight, i.e. 50%, 100%, 150%, 200%, 250%, and 300%. It was observed that the minimum proportion by weight of cassava starch required for briquette formation was 200%. Compression experiments were performed using a simple tabletop closed - end die piston press fitted with both a pressure and a dial gauge. It was concluded that stable briquettes could be formed from rattan strands mixed with cassava starch paste.

Olorunnisola (2007) undertook a study to investigate the properties of fuel Briquettes produced from a mixture of a municipal solid waste and an agricultural residue, i.e., shredded waste paper and hammer milled coconut husk particles. Briquettes were manufactured using a manually-operated closed – end die piston press at an average pressure of 1.2 x 10^3N/m^2 using four coconut husk: waste paper mixing ratios (by weight), i.e., 0:100; 5: 95; 15: 85; and 25: 75. Results obtained showed that briquettes produced using 100% waste paper and 5:95 waste paper-coconut husk ratios respectively exhibited the largest (though minimal) linear expansion on drying. While the equilibrium moisture content of the briquettes ranged between 5.4 % and 13.3%, there was no clearly discernible pattern in equilibrium moisture content variation with increase in coconut husk content. A reciprocal relationship was observed between compressed/relaxed density and relaxation ratio of the briquettes. The mean durability rating of all the briquettes exceeded 95%. It was concluded that stable briquettes could be formed from waste paper mixed with coconut husk particles.

Sani (2008), carry out the modification of the existing CINVA RAM press and evaluation of the products produced. He selected agricultural residues (i.e. rice straw and rice husk), saw dust residue of softwood and a combination of 50% rice husk + 50% saw dust by weight with 30% optimum cassava starch by weight as binder were used to produce briquettes. Performance characteristics were evaluated for the briquettes produced based on average fuel efficiency, burning rate and specific fuel consumption. Calorific value of 16,577kJ/kg was obtained for rice straw briquette, 14,396kJ/kg for rice husk briquette, 15,547kJ/kg for sawdust briquette; 17,529kJ/kg for 50% rice husk + 50% saw dust briquette and 12,378kJ/kg for firewood (Parkia biglobosa). The average fuel efficiency, burning rate and specific fuel consumption values of 10.68%, 1.10kg/hr, 0.3g/g, 22.42%, 0.83kg/hr, 0.13g/g, 15.40%, 1.03kg/hr, 0.26g/g, 18.52%, 0.93kg/hr, 0.16g/g and 12.29%, 1.62kg/hr, 0.36g/g were obtained for rice straw briquette, rice husk briquette, saw dust briquette, 50% rice husk + 50% saw dust briquette and firewood respectively. Statistical analysis using the least square differences in comparison to each of the fuel samples average performances showed that rice husk briquette had the most outstanding thermal performance.

2.2 Thermo Chemical Conversions

In the presence of excess air it becomes combustion, gasification in reduced air and pyrolysis in the absence of air. This technique is capable of producing both heat and electricity energy from waste through direct combustion.

Consonni and Larson (1994), Faaiji et al (1997) suggested that it is possible to generate electrical efficiencies of around 40% (low high voltage) are possible on a scale of about 30MW on short term.

Naber et al (1997) study found that thermal upgrading a process originally developed by shell and pre-pilot phase converts biomass at a high pressure in water and moderate temperature to bio crude are other ways of producing raw intermediate liquid from biomass.

Kaltschmitt et al (1998) and Stassen (1995) studied that using fuel cells and micro-turbines could means a breakthrough for small scale electricity production from biomass, but such system need further development and will depend on cheap and reliable fuel cells and again major advances in small scale cleaning.

Oudhuis., *et al* (2000) in a study described pyrolysis application as a means to reduce the size of waste streams, like electronic scrap, plastics and so forth while in some processes even high calorific value gas is generated, precious metals are recovered and environmentally hazardous waste metals are immobilized.

Antal *et al* (2000) described Liquefaction Hydrothermal upgrading of a low temperature (250-500°C), high-pressure (up to 150 bar) process in which a reducing gas, usually hydrogen, is added to the slurries feed. The product is an oxygenated liquid with a heating value of 35-40 MJ/kg, compared to 20-25 MJ/kg for pyrolysis oils. It takes place in a high-pressure reactor close by the critical point of water. During this process biomass decomposes into CO_2 and a so-called biocrude. This latter product is easily separated from water in which it forms, but still has to be hydrogenated to become a fuel comparable with conventional ones. The work has been started to generate an alternative to the ever-increasing oil price some decades ago.

ECN, (2000) described another study of the supercritical gasification. The process is basically the same as Hydrothermal upgrading, but occurs at more extreme conditions in terms of temperature and pressure. Therefore the product yield will be composed of gaseous products rather than liquid. Water becomes supercritical at temperatures over 374^{o}C and a pressure of 221 bar and the distinction between gas and liquid phases disappear. Usually the reaction temperature is chosen much higher than this latter. In the phase change from sub to supercritical, the properties of water change dramatically. It becomes highly reactive and can break C-C, C-H and C-O bonds in such a way that smaller fractions are obtained if higher temperatures are applied. The selectivity and efficiency is, however, significantly enhanced by the presence of a catalyst. Under the most extreme conditions temperatures over 600 ^{0}C the organic molecules are split into the smallest possible entities like H_2 and CO_2, but at more moderate temperatures the selectivity towards CH_4 becomes larger. Even lower temperature than say 400^{o}C will yield complicated waxes and higher hydrocarbons.

2.2 Bio Chemical Conversions

This article gives an overview of the state-of-the-art of key biomass conversion technologies currently deployed and technologies that may play a key role in the future, including possible linkage to CO_2 capture and sequestration technology (CCS). In doing so, special attention is paid to production of biofuels for the transport sector, because this is likely to become the key emerging market for large-scale sustainable biomass use. Although the actual role of bio-energy will depend on its competitiveness with fossil fuels and on agricultural policies worldwide, it seems realistic to expect that the current contribution of bio-energy of 40–55 MJ per year will increase considerably. A range from 200 to 300 MJ may be observed looking well into this century, making biomass a more important energy supply option than mineral oil today. A key issue for bio-energy is that its use should be modernized to fit into a sustainable development path. Especially promising are the production of electricity via advanced conversion concepts (i.e. gasification and state-of-the-art combustion and co- firing) and modern biomass derived fuels like methanol, hydrogen and ethanol from ligno-cellulosic biomass, which can reach competitive cost levels within 1–2 decades (partly depending on price developments with petroleum). Sugar cane based ethanol production already provides a competitive biofuel production system in tropical regions and further improvements are possible. Flexible energy systems, in which biomass and fossil fuels can be used in combination, could be the backbone for a low risk, low cost and low carbon emission energy supply system for large scale supply of fuels and power and providing a framework for the evolution of large scale biomass raw material supply systems. The gasification route offers special possibilities to combine this with low cost CO_2 capture (and storage), resulting in concepts that are both flexible with respect to primary fuel input as well as product mix and with the possibility of achieving zero or even negative carbon emissions. Pro- longed RD&D efforts and biomass market development, consistent policy support and international collaboration are essential to achieve this.

Meuleman and Faaij (1999) observed that Co-combustion of biomass, in particular in coal-fired power plants is the single largest growing conversion route for biomass in many EU countries (e.g. in Spain, Germany, and the Netherlands to name a few). That the advantages of co-firing are apparent: the overall electrical efficiency is high (usually around 40%) due to the economies of scale of the existing plant and investments costs are low to negligible when high quality fuels as pellets are used. Also, directly avoided emissions are high due to direct replacement of coal. Combined with the fact that many coal-fired power plants in operation are fully depreciated, this makes co-firing usually a very attractive green house gas mitigation option. In addition, biomass firing leads to lowering sulphur and other emissions.

Van Loo and Koppejan (2002); DOE (1998); van den Broek, et al. (1996) identified that the application of fluid bed technology and advanced gas cleaning allows for efficient and production of electricity (and heat) from biomass. On a scale of about 50–80MWe, electrical efficiencies of 30–40% are possible and in addition that Finland is on cutting edge of the field with development and deployment of Bubbling Fluidized Bed (BFB) and Circulating Fluidized Bed (CFB) boilers with high fuel flexibility, lower specific investment costs, high efficiency are deployed on a large scale. One of the latest plants realized in Finland has a capacity of 500MW and is co-fired with a portfolio of biomass fuels, partly supplied by water transport.

Christy et al, (2013) carried out a study that animal wastes have been recognized as suitable substrates for anaerobic digestion process, a natural biological process in which complex organic materials are broken down into simpler molecules in the absence of oxygen by the concerted activities of four sets of metabolically linked microorganisms. This process occurs in an airtight chamber (biodigester) via four stages represented by hydrolytic, acidogenic, acetogenic and methanogenic microorganisms. The microbial population and structure was identified by the combined use of culture-based, microscopic and molecular techniques. Overall, the process is affected by bio-digester design, operational factors and manure characteristics. The purpose of anaerobic digestion is the production of a renewable energy source (biogas) and an odour free nutrient-rich fertilizer. Conversely, if animal wastes are accidentally found in the environment, it can cause a drastic chain of environmental and public health complications.

Edison (2014) studied that anaerobic digestion of organic waste can address both energy recovery and pollution control. A variety of agricultural, industrial and domestic wastes can be anaerobically digested as they contain easily biodegradable material. Biogas contains 50 -70% methane and 30-50% carbon dioxide as well as small a amounts of other gases with calorific value of about 21-24 MJ/m^3. In his paper reviews the history of biogas, biogas production stages and operating parameters were included. The anaerobic digestion configuration and potential substrates for biogas production were also considered. Njom

(2016) study says that in order to attain economic growth and development, all the world's economies have to place greater emphasis on renewable energy development and production. This will lead to the advancement of technologies to invent conversion machineries that could transform biomass residues into electrical energy.

The goal of his paper is to contribute to a sound energy market that would provide sufficient, viable and efficient energy services for the economic development of Wabane, a forest adjacent community to the newly created Tofala Hill Wildlife Sanctuary and other neighbouring villages/towns through the formulation of a comprehensive program that would identify the optimal path for the development, exploitation and proficient management of biomass-energy (palm kennel waste, cocoa waste, saw dust waste, sugar cane waste etc.) resources available in this area and the needed technological means to convert them into electrical energy.

Jeff and Jason (2017) described that increase in biopower production from sustainable biomass can provide many economic and environmental benefits. For example, increasing biogas production through anaerobic digestion of food waste would increase the use of renewable fuels throughout California and add to its renewables portfolio. A case study was conducted by collecting field data from a wastewater treatment plant that employs anaerobic codigestion of fats, oils, and grease (FOG), food waste, and wastewater sludge, and also uses an internal combustion (IC) engine to generate biopower using the biogas. This research project generated scientific information on (a) quality and quantity of biogas from anaerobic codigestion of food waste and municipal waste watersludge, (b) levels of contaminants in raw biogas that may affect beneficial uses of the biogas, (c) removal of the contaminants by the biogas conditioning systems, (d) emissions of NOx, SO_2, CO, CO_2, and methane, and (e) types and levels of air toxics present in the exhausts of the IC engine fueled by the biogas. Implications: Full-scale operation of anaerobic codigestion of food waste with municipal sludge is viable, but it is still new. There is a lack of readily available scientific information on the quality of raw biogas, as well as on potential emissions from power generation using this biogas.

3. CONCLUSION

This study use literature available to identify various developments going on in the area of Biomass conversion processes and how it is becoming a big sector in contributing to value added agriculture with a supply that is never ending. Its production and contribution as a resource for the next generation have the promise for economic growth and environmental sustainability. This resource is still largely underutilized and left to rot or openly burned in the fields especially in Nigeria that do not have strong regulatory instrument to control such pollutive practices. The benefits of Biomass conversion include the production of bio fuel, biogas, particle and straw board production, briquette, electricity generation and so on. The various methods of conversion of biomass to resources give us much information on the physical, chemical, biological and mechanical properties of biomass which is useful in design, construction and development of useful products.

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Yield, Characterization and Potential Application of Activated Carbon Produced from Co – pyrolysis of Wood and Plastic Wastes as Adsorbent for Aquaculture Wastewater Treatment

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ABSTRACT

Pollution from municipal solid wastes and wastewater from different agricultural operations pose detrimental effect to the environment such as wood and plastic wastes as well fish pond effluent. Co – pyrolysis of these solid wastes to produce activated carbon for the treatment of fish pond effluent serves as a means of reducing their negative impact on the environment as well as a viable alternative means of producing energy. Hence, plastic and wood wastes and fish pond effluent were collected for this study. The plastic wastes were washed, dried, shredded using cutlass and hammer milled to a particle size in the range of 1 – 5 cm. The sawdust was oven dried to a moisture content of 10% on dry basis and sieved through a 2mm mesh. In this work, sawdust (80%) and plastic (20%) wastes were co – pyrolysed in a pyrolysing unit. The influence of pyrolysis temperature on the product yields was investigated and part of the produced biocharwas activated using 460ml of nitric acid (HNO_3). The collected fish pond effluent was subjected to adsorption using activated and non – activated biochar as the adsorbents at 3g, 4g and 5g dosage levels. Results showed that the yield of biochar reduced with increase in temperature. Biochar produced at 400°C had the highest carbon content of 77.20%. Also, the fixed carbon, moisture content and ash of the produced biochar increased with increase in temperature while the volatile content decreased with increase in temperature. The results indicated that there were significant differences in the dosage levels of biochar utilized for the treatment in both cases for all the considered parameters except for pH. The removal efficiencies of phosphate and turbidity were the highest for the two absorbents: 89.17%, 71.93% respectively for the activated biochar and 86.36%, 78.25% respectively for the non – activated biochar. However, there was no significant difference between the two treatment options at 5% significance level (α) for all parameters such as pH, turbidity, total Kjeldahl nitrogen, nitrate, nitrite, phosphate, total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and dissolved oxygen (DO) except for total suspended solid (TSS) with probability level less than 0.025.

Keywords: Plastic and wood wastes, Fish pond effluent, Activated biochar, Biochemical oxygen demand, Biomass pyrolysis.

1. INTRODUCTION

The growth of human population, industrial and agricultural practices is the major causes of pollution (Owa, 2014). Pollution of water resources by fish farms effluent is probably the most common complaint, and this concern has attracted the greatest amount of official attention in various nations (Cobbina *et al*., 2014). The principal sources of aquaculture waste is ultimately the manufactured feeds that are necessary to increase production beyond natural levels (Yeo *et al.*, 2004), and also the use of hormones (antibiotics) with a known impact on the environment (Turcios and Papenbrock, 2014).

Four main components of aquaculture waste water of interest include: nutrients (nitrogen (N) and phosphorus (P)), biochemical oxygen demand (BOD), suspended solids and pathogens.Up to 80% of feed ingested by fish is released to the pond environment as faecal solids and dissolved nutrient and organic matter with just about 20% retain as fish biomass. Nitrogen and phosphorus are the key nutrients generated in aquaculture systems. Increase in concentration of organic matter, nutrients and suspended solids in culture ponds leads to an increase in oxygen demand, eutrophication and turbidity in receiving waters (Cobbina *et al*., 2014).

Efficient techniques for the removal of highly toxic organic compounds, suspended solids and nutrients from water and wastewater have drawn significant interest. A number of methods such as coagulation, filtration with coagulation, precipitation, ozonation, adsorption, ion exchange, reverse osmosis and advanced oxidation processes have been used for the removal of organic pollutants from polluted water and wastewater. These methods have been found to be limited, since they often involve high capital and operational costs. On the other hand, ion exchange and reverse osmosis are more attractive processes because the pollutant values can be recovered along with their removal from the effluents. Reverse osmosis, ion exchange and advanced oxidation processes do not seem to be economically feasible because of their relatively high investment and operational Cost (Rashed, 2013).

Among the possible techniques for water treatments, the adsorption process by solid adsorbents shows potential as one of the most efficient methods for the treatment and removal of organic contaminants in wastewater treatment (Rashed, 2013). Adsorption works on the principle of adhesion. The process of adsorption involvesseparation of a substance from one phase accompanied by its accumulation or concentration at the surface of another. The process can take place in any of thefollowing systems: liquid-gas, liquid-liquid, solid-liquid and solid-gas. The adsorbingphase is the ‘adsorbent’, and the material concentrated or adsorbed at the surface ofadsorbing phase is the ‘adsorbate’ (Vigneswaran *et al*, 2005).

Adsorption has advantages over the other methods because of simple design and can involve low investment in term of both initial cost and land required. The adsorption process is widely used for treatment of industrial wastewater from organic and inorganic

pollutants and meet the great attention from researchers (Rashed, 2013). Since early history, activated carbon was the first widely used adsorbent. Its applicationin the form of carbonized wood (charcoal) has been described as early as 3750 BC in an ancient Egyptian papyrus. The use of activated carbon is perhaps the best broad spectrum technology available at present to control contamination of water by organic pollutants (Vigneswaran *et al*, 2005).
The adsorption properties of carbon-reach materials (e.g. wood charcoal, bone charcoal) have been known for millennia, but only since the beginning of the twentieth century has this material been improved by special activation processes (Worch, 2012). In recent years, the search for low-cost adsorbents that have pollutant –binding capacities has also intensified. Materials locally available such as natural materials, agricultural wastes and industrial wastes can be utilized as low-cost adsorbents (Rashed, 2013). The most common raw materials, presently utilized, for the production of activated carbon are wood, wood charcoal, peat, lignite and lignite coke, hard coal and coke, bituminous coal, petrol coke as well as residual materials, such as coconut shells, lignocellulosic wastes, or plastic residuals (Worch, 2012).

Lignocellulosic wastes are the waste derived from agricultural material, including forest biomass. These materials are abundant in various sawmills and landfills across the nation. Sawmills generate much waste: sawdust, wood off-cuts, wood barks, plain shavings, wood rejects, etc. In the absence of proper disposal methods, these wastes are burnt in the open air, dumped along the bank of streams and rivers or left on any available space to rot. It was estimated that the amount of sawdust generated in Nigeria is about 1.8 million tons per annum while the corresponding figure for wood waste is 5.2 million (Oluoti *et al*., 2014).

Similarly, in Nigeria, there has also been a monumental increase in the yearly generation of plastic waste with minimal percentage of it being recycled. The rate of recycling is not commensurate with the rates at which the wastes are being generated and deposited into the environment. Only 14 kg (14.24%) in 2001 and just 13.06% of 268 kg in 2013 were recycled. Relative proportion of the quantity that may be recycled may be decreasing over time (Aderogba, 2014).

The conversion of these solid wastes into activated carbon requires two major processes, namely: carbonization and activation(Worch, 2012).Carbonization can be achieved through a process known as co – pyrolysis, which involves the thermochemical degradation of two or more feedstock in the complete absence of oxidizing agent (i.e. air), or with such a limited supply that gasification does not occur to an appreciable extent, to produce biochar, bio – oil and non – condensable gases. Generally, co – pyrolysis of plastic with biomass is mostly aimed at improving the quality of bio – oil. Bio – oil from pyrolysis of biomass is usually of high water content, high viscosity, poor ignition characteristics and corrosiveness, as well as high oxygen content, high solids content and chemical instability (Garcia et al., 2014).

Bai *et al*., (2015)co-pyrolysed red oak and HDPE using a laboratory- scale continuous fluidized bed reactor (in the temperature range of 525 – 625°C). The biochar produced was characterised and it was discovered that as compared to pyrolysis of red oak alone, the char produced from co-pyrolysis has higher carbon content and lower hydrogen and oxygen contents. As a result, the high heating value of the char produced from co-pyrolysis was about 10% higher than that obtained from pyrolysis of red oak at the same temperature. However, it was noted that the co-presence of HDPE inhibited char formation from red oak.This work is thus primarily concerned on the need to determine the effectiveness of activated carbon produced from wood and plastic wastes in the treatment of aquatic wastewater.

2. EXPERIMENTAL

1. Production of activated carbon

Theplastic waste bottles were obtained from dumpsite at Agbowo area of Oyo state, Nigeria. While, sawdust from *Anogeissus leiocarpus* (Ayin tree) was collected from Bodija Isopako in Ibadan metropolis. The plastic wastes were washed, dried, shredded using cutlass and hammer milled to a particle size in the range of 1 – 5 cm. The sawdust collected was stored in a suitable packaging unit to conserve its moisture content. The sawdust was oven dried to a moisture content of 10% on dry basis. It was further sieved through a 2mm mesh.

Plate 1: Plastic waste bottles (high density polyethylene).

Plate 2: Sieved saw dust of *Anogeissus leiocarpus*.

Mixing ratio of 80: 20 was adopted for the mixture of wood and plastic wastes in the co – pyrolysis process, which is in conformity with the work of Bai *et al*., (2015). Temperature was varied in a step of 50ºC from 300ºC to 400ºC as it had been reported by various authors that biochar yield decreases with increase in temperature (Jindo *et al*., 2014, Park et al., 2016, Bai *et al*., 2015, Sarker *et al.*, 2010).

Plate 3: The Pyrolizing unit

A series of experimental process was afterwards initiated to determine the yields of the biochar at different temperatures, as well as its physical and chemical characteristics.

Determination of the char yield from pyrolysis process

The weight of the empty flask was determined and recorded as W_r. The weight of the flask after it has been cooled to room temperature at the end of the reaction was determined and recorded as W_{rf}. The weight of the char (W_{char}) produced is expressed as the difference between the weight of flask measured before and after the reaction. The char yield (Y_{char}) is obtained as a ratio between the char yield and the oven dry weight of the feedstock.

$W_{char} = W_{rf} - W_r$ Equation 1

$Y_{char} = \frac{W_{char} \times 100}{W_f}$ Equation 2

W_f = oven dry weight of the feedstock

Biochar activation

The activation of biochar was done according to the method used by Berisha*et al* (2016). For the purpose of this research work, 30g of the produced biochar was weighed and placed in a suitable container. It was then soaked in 460ml of HNO_3 and left overnight. After this, the mixture was passed through a muslin cloth and the acid was allowed to drain off. The resulting activated carbon was washed thoroughly under running water to remove residual acid. The washing was done repeatedly until the waste water was clear and clean. The activated carbon was then washed with deionized water to remove any form of residual acid. It was later oven dried at 120°C for 8 hours.

2. **Treatment of fish pond effluent**

Water samples were collected in duplicate using 5 liters' kegs as sampling bottles and small plastic bottles of 50ml from a fish farms located in Akuro, a suburb of Ibadan town. Until analysis, the collected water samples were kept in a cool container and was preserved for various analysis by addition of 1.0 ml of concentrated nitric acid. The collected wastewater was sieved to remove some foreign materials.500ml of wastewater was measured and poured into six plastic bottles individually.The produced biochar was measured as 3g, 4g, 5g and were poured into three different bottles filled with the waste water.The activated biochar was measured as 3g, 4g, 5g and were poured into three different bottles filled with the waste water.The six bottles were properly shaken for a flocculation period of 30 minutes.

Plate 4: Fish pond effluent treated with Non – Activated bio – chars at 3g, 4g and 5g.

Plate 5: Fish pond effluent treated with Activated bio – chars at 3g, 4g and 5g

3. RESULTS AND DISCUSSION

Biochar yield

The biochar yield was calculated as the proportion of the weight of pyrolysis product to the original material. Table 1 presents the biochar yield at 300 ^oC, 350 ^oC and 400 ^oC under a fixed residence time of 50 minutes respectively with two replicates. It was observed that the biochar yield significantly decreased with increased in temperature. At 300 ^0C, the average yield of biochar is 43.85% while at 350 ^0C the average biochar yield decrease to 34.85%. Also, at 400 ^oC, the biochar yield further decreases to 25.91%. As previously reported by many researchers, who have attributed this decrease in the char yield with increasing temperature, this can either be as a result of the primary decomposition of the wood at higher temperatures or to secondary decomposition of the char produced. This conclusion is consistent with previous studies of cellulose and lignocellulosic materials (Jindo *et al*., 2014). In addition, at lower temperature the co-presence of HDPE inhibited char formation (not properly melted) thus increases the mass of the produced biochar. This is also in agreement with the co-pyrolysis of red oak with HDPE reported by Bai *et al*., (2015).

Table 1: Biochar yield at different temperatures and residence time of 50 minutes

Residence time (mins.)	Temperature (^oC)	Weight of feedstock (g)	Weight of biochar (g)	% Yield
50	300	100	43.64	43.64
		100	44.03	44.03
			Mean	43.85
	350	100	35.00	35.00
		100	34.70	34.70
			Mean	34.85
	400	100	25.90	25.90
		100	25.92	25.92
			Mean	25.91

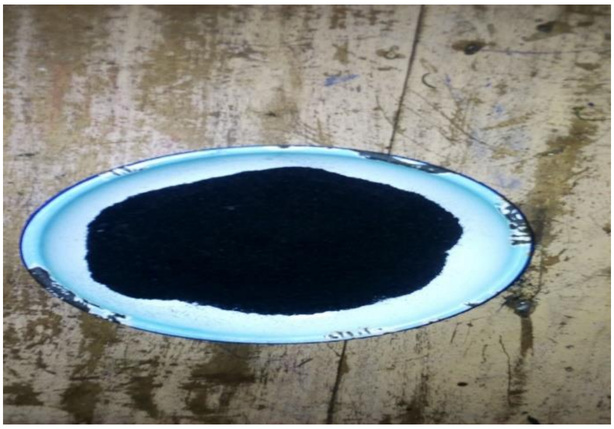

Plate 6: Biochar produced at 400°C and 50 minutes' residence time.

Plate 7: Biochar produced at 300°C and residence time of 50 minutes.

Biochar characteristics

Table 2 presents the proximate analysis of the biochars derived from the mixture of wood and plastic at different temperatures. The determination of the volatile matter and ash content was conducted according to the American Society for Testing and Materials (ASTM) D1752-84, which is recommended by the International Biochar Initiative (Jindo *et al*., 2014). Biochar obtained at 400°C had the best potential as a carbon-rich material (a suitable criterion for selecting char to be used as activated carbon), it contains 8.04% volatile matter, 8.70% ash and 75.40% fixed carbon.

It is evident from Table 2 that the fixed carbon content of the produced biochar increases with increase in temperature but with consequential reduction in biochar yield. Low-temperature pyrolysis produced higher and an enriched volatile-matter composition than the high-temperature pyrolysis. Which gradually reduces as the pyrolysis temperature increases. The ash and moisture contents of the biochar steadily increases with increase in temperature. This is consistent with the work reported by Jindo *et al*., 2014.

Table 2: Proximate analysis of biochar derived from wood and plastic mixture at different temperature.

S/N	**Temperature (^{0}C)**	**Biochar Yield (%)**	**Fixed carbon (%)**	**Volatile matter (%)**	**Moisture content (%)**	**Ash content (%)**
1	300	43.85	64.85	21.10	6.55	7.50
2	350	34.85	70.10	14.49	7.28	8.13
3	400	25.91	75.40	8.04	7.86	8.70

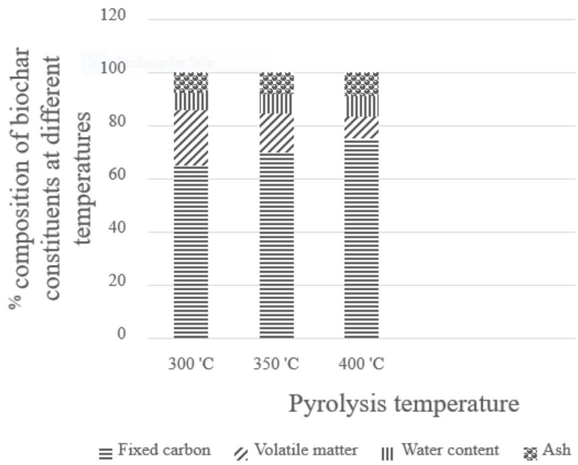

Fig 1: Variation in char content at different temperatures.

Analytical elements, hydrogen: carbon ratio (H:C) and oxygen: carbon (O:C) ratios are useful indicators of the character of biochars (Jindo *et al*., 2014). Data in Table 3 suggest that an increase in the temperature results in a larger loss of H and O compared to that of C. The dehydrogenation of CH_3 as a result of thermal induction indicates a change in the biochar recalcitrance. In addition, a biomass material typically comprises of easily decomposed and recalcitrant O fractions; the former is rapidly lost after the initial heating, while the latter is retained in the char of the final product (Jindo *et al*., 2014). Because of the high temperature of the charring process, the H:C and O:C ratios are reduced as a result of dehydration and decarboxylation reactions.

Table 3: Elemental composition of the biochars derived from mixture of wood and plastic feed.

Temperature (°C)	C (%)	H (%)	O (%)	H:C	O:C
300	70.95	7.40	12.60	1.2516	0.1332
350	73.80	7.28	11.25	1.1830	0.1143
400	77.20	7.16	10.18	1.1124	0.0989

Treatment of fish pond effluent

Tables 4 and 5 present the laboratory analysis of the fish pond effluent treated with activated Biochar (A) and Non- activated Biochar (NA) at 3g, 4g and 5g respectively as compared with the raw water sample.

Table 4: Average values of parameters for raw and treated fish pond effluents using activated biochar

	Parameters	Water samples			
		RAW	A-3g	A-4g	A-5g
1	pH	6.93	6.55	6.40	6.15
2	Turbidity (NTU)	57.00	38.00	26.50	16.00
3	TKN	2.70	2.40	2.21	1.17
4	Nitrate	4.91	3.72	3.10	2.41
5	Nitrite	1.50	1.23	1.06	0.83
6	Phosphate	4.4	3.19	1.61	0.45
7	Total suspended solids (mg/l)	221.00	184.50	152.50	103.50
8	Total dissolved solids (mg/l)	254.00	205.50	175.50	125.00
9	Biological oxygen demand (mg/l)	861.00	738.00	678.00	549.00
10	Chemical oxygen demand (mg/l)	1578.00	910.50	771.00	643.50
11	Dissolved oxygen (mg/l)	2.85	3.30	4.55	5.20

Table 5: Average values of parameters for raw and treated fish pond effluents using Non – activated biochar

	Parameters	Water samples			
		RAW	NA-3g	NA-4g	NA-5g
1	pH	6.93	7.10	7.14	7.20
2	Turbidity (NTU)	57.00	31.00	25.30	12.40
3	TKN	2.70	2.25	2.00	1.15
4	Nitrate	4.91	3.51	2.41	2.10
5	Nitrite	1.50	1.29	1.11	0.75
6	Phosphate	4.4	2.75	1.20	0.60
7	Total suspended solids (mg/l)	221.00	164.00	127.50	85.50
8	Total dissolved solids (mg/l)	254.00	183.50	134.00	106.50
9	Biological oxygen demand (mg/l)	861.00	654.00	498.00	460.50
10	Chemical oxygen demand (mg/l)	1578.00	823.50	729.75	609.00
11	Dissolved oxygen (mg/l)	2.85	4.70	4.98	5.42

It was observed that the pH of the activated biochar treated effluent became more acidic, this might be as a result of the acid used in the activation process, while the pH of the non – activated biochar treatment became slightly neutral. Figures 2 and 3 depicted the removal efficiency for all the parameters. The results indicated that the removal efficiencies of all the parameters increase with increase in the utilised dosages of activated biochar. The non – activated biochar treatment is more effective in the removal of organic compounds that were responsible for the turbid nature of wastewater when compared with activated biochar treatment.

The maximum removal efficiency for non – activated biochar treatment was 78.25% while for activated biochar treatment was 71.93%. All the biochar dosages for both activated and non-activated were effective for the removal of phosphate, the removal efficiency increases greatly as the biochar dosage increases from 3g to 5g. The maximum removal efficiency for phosphate was recorded as 89.77% when activated biochar was utilized and 86.36% when non – activated biochar was used. This showed that the activated biochar is more efficient in the removal of phosphate from fish pond effluent. The dissolved oxygen in the treated fish pond effluent increases from 15.78% to 82.46% for activated carbon treatment and 64.91% to 90.18% for non – activated carbon treatment as the dosages increase from 3g to 5g.

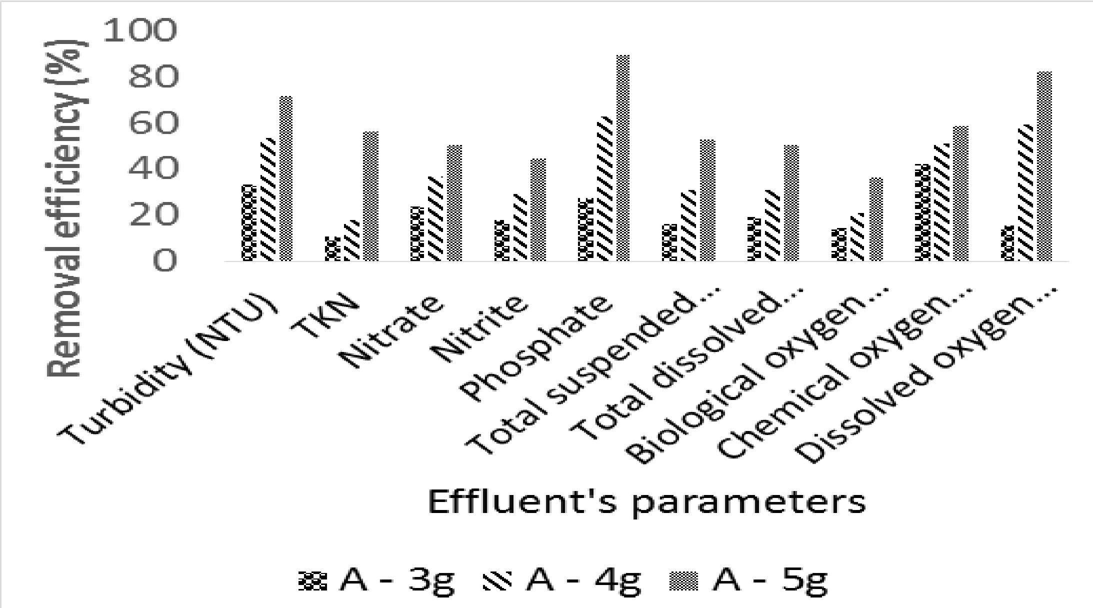

Fig 2: Removal efficiency for the parameters in treated fish pond effluents using activated biochar.

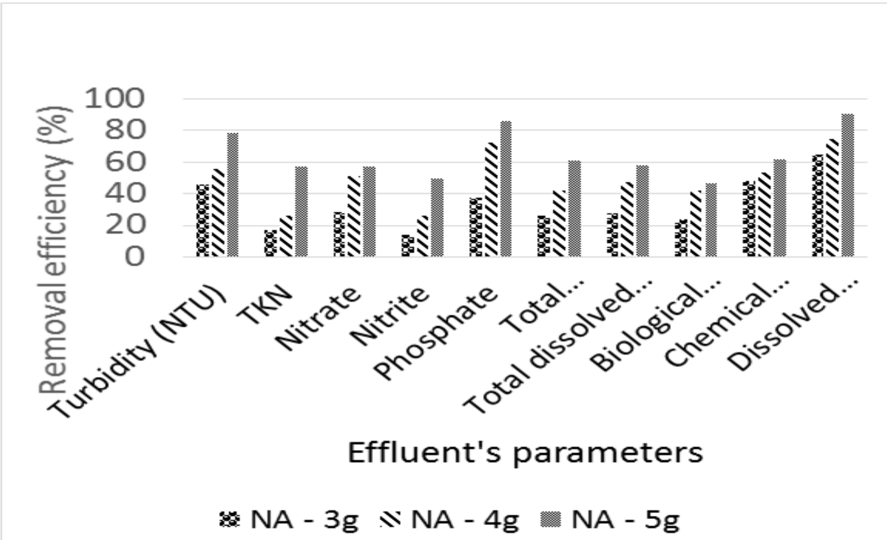

Fig 3: Removal efficiency for the parameters in treated fish pond effluents using Non – activated biochar.

The activated and non – activated biochar treatments were compared statistically using coefficient of variation and two – tailed t – test. The results in Table 6 showed that there was slight variation between the two treatment options for total Kjeldahl mitogen (TKN), nitrite as well as chemical oxygen demand (COD) with coefficient of variation of 4.92%, 0.68% and 5.13%. This showed that the activation process has no effect on the performance of the biochar for fish pond effluent treatment. However, there was a high variation between the two treatments for other parameters such as pH (8.13%), turbidity (11.18%), nitrate (10.08%), phosphate (9.95%), total suspended solid (10.98%), total dissolved solid (12.47%), biochemical oxygen demand (13.93%) and dissolve oxygen (10.25%). The result of the t – test indicated that there was no significant difference between the two treatment options at 5% significance level (α) for all the considered parameters except for total suspended solid (TSS) with probability level less than 0.025.

Table 6: Comparison between non - activated biochar and activated biochar treatments.

	Parameters	CV (%)	T - values	Probability (p)
1	pH	8.13	5.35	0.03
2	Turbidity (NTU)	11.18	2.34	0.14
3	TKN	4.92	2.26	0.15
4	Nitrate	10.08	2.76	0.11
5	Nitrite	0.68	0.22	0.85
6	Phosphate	9.95	1.22	0.35
7	Total suspended solids (mg/l)	10.98	10.34	0.01
8	Total dissolved solids (mg/l)	12.47	3.82	0.06
9	Biological oxygen demand (mg/l)	13.93	3.76	0.06
10	Chemical oxygen demand (mg/l)	5.13	3.29	0.08
11	Dissolved oxygen (mg/l)	10.25	1.88	0.20

A = Activated carbon
NA = Non - activated carbon
CV = Coefficient of variation

Tables 7 and 8 depicted the comparison of treated fish pond effluent's parameters with WHO and FEPA standards. The pH of the raw and activated biochar treated effluents are slightly acidic, though the results are still in conformity with both standards. The pH of non – activated biochar treated effluent is however moderately neutral. The turbidity of the raw and the treated effluent range far above the WHO standard and as such further treatment of the effluent is required before it can be discharged to the environment.

Also, nitrate values for both activated and non – activated biochar at the three different dosages all fall considerably below the standard. Initially, the concentration of phosphate in the raw fish pond effluent rises beyond the standard. With dosage increment for both the treatment options, the phosphate concentration was greatly reduced below the set standard. The char can thus be viewed as being efficient for phosphate removal.

Table 7: Comparison of activated biochar treatment parameters with international standards.

	Parameters	Raw	A – 3g	A – 4g	A – 5g	WHO standard	FEPA standard
1	pH	6.93	6.55	6.40	6.15	6.5 – 8.5	6 -9
2	Turbidity (NTU)	57.00	38.00	26.50	16.00	5.0	–
3	TKN	2.70	2.40	2.21	1.17		–
4	Nitrate	4.91	3.72	3.10	2.41	10	–
5	Nitrite	1.50	1.23	1.06	0.83		–
6	Phosphate	4.4	3.19	1.61	0.45	2.5	–
7	TSS (mg/l)	221.00	184.50	152.50	103.50	30	15 – 30
8	TDS (mg/l)	254.00	205.50	175.50	125.00	1000	2000
9	BOD (mg/l)	861.00	738.00	678.00	549.00	20	10 – 50
10	COD (mg/l)	1578.00	910.50	771.00	643.50	–	15 – 50
11	DO (mg/l)	2.85	3.30	4.55	5.20	4	5 – 20

The dissolved oxygen as well as total dissolved solid both conformed with the two standards.While there is a huge difference between the result values and those of the standards for biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TDS).

Table 8: Comparison of non - activated biochar treatment parameters with international standards.

	Parameters	Raw	NA – 3g	NA – 4g	NA – 5g	WHO STANDARD	FEPA STANDARD
1	pH	6.93	7.10	7.14	7.20	6.5 – 8.5	6 -9
2	Turbidity (NTU)	57.00	31.00	25.30	12.40	5.0	–
3	TKN	2.70	2.25	2.00	1.15		–
4	Nitrate	4.91	3.51	2.41	2.10	10	–
5	Nitrite	1.50	1.29	1.11	0.75		–
6	Phosphate	4.4	2.75	1.20	0.60	2.5	–
7	TSS (mg/l)	221.00	164.00	127.50	85.50	30	15 – 30
8	TDS (mg/l)	254.00	183.50	134.00	106.50	1000	2000
9	BOD (mg/l)	861.00	654.00	498.00	460.50	20	10 – 50
10	COD (mg/l)	1578.00	823.50	729.75	609.00	–	15 – 50
11	DO (mg/l)	2.85	4.70	4.98	5.42	4	5 – 20

4. CONCLUSIONS

The treatment of fish pond effluent with activated carbon revealed that the concentration of TDS, phosphate, nitrate and pH all fall within the acceptable limits of FEPA (1991) and WHO (2004) for discharged of wastewater into nearby waterways. However, the huge amount of COD, BOD and TSS needs to be drastically reduced to prevent adverse effect on the environment. Hence, physical separation methods such as clarification and flocculation are essential to reduce the TSS concentration, while biological treatments such as biological filter and activated sludge system should be employed prior to treatment to reduce BOD and COD concentrations.

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Development of a Locust Bean Seed Dehulling Cum Washing Machine

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ABSTRACT

A wet locust bean seeds (*Parkia biglobosa*) dehulling and washing machine was developed to reduce drudgery attached to traditional dehulling of the seeds which are processed for use as condiment and flavours' for food in many African countries. The machine consisted of dehulling and washing units, the dehulling mechanism obtains its drive from a 0.38 kW gear motor of 30 - 50 rpm. The dehulling shaft; has rods arranged concentrically to break seed coat and radial fan - like blades used as stirrer. The dehuller cum washer was evaluated based on boiling time of the seeds on an electric cooker. The result indicated that efficiency of the machine increased linearly with increase in boiling time. The throughput capacity decreased with increase in boiling time and moisture content decreased with increase in boiling time from the sixth hour. Dehulling efficiency ranged from 59.7 to 68 %, and cleaning efficiency ranged from 83.4 to 87.4 % while average throughput capacity was 108 kg/hr.

Keywords: Locust bean, Dehulling, Washing and boiling, separation and dehuller efficiency

1. INTRODUCTION

African locust bean (*Parkia biglobosa*) is a member of the Leguminosae family crop ormally found around the tropics and several towns in the savannah territories of West Africa especially in the middle belt and south western area of Nigeria (Faleye *et al.*, 2013). It is common in Nigeria particularly in the Northern and South-Western Nigeria (Kamaldeen *et al.*, 2017). African locust bean tree produce fruits from December to March. The fruits are ready for harvest in April and have many leguminous pods each with a tough pericarp. The matured locust bean fruit is shown in Figure 1. Although all the parts of the African locust bean are useful, the seed is used as a food condiment and is a good substitute for meat because it is high in protein, fat, and vitamins, tannin and mineral contents (Obizoba and Atu, 1993; Enujiugha and Ayodele, 2003).

The pods were harvested and processed into the fermented product known as *'iru', 'dawadawa', 'ogiri'* in the Yoruba, Hausa, and Igbo languages respectively. The pods also contain yellow powdery pulp in which seeds are embedded. The seeds have hard, black testa making them less vulnerable to insects and rodent infestation (Sadiku, 2010).

On a moisture-free basis, the fermented locust bean contains about 40 % protein, 32 % fat and 24 % carbohydrate (Campbell-Platt, 1980). Thus, apart from being a food condiment the fermented bean also contributes to human calorie and protein intake. According to Diawara *et al*. (2000), it has essential acids and vitamins and serves as a protein supplement in the diet of the poor. Locust bean could be added to maize to produce fortified-pap with a better protein base, just as in the case of soy-ogi. *Dawadawa* is used in soups, sauces and stews to enhance or impart meatiness (Klanjcar *et al*., 2002)

a. Fresh bunches of locust bean b. harvested locust bean

Figure 1: Fresh bunches of locust bean and harvested pods

The African locust beans can only be safe for consumption after it has been processed i.e. when the toxins and the anti-nutrients have been removed (Olaoye, 2010a). The major processing procedures involves harvesting, decorticating, de-pulping, and drying to get the locust beans seed that represent the major raw material from this important crop (Olaoye, 2010b). There are mainly two locust beans processing methods namely: traditional and the improved (modern) method. Traditional method of locust bean processing is a rigorous, time consuming, and unhygienic one (Olaoye (2010a). Traditional dehulling of locust beans is untimely, laborious and inefficient. The procedure had witnessed little or no substantial technological transformation and progress in the manufacturing techniques. Olaoye (2010b) postulated two major constraints involved in the production and processing of locust bean as bottleneck associated with the crop's seasonality and traditional technology with its attendant low quality and quantity of the derived products.

Increased consumption of "i*ru"* as a condiment has attracted research interests in development of machines to take care of some of its unit process operations. Traditional "*iru"* processing is still being carried out at a domestic level. Sadiku (2010), considered in detail the different methods of processing locust bean in South West of Nigeria. The methods of processing locust bean that were assessed were: *Ajibode*, *Saki*, *FRIN* and improved methods as described by Sadiku, 2010. A control method in which there was no addition of chemical substances was included.

Mechanizing post-harvest processing of locust bean will reduce drudgery associated with its processing, improve the quality and acceptability of condiment, improve the shelf life of the condiment and enhance the rural economy (Simonyan and Yiljep, 2008) There is a general awareness in developing countries that rapid development of agriculture depends largely on the successful introduction of modern and small-scale agricultural machinery (Timothy and Olaoye, 2013).

Faleye *et al.,* (2013) observed that decorticating by hand is labour intensive, grossly inefficient and consumes time. Therefore, a simple and relatively inexpensive decorticating machine must be developed to overcome these predicaments. Agricultural processing includes activities that maintains, raises the quality or changes the form or characteristics of an agricultural product (Adekanye *et al.,* 2013). Processing activities are undertaken to provide a greater yield from a raw farm product by either increasing the amount of the finished product, the number of finished products or both and to improve the net economical value of a product. Many processes (unit operations) are involved in converting a raw product to a finished product that is consumable by the end users. Each of these processes is referred to as a unit operation. The major unit operations in processing of agricultural products includes; dehulling, cleaning, size reduction, grading, parboiling, blanching, drying, separation, mixing, packaging, etc. There are two basic methods of cleaning which can be dry and wet cleaning, (Onwualu, et. al., 2006).

Dehulling of locust beans is basically a wet cleaning process vital in the removal of foreign materials from crops and guarantees less damage to the crop. Effectiveness of dehulling is determined by the availability of water as the cleaning liquid, which helps in the removal of dirt, dust and other light particles from the locust beans. They are usually in a pulpy media after they have been soaked or fermented in water and must be separated from their pulpy media before they can be further processed into consumable products. The separation is accomplished by washing with water. This work develops and evaluates a machine that performs wet dehulling cum washing with a view to obtain an insight on the best processing parameters that should be met to have efficient processing of the locust beans seed thereby reducing wastage, improving product quality, reducing drudgery and fatigue. The parameters to be considered for evaluation of machine's performance include parboiling time, weight of seeds, moisture content and its effect on dehulling efficiency and throughput capacity.

2. MATERIALS AND METHODS

2.1 MATERIALS SELECTION

The factors considered in the development of the wet locust beans seeds dehulling machine includes: cost of the materials, construction technique, availability of materials, durability of materials, cost of maintenance and effect of the material used on the food material. Galvanized steel was used for the dehulling and washing chambers, while angular mild steel was used for the frame of the machine for rigidity and stability.

2.1.1 MACHINE OPERATION

The wet locust bean seeds dehulling machine dehulls and separates locust beans from its coat. These beans are first dehulled in the dehulling chamber. The dehulling shaft is powered by a 0.5hp electric motor which is connected to a gear reduction device to further reduce the dehulling and washing speed. As the dehulling shaft rotates, it provides drive to the dehulling stirrer mechanism inside the dehulling unit and the washing unit respectively. As the locust beans are fed into the dehulling cylinder through the feeding chute (hopper), they are dehulled by abrasive action and then conveyed to the washing unit under the dehulling unit. The stirrer in the inner concentrate cylinder of the washing unit gently stirs the dehulling beans solution to dislodge the coats from the seeds. Due to the variation in the density of the coat and the seed from the density of water, the coat floats on the water which is collected by lowering the outer concentrate of the washing unit with hand operated handle.

2.2 MACHINED DESIGN ANALYSIS

2.2.1 Design of the dehulling unit

Capacity of dehulling unit was designed to be portable and to avoid over feeding the machine by using eqn.1

$$V = \pi r^2 h \qquad (1)$$

Where; V = volume of the dehulling cylinder, m^3

$$V = \pi \times 0.1935^2 \times 0.15 = 0.0176\, m3$$

2.2.2 Washing unit capacity

Volume of inner cylinder, V

$$V = \pi r^2 h \qquad (2)$$

$$V = \pi \times 0.135^2 \times 0.21\ V = 0.012 m^3$$

$$p = \frac{m}{v} \qquad (3)$$

$$551.66 = \frac{m}{0.012}$$

Capacity, m = 6.62 kg

2.2.3 Determination of shaft torque

$$T_S = \frac{P_S}{\omega_S} \qquad (4)$$

Where T_s = torque of shaft, p_s = power delivered from the motor to drive the shaft
ω_s = angular speed of shaft

$$\omega_s = \frac{2\pi N}{60} \qquad (5)$$

Where N = speed of gear motor, which is 30 rpm

Therefore,

$$\omega_s = \frac{2 \times \pi \times 30}{60} = 3.142 \text{ rad/s}$$

Power generated from the gear motor = 0.5 hp (0.375 kW.

Assume 5% of power is lost during transmission;

5% of 0.375kw= $\frac{5}{100} \times 0.375$ = 0.019 Kw W

Therefore, power delivered from the motor to the shaft, p_s

$p_s = 0.375 - 0.019 = 0.356\ kw$

Finally, torque of shaft, T_s

$T_s = \frac{0.356 \times 10^3}{3.142}$

$T_s = 113.3\ Nm$

2.2.4 Determination of minimum shaft diameter

Eqn. 6 was used to design minimum shaft diameter

$d^3 = \frac{16T_s}{\sigma\pi}$ (6)

Where, $T_s = torque\ of\ shaft, 113.3\ Nm$

d = minimum shaft diameter (Factor of safety for steel materials = 4, Maximum allowable working stress = 112MN/m^2) (Khurmi and Gupta, 2008)

Factor of safety F. S = $\frac{allowable\ stress}{Working\ stress}$

$$d = \sqrt[3]{\frac{16*(113.3*10^3)}{\pi*28}} = 27.4mm, d = 2.7cm$$

Therefore, in the design we used 3cm shaft

2.2.5 Determination of torsional deflection of the shaft

Khurmi and Gupta 2008 gave an equation to evaluate the torsional deflection of a shaft. Below is the equation

$\sigma = \frac{584TL}{D^4G}$ (7)

Where G = torsional modulus of elasticity, 8000 N/mm, D = shaft diameter, 25 mm and L= length of shaft, 510 mm

Hence, $T = (\frac{D}{2.26})^4$

$T = 31 \times 10^3$ N-mm

Finally,

$\sigma = \frac{584 \times (31 \times 10^3) \times 510}{30^4 \times 8000}$

$\sigma = 1.43°$

2.2.6 Determination of the power requirement of the machine

a. Determination of the power requirement to dehull the boiled locust bean

$P_h = T_s\omega$

Where $P_h = Power\ required\ to\ dehull, T_s$ = torque of shaft, $\omega = angular\ speed$

$P_h = 113.3\ Nm \times 3.142$

$P_h = 0.36\ kw$

b. Determination of power required to drive the dehulling and washing shaft.

$P_{c1} = W_{c1} r_{c1}$ (8)

Where $P_c = Power\ required\ to\ drive\ the\ shaft, W_c = weight\ of\ the\ conveyor$

$r_c = radius\ of\ the\ conveyor = 0.1m$

$mass = 1.5kg$

$W_c1 = 1.5 \times 9.81 = 4.72N$

$P_{c1} = 19.62 \times 0.1 = 0.001472$ kW

$P_{c2} = 4.905 \times 0.05 = 0.00025$ kW

Total power required by the machine

P $= P_h + P_c1 + P_{c2}$

$= 0.36+0.001472+0.00025 = 0.326$Kw

P = 0.48hp. Hence, 0.5hp motor was selected

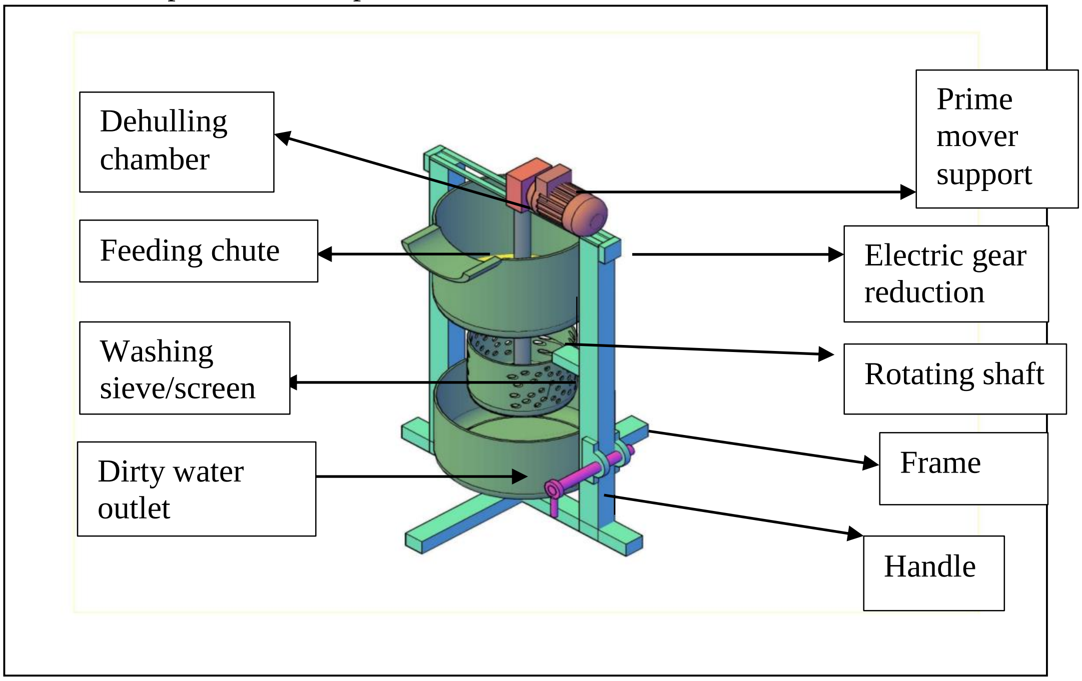

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Figure 2: AUTOCAD representation of the machine

2.3 Preparation of Samples

The locust bean seeds were obtained from the teaching and research farm of Landmark University. The locust bean seeds were weighed using a digital weighing balance (CAMRY ACS-30-ZE41, CAMRY), and each was sorted out for material other than the bean after which it was divided into four (4), each of 1.5 kg before parboiling. The locust bean seeds were boiled in a stainless cooking pot with lid before dehulling at different boiling time (6, 8, 10 and 12 hours). Moisture content (dry basis) was determined using the digital moisture analyser. Weight of the boiled beans was determined using the weighing balance. The boiled beans were then dehulled and washed using the fabricated wet locust bean seed dehuller and washer at desired operating speed. After the dehulling and washing process, the samples were collected. The mass of un-dehulled beans, whole beans, broken beans in the final product and the mass of the coat were determined respectively. The dehuller efficiency, coefficient of wholeness of beans defining the quality of beans recovered, the throughput capacity, coefficient defining the quantity of beans dehulled, cleaning efficiency were calculated respectively and at different boiling time.

2.4 Performance Evaluation of the Machine

The machine operational parameters such as throughput capacity, dehulling efficiency, cleaning efficiency and quality performance efficiency were determined using eqn. 9 – 13;

Throughput capacity, $T_P(Kg/h)$ (9)

$$T_P = \frac{3.6M_t}{t_D}\left(\frac{Kg}{h}\right)$$

Where, $\mathrm{M_t}$ = Mass of sample before dehullin,

$\mathrm{t_D}$ = Time used in dehulling in secs

Dehuller efficiency,

$$DE = 100(C_h \times C_w) \quad (10)$$

Where, $\mathrm{C_h}$ = coefficient defining the quantity of beans dehulled

$$C_h = 1 - \left(\frac{M_u}{M_t}\right) \quad (11)$$

where $\mathrm{M_u}$ = mass of undehulled beans in the final product(Kg)

$\mathrm{M_t}$ = mass of sample before dehulling(Kg),

C_w, *coefficient of wholeness of beans*

$$C_w = \frac{K}{K+b} \quad (12)$$

Where; k = mass of whole beans in the final product, kg

b = mass of broken beans in the final product, kg.

Cleaning efficiency,

$$CE = \frac{W_C}{W_{O+W_S}}$$

(13)

Where$\mathrm{W_c}$ = weight of clean beans, kg, Wo = weight of coat, kg, Ws = weight of un-dehulled bean, kg.

3. RESULTS AND DISCUSSION

3.1Effect of Moisture Content

Fig. 3 shows the variation of moisture content (MC_{db}) of the locust bean with different boiling time. From figure 4 it can be seen that the moisture content decreased with duration of boiling. The maximum was 102.51 %, at the sixth hour of boiling, and the minimum moisture content was 53.68 %, at the twelfth hour. After the sixth hour of boiling the coat is already very soft and further boiling cause’s reduction in the water holding capacity of the coat. This confirming to Audu *et al.*, (2004), where it was stated that moisture content increases and get to it maximum at the sixth hour.

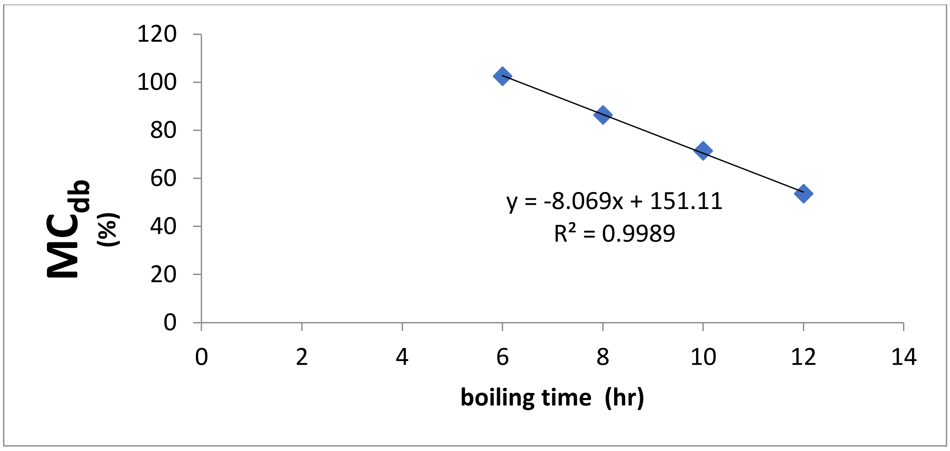

Figure 3: Variation of locust beans moisture content with boiling time

3.2 Effect of Duration of Boiling on Dehulling Efficiency (DE)

The effects of boiling time on Dehulling efficiency (DE) is shown in fig. 4 DE increased with the boiling time. Minimum and maximum efficiencies of 44.13 and 59.72% were obtained at 6 and 12 hours respectively. The low efficiency obtained initially was probably due to hard seed coats which were difficult to remove, thereby leaving many undehulled locust beans and a larger part of few cotyledons obtained were broken. At a higher boiling time, the coat were softened, therefore making dehulling easier with less breakage, since it elasticity increases with boiling time, this is in agreement with Faleye *et al* (2013) and Gbabo *et. al*., (2013).

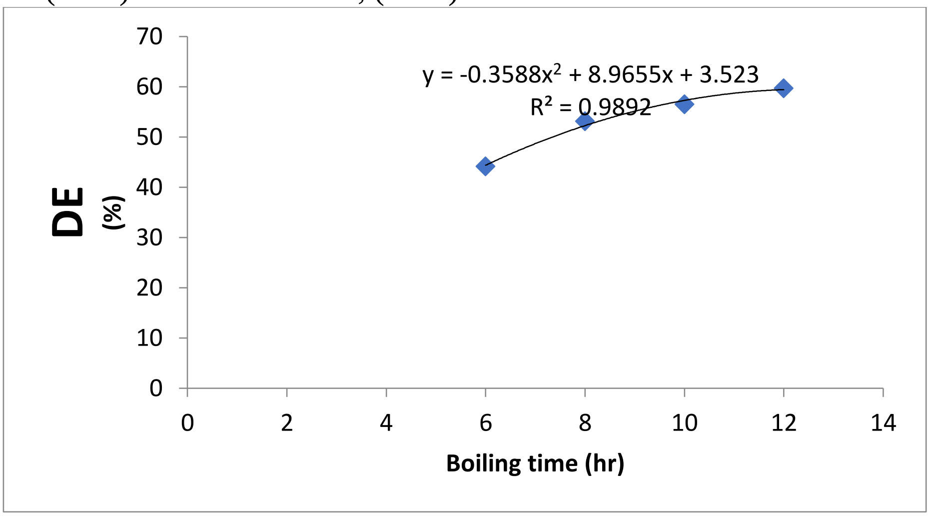

Figure 4: Effect of locust beans boiling time on dehulling efficiency

3.3 Effect of duration of boiling on cleaning efficiency, CE

Figure. 5 shows that the cleaning or separation efficiency increased with boiling time. This is probably because as the dehulling efficiency increase, the quantity of whole dehulled beans also increase weight of undehulled bean reduces, making the separation efficiency to be on a positive increase. It also shows it is highly correlated and linear. This is in relation with the study carried out by Gbabo *et. al*., (2013).

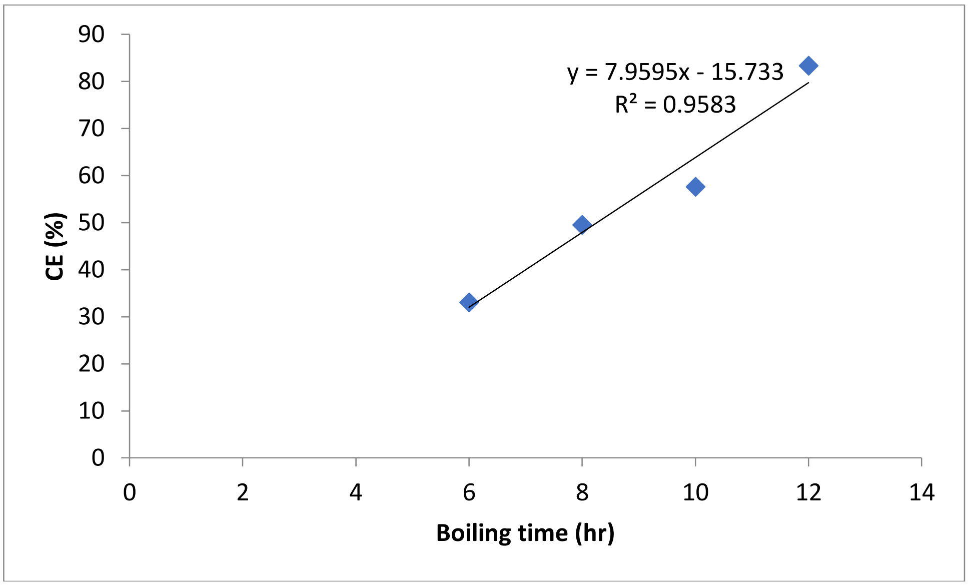

Figure 5: Effect of boiling time on cleaning efficiency

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The wet locust bean seed dehuller washer was developed. Below are the following conclusions:

a) The bean dehuller cum washer works more efficiently as the boiling time increases. The machine attained a dehulling efficiency of 59.72 % and separation or cleaning efficiency of 83.39 % when the boiling time was 12 hours as compared to the value of 6 hours.
b) The best set of conditions under which the dehuller operates is a boiling time of 12 hours, moisture content of 53.7 %, at which maximum dehulling efficiency of 59.72 % and cleaning efficiency of 83.4 %.

4.2 Recommendations

a) To increase the dehulling efficiency the dehulling surface should be rough. This would help increase the abrasion contact with the boiled seeds, in turn increasing the coat detachment and throughput capacity.
b) The dehulling shaft should be fitted with rubber-like paddle to help in easy evacuation of the sticky dehulled bean with it coat to the washing unit.
c) The washing unit should be placed in an off-set from the dehulling unit due to the challenges faced in evacuation of the clean seed from the washing unit

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Analyzing the Distribution of Airflow Inside a Low-cost Tomato Cold Store Room to Evaluate the Efficacy of The Combined Use of Evaporative Cooling and Air Conditioning System

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ABSTRACT

In this paper, the magnitude and uniformity of airflow inside tomato storage container fitted with an evaporative cooler (EC) and CoolBot-air-conditioner (CBAC) systems is investigated. Computational fluid dynamics (CFD) model of the airflow was developed and experimentally validated. The validated CFD model was employed to investigate the airflow distribution inside cold storage container. The result showed that using the EC alone during the initial stage of the cooling process is insufficient in terms of the magnitude and uniformity of the cooling airflow through the stacked tomato. Particularly, for a fully loaded storeroom, the level of ventilation in the central region of the room and in the region at the downstream end of the EC was found to be very low (< 0.01 m s^{-1}). Therefore, using the EC and CBAC simultaneously during the first few hours of the cooling process is recommended and afterwards the EC alone can be used. The study underlined the importance of accurately sizing and selection of the air driving devices. The airflow analysis obtained from this study is useful to assess the cooling kinetics and temperature distribution of the low-cost operation to completely evaluate the potential.

Keywords: Airflow distribution, CoolBot-air-conditioner, CFD models, evaporative cooling, discrete model, fully-loaded tomato stacks, semi-loaded tomato stacks.

1. INTRODUCTION

Cold chain management is emphasized as the most crucial element of postharvest losses reduction strategy. Especially, fruit and vegetables rapidly loss quality after harvest and has limited shelf life. Controlling the temperature and humidity to an optimum value for a produce extend the shelf life considerably. Temperature and humidity are controlled through utilization of a specially designed refrigeration system that uses electricity or diesel fuel to extract the excess heat from the storage environment. Conventional refrigeration facilities are generally expensive and require availability of reliable electricity supply. Besides, conventional refrigerators may not be suitable for on-farm storage of many tropical fruit and vegetables such as banana, tomatoes, mangoes, and other leafy vegetables because of chilling injury and discoloration (Workneh and Woldetsadik, 2004; Saran *et al.*, 2010; Rao, 2015). Hence, there exists a pressing need to develop a low-cost and appropriate alternative.

Low-cost cold storage techniques for reducing food produce wastage has been proposed by several researchers. Evaporative cooling (EC) is a technique of cooling air through the evaporation of water (Bom *et al.*, 1999; Kovačević and Sourbron, 2017). When liquid water changes to water vapor (evaporation), the heat of vaporization is taken from the process air. Due to this phenomenon the temperature of dry air can be dropped significantly. This process requires a small fan to blow or draw the dry air through wet porous material, hence uses much less energy than conventional refrigeration (Kapilan *et al.*, 2016). To this end, EC is identified as one of the potential techniques for rural and remote areas (Gunhan *et al.*, 2007; Kapilan *et al.*, 2016). In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture which is very essential to reduce moisture loss from stored produce. EC has been used for cooling residential buildings, commercial buildings and greenhouse cooling. However, the efficiency of this technique is limited by the relative humidity of the ambient air that the use of conventional evaporative coolers is only appropriate to dry geographical areas (Roy and Pal, 1994; Pal *et al.*, 1997; Workneh, 2010). To use the EC effectively and reliably, supplementing it with a low-cost conventional refrigeration system is investigated in this study. Hence, the aim of this study is to investigate the combined use of EC and CoolBot-Air-Conditioner (CBAC). The CBAC is a low cost, forced-air, portable modification of the domestic air conditioner. This paper presented the experimental and computational fluid dynamics (CFD) analysis of the magnitude and distribution of airflow inside tomato cool store room fitted with EC and CBAC units.

2. MATERIALS AND METHODS

2.1 FRUIT

Tomato fruit (*Lycopersicon esculentum Mill. cv. Nemonetta*) samples were obtained from the ZZ2 farm, Limpopo, South Africa, and collected for the experiment in February 2017. The average weight of a single tomato box was 6.00 ± 0.15 kg (40-48 tomatoes in each box) and fruit diameter ranges from 65 to 68 mm. Fruits were transported overnight in refrigerated trucks and stored inside the experimental cold storage chamber at the Ukulinga Research Farm of the University of KwaZulu-Natal, South Africa.

2.2 PACKAGING BOX

Open-top tomato packaging boxes, with the dimensions shown in Fig. 1 was used. The venthole proportion on the small side and large side of the box were 8.7% and 15.1%, respectively. The packaging boxes were made of paper cardboard of 3 mm thichness.

2.3 COLD ROOM SET-UP

An insulated experimental cold room with internal volume of 53 m^3 was installed at the Ukulinga Research Farm, Pietermaritzburg, South Africa (Fig. 2). The room was fitted with Samsung Inverter R410A air conditioner (Model No. AR24FSFNAWKN). The AC has a max cooling capacity of 6.5 kW with an air circulation rate of 20 $m^3\ min^{-1}$**.** The AC allows temperature adjustment by 1 °C within the range of 16 to 30 °C. To overcome the low temperature limit of the AC a CoolBot™ Walk-In Cooler Controller (Store It Cold, LLC Company, USA) was used. In addition, the cool store room was fitted with EC with charcoal pad as a porous evaporative cooler (blower-wet-charcoal assembly). The EC was equipped with a blower with air driving capacity of 0.22 m^3s^{-1} and a pump to sprinkle water on the charcoal pad.

Four 10 cm diameter circular exhaust openings were provided at the top rim of one wall, opposite the EC and air conditioner, to avoid presser buildup inside the cool store (see Fig. 2). The floor of the store was made up of concrete.

Fig. 1**.** Open-top tomato packaging box.

2.4 MEASUREMENTS

The experimental set-up to measure the airflow distribution in a partially filled room is shown in Fig. 3. Tomato loaded boxes were arranged in a 3 × 3 × 4 stack and placed centrally at the front region of the room 0.75 m away from the EC unit. During the experiment, the fans of the EC and the CBAC were turned on. Six velocity meters (DS-2 sonic anemometer, Decagon Devices, Inc., USA): at three locations in the region in front of the stack and three locations behind the stack were placed to monitor the air velocity. The sensor was placed 50 cm from the floor and 1 cm away from the stack.

2.5 NUMERICAL MODELLING

2.5.1 GOVERNING EQUATIONS

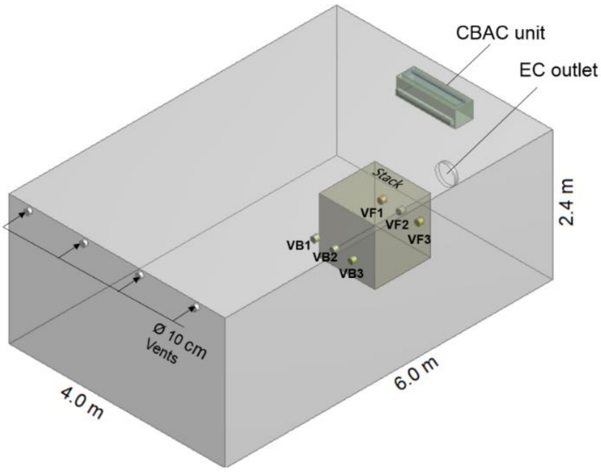
The mass and momentum conservation equations, as given by Eq. (1 and 2), respectively, are used to model the airflow inside the cold storage room.

$$\boldsymbol{\nabla . V = 0} \quad \textbf{(1)}$$

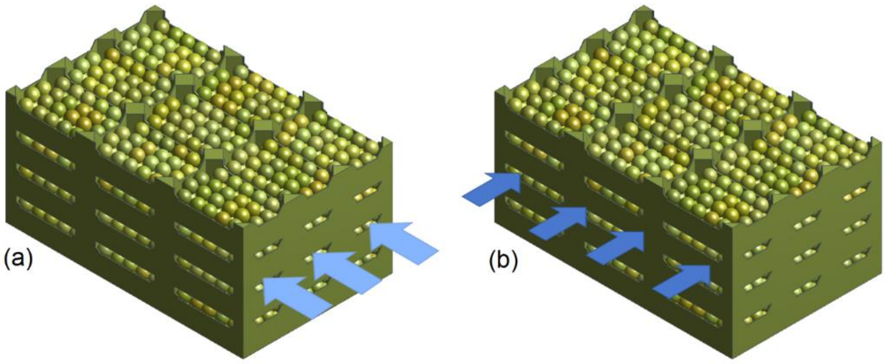
$$\frac{\partial \boldsymbol{V}}{\partial \boldsymbol{t}} + \boldsymbol{\nabla}\left(\boldsymbol{V} \otimes \boldsymbol{V}\right) - \boldsymbol{\nabla}\left(\left(\frac{\mu + \mu_t}{\rho_a}\right)\boldsymbol{\nabla V}\right) - \boldsymbol{S_v} + \frac{\boldsymbol{1}}{\rho_a}\boldsymbol{\nabla P} = \boldsymbol{0} \quad \textbf{(2)}$$

Where V is the vector of airflow velocity (m s^{-1}), t is time (s), ρ_a is density of air (kg m^{-3}), P is the pressure (Pa), and μ and μ_t are the dynamic and turbulent viscosity (kg m^{-1} s^{-1}), respectively. In this study, the shear stress transport (SST) k-ω turbulence model was used to calculate the turbulent eddy viscosity.

First, the airflow resistance characteristics of the stacked tomato were obtained using a detailed CFD model of horizontal airflow through the stack, along two different directions, as shown in Fig. 3.



xi- Fig. 2. The experimental setup to acquire airflow velocity data inside the cold storage room. VB1, VB2 and VB3 are velocity meters behind the stack and VF1, VF2 and VF3 are velocity meters in front of the stack.



xii- Fig. 3. Schematics showing stacked tomatoes as placed in a wind tunnel to determine the resistances to horizontal airflow perpendicular to the short side of the stack (a) and to the long side of the stack (b).

The detailed CFD model furnished the pressure drop vs. airflow data of the stack along the two direction for three different pressure differentials: 1, 10 and100 Pa. Curve fitting of the pressure drop vs. airflow data to the Darcy- Forchheimer model (Eq. (3)) gives the airflow resistance coefficients of the stack. This method of quantifying the flow resistance of stacked produce has been successfully used by Ambaw *et al.* (2013b).

$$\nabla \mathbf{P}_i = \boldsymbol{K_{1i}} \mathbf{u}_i + \boldsymbol{K_{2i}} |\boldsymbol{U}| \boldsymbol{u_i} \qquad \textbf{(3)}$$

Where i stands for the direction in the Cartesian coordinate system (x, y or z), K_{1i} $(= \mu/k)$ and K_{2i} $(= \beta\rho)$ are the viscous and inertial resistance coefficients, respectively. ∇P_i is a pressure drop across the stack (Pa m^{-1}), μ [kg m^{-1}s^{-1}] is the dynamics viscosity of air (fluid), k (m^2) is the permeability of porous medium (stack), u is superficial velocity (m.s^{-1}) and β is Forchheimer coefficient (m^{-1}). Using the airflow resistance coefficients of the stacked tomato from Eq. (3), a porous medium CFD model corresponding to the test setup (Fig. 2) was developed and validated using velocity measurement data. Finally, a porous medium model of airflow inside a fully loaded room (fruit load occupying 60% of the internal volume) was developed for the airflow and thermal analysis.

2.5.2 BOUNDARY AND INITIAL CONDITIONS

The detailed CFD model is based on explicit incorporation of the shape and vent hole design of the package box and the tomato fruit (assumed to be a perfect sphere) (Fig. 3). The surface of the produce and the packaging boxes are no slip boundaries. One end of the tunnel is at suction pressure while the other is open boundary, with a gauge pressure of 0 Pa. Simulation at four different suction pressures: 1, 10, 30 and 300 Pa, were run to acquire the pressure drop vs velocity data across the stack. Curve-fitting of the data to the Darcy-Forchhimer equation (Equation 3) gives the pressure loss coefficients (inertial and viscous coefficients) of the stack.

In the porous medium CFD model, the stacked produce was modeled as a porous domain based on the inertial and viscous coefficients as obtained from the detailed CFD model. In this model, the region representing the CBAC equipment and the remaining region, which is the free air stream, are fluid domains. Accordingly, the fluid-porous (between the porous domain and fluid domain) interfaces are defined as a conservative flux interface boundary. The CBAC was completely inside the cool store and circulates the internal air only. The inlet and outlet cross-section of the CBAC were interfaced with the room atmosphere, so that, the air recirculation effect of the AC is realistically captured. A momentum source is added in the CBAC domain to model the air driving effect of the evaporator fans. The magnitude of the momentum source was determined based on the air velocity data at the CBAC outlet. The EC was modeled using air velocity data at circular cross-section representing the outlet of the EC. All the walls, doors, floors, and ceilings of the store and the surface of the CBAC were no-slip walls.

2.5.3 MESH GENERATION, SENSITIVITY ANALYSIS AND SIMULATION

The model geometry was developed using the ANSYS® Design Modeler™ Release 17.0 (ANSYS, Canonsburg, PA, USA). Also, fine mesh were used near the vent holes and between the tomato fruit of the detailed CFD model. Fine mesh was used at the inlet and outlet of the CBAC and at the cross-section representing the exit of the EC of the porous CFD model since large velocity gradient is expected in these locations. A hybrid grid (tetrahedral and hexahedral elements) was used for the discretization of the computational domain, as this method of discretization is robust and appropriate for complex geometries in the postharvest cold handling system (Ambaw *et al.*, 2013a). Discretization of the domain was accomplished by using the ANSYS® Meshing™ Release 17.0. The problem set-up, simulation and post processing were done using the ANSYS® CFX™ Release 17.0 (ANSYS, Canonsburg, PA, USA). The airflow in both models was solved, assuming a steady state condition. The transport equations were solved using the finite volume method. The advection scheme of the numerical solution uses a blend between central differencing and upwind differencing locally. Under the selected optimum solver format, a single full simulation took 10 to 15 hours on a 64-bit, Intel (R) Core (TM) 2 Quad CPU, 3 GHz, 8 GB RAM, Windows 7 PC.

The Richardson extrapolation method (Roache, 1994; Franke, 2007) was used to measure the level of grid independence in both models. Grids with four and three million cells were used for Models 1 and 2, respectively, with discretization errors of 3.2 and 5.0% in estimating mass fluxes through selected boundaries.

2.5.4 ERROR CALCULATION

The performance of the velocity prediction by the porous CFD model is evaluated by comparing simulated results to experimental data. For this, the root-mean-square error (RMSE) was calculated, as given by Eq. (4).

$$\boldsymbol{RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(U_{sim,i} - U_{Exp,i})^2}} \quad \textbf{(4)}$$

Where $U_{Sim,i}$ and $U_{Exp,i}$ = the simulated and measured velocity magnitudes (m s^{-1}), respectively.

3. Results and discussion

3.1 The pressure loss characteristics

The airflow through the stacked tomato perpendicular to the short side and the long side of the stack are shown in Fig. 4 (a) and (b), respectively. Fig. 5 displays the simulated pressure drop vs. air velocity data corresponding to the two flow directions. The airflow resistance along the two horizontal conditions are significantly different. This is due to the difference in venthole proportion of the two sides. The airflow resistance for flow, perpendicular to the short side, which has an 8.7% venthole proportion is higher than flow perpendicular to the large side which has a venthole proportion of 15.1%. Table 1 gives the viscous and inertial coefficients obtained from fitting the simulated pressure vs. velocity data to Eq. (3).

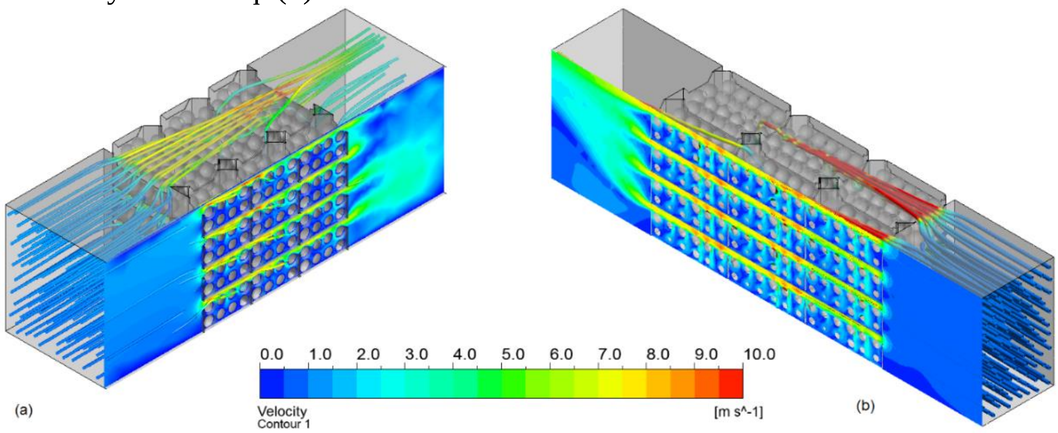


Fig. 4. Simulated velocity streamline and velocity contours under a 100 Pa pressure differential. Airflow perpendicular to the long side of the stack (a) and to the short side of the stack (b).

3.2 Model validation

Fig. 6 (a) shows the simulated air velocity streamlines inside the partially loaded cold storage room corresponding to the experiment. The results show that the spatial distribution of the velocity magnitude varied from 0 m s^{-1} to 2 m s^{-1} inside the cold room. The blower of the EC and the air circulation fan of the CBAC determine the relative magnitude and uniformity of the airflow inside the cold room. The model agrees well with the measured data with a RMSE of 0.12 m s^{-1} in the region in front of the stack and 0.18 m s^{-1} in the region at the back of the stack.

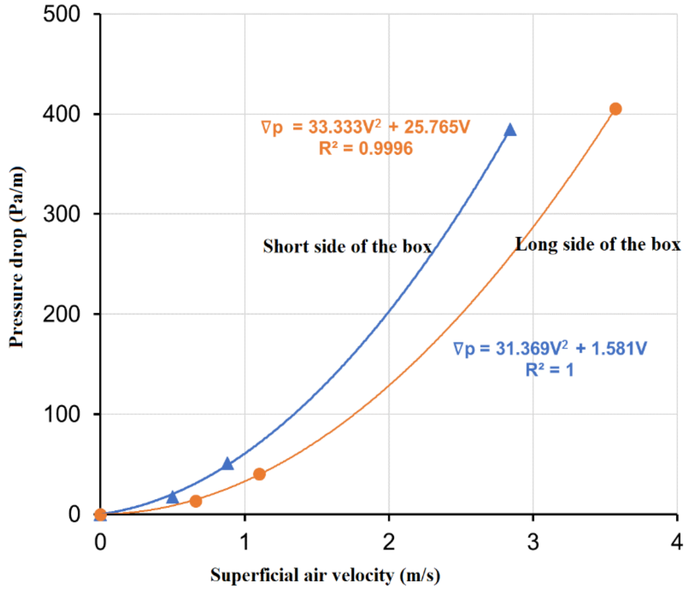
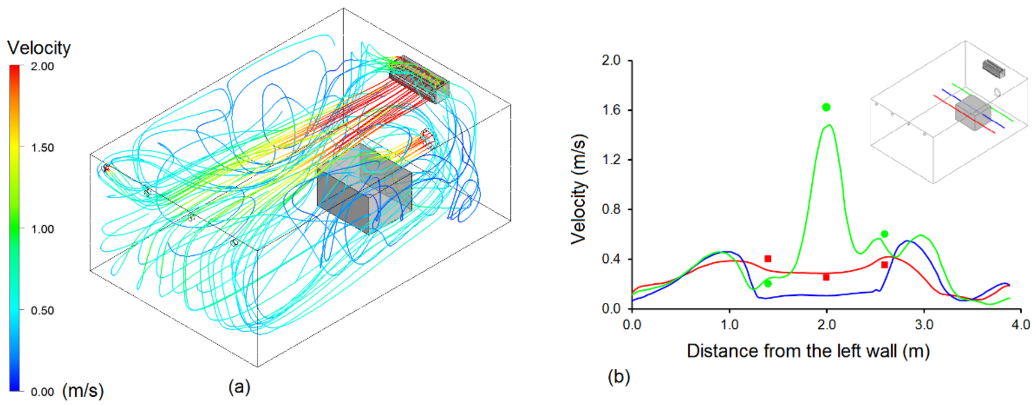


Fig. 5. Graph of pressure vs superficial velocity of the airflow through the stacked tomatoes. Data is obtained from the CFD model.

Table 1 Quantification of the inertial (Forchheimer) term ($K_{1i} = \rho\beta$) and the viscous (Darcy) term ($K_{2i} = \mu/K$) of the Darcy- Forchheimer equation (Eqn. 3) of stacked tomato.

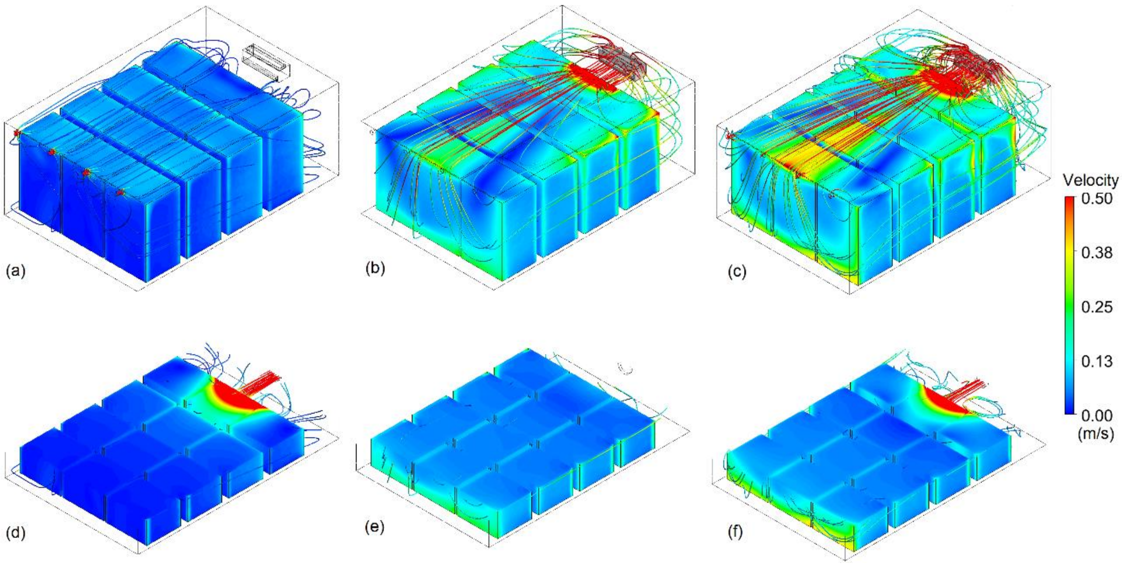
Flow perpendicular to	Inertial term (kg m^{-4})	Viscous term (s^{-1})	R^2
Short side	33.33	25.76	1
Long side	31.37	1.58	1



xiii- Fig. 6. Velocity field inside the partially loaded room. (a) Simulated velocity streamline inside the cool room corresponding to the experimental setup and (b) velocity magnitudes along horizontal line passing through the inlet region of the stack (green (line is model and symbol is the experimental value)), inside the stack (blue) and at the exit region of the stack (red, (line is model and symbol is the experimental value)), in the cold room operating under EC + CBAC.

3.3 INVESTIGATING THE AIRFLOW INSIDE A FULLY-LOADED COOL STORE ROOM

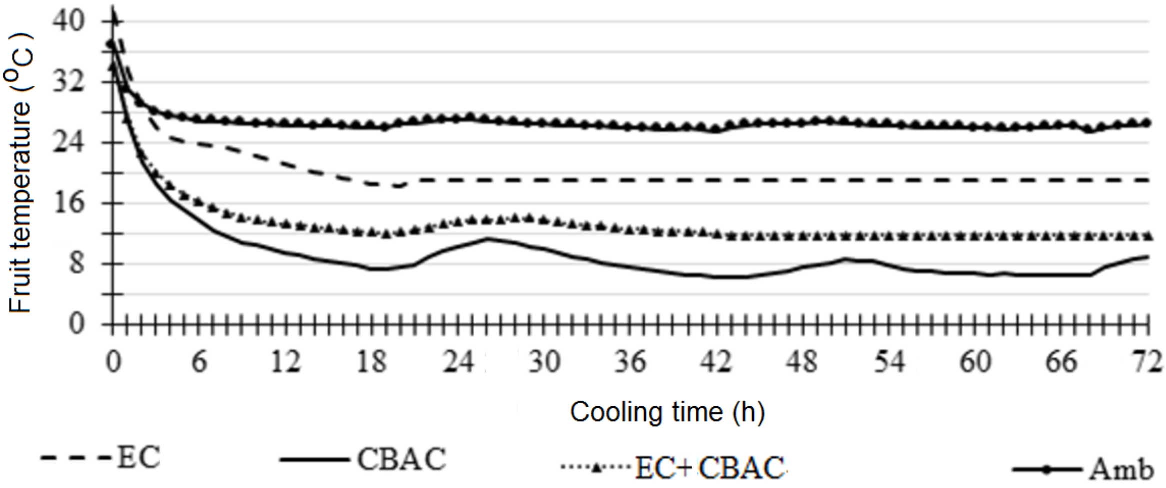
Using the validated CFD model, investigation has been made to evaluate and characterise the airflow inside a fully-loaded cold storage room under EC only (Fig. 8 (a) and (d)), CBAC only (Fig. 8 (b) and (e)) and EC and EC+CBAC (Fig. 8 (c) and (f)). The room operated under EC fan only may leave the central and the back region of the stack under relatively low ventilation condition (Fig. 8 (a) and (d)). On the other hand, the room operated by CBAC only was relatively displayed better distribution of airflow at front, rear and central region of the stacks (Fig. 8 (b) and (e)). The combined operation of EC and CBAC (EC+CBAC) was relatively showed the best airflow distribution inside the fully-loaded store (Fig. 8 (c) and (f)). This might be due the better turbulence creation inside the store because of the presence of air conditioner (top centre of inlet wall) and axial fan (bottom centre of inlet wall), hence, improved the air circulation inside the store chamber.



xiv- Fig. 8. Contour of airflow velocity magnitudes. On the surface of the porous domain (Top row) and on horizontal plane through the stack (bottom row). Only the fan of the EC working ((a) and (d)), only the fan of the CBAC working ((b) and (e)), and while both the EC and fan of the CBAC working ((c) and (f)).

3.4 INVESTIGATING THE COOLING RATE AND COOLING UNIFORMITY

Cooling rate is the most important aspect of postharvest handling of fresh produce. Fig. 9 depict the temperature at the centre of sample tomato fruit inside the three cooling operations in a 72 h period. The CBAC achived the fastest cooling. The combined use of the evaporative cooler and the CBAC closely follow the solitary use of the CBAC.



xv- Fig. 9. The averaged cooling temperature and time step series of EC, CBAC and EC+CBAC cooling systems.

4. Conclusions

The development of a CFD model to characterize the resistance of the stack of tomato packages and the application of the CFD to model fully loaded cold room subjected to different scenarios (i.e. EC, CBAC and EC+CBAC cold rooms) were performed. The pressure drop resistance coefficients of the stacked tomato were determined and further used to model the fully-loaded stack. The model fitted well, with an RMSE air velocity of 0.18 m.s-1 and 0.12 m.s-1, across the inlet and outlet of the tomato stacks. The CFD model showed that using the EC alone may leave a large portion of the produce (those at the center and back region of the cool room) without sufficient ventilation. Hence, the combined use of the EC with the CBAC is essential. The airflow, cooling rate, temperature distribution, and produce quality should be further analysed numerically and experimentally to completely evaluate the situation.

5. Acknowledgements

We would like to warmly acknowledge the Federal Ministry of Education, Ethiopia. South African National Research Foundation (NRF – TWAS); Tomato Producer Organization (TPO); Postharvest Innovation Program (PHI) for provision of financial support; ZZ2 Tomato Farm for the prevision of the required sample tomatoes and the host institute, University of Kwa-Zulu Natal.

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Characterization of the Strength and Microscopy of Cassava Flour Extrudates

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ABSTRACT

Knowledge of the microstructure of foods is fundamental to understand its properties, to be able to describe, forecast, and control its behaviour and the organization of its components. Also, their force-deformation characteristic finds application in the design of relevant processing equipment. In this study, a JSM 7600F Jeol ultra-high resolution field emission gun scanning electron microscope (FEG-SEM) was used to study the microstructure and energy dispersive spectroscope (EDS) of extrudates of cassava flour extrudates while the compressive strength was measured with a Testometric Universal testing machine UTM 500-532. The cassava flour was prepared from cassava tubers (*Manihot esculenta* Crantz) TMS 30572 at 25% w.b. moisture content and extruded for 30 minutes. The extrusion of the samples was done with a locally developed single screw extruder (L\D- 12:1, CR – 4.4:1, die diameter 6mm and 12mm). The result indicated that melting of the starch samples increase with increase in extrusion time. Also, extruded cassava flour samples have stronger cell walls than samples mixed with other ingredients. More gelatinization was observed in samples extruded with 6mm die than those with 12 mm die. Extrusion cooking resulted in changes in percentage by weight of the elements composition of cassava flour. There was increase in the percentage composition of oxygen from 26.17% to 52.12 % and 41.98% due to oxidation. The compressive test result showed that compressive strength of cassava flour extrudates reduced with extrusion time with a maximum strength of 1098.6 N at 100 rpm extrusion speed. This result is an indication that cassava flour extrudates are hard at low temperature while they become softened with increase in extrusion temperature.

Keywords: Food extrusion, scanning electron microscopy, cassava flour, compressive strength, extrusion time.

1. INTRODUCTION

Micro structural studies are indispensable in describing, forecasting, and control the behavior of food products and the organization of its components (Xiao and Gao, 2012). This is because structure of foods can have a profound influence on its nutritional value, rheology and textural attributes. Food processing such as thermal and non-thermal processes can be thought of as altering the natural structure and the composition of food materials. Therefore, electron microscopy has been widely employed for the evaluation of the microstructure of food and biological products. Knowledge of the microstructure of foods is fundamental to understand its properties, so as to be able to describe, forecast, and control its behavior and the organization of its components. Their force-deformation characteristics finds application in the design of relevant processing equipment. Changes in porosity as well as the cellular structure of food materials during processing are known to influence processing rates, mechanisms and thus the product quality. Pore dimensions affect the energy required to cause fracture. Microstructure is determined by nature of processing. Cells were generally not evenly distributed. According to Fazaeli et al. (2012), microscopy is used to study the influence of processing conditions and ingredients on food structure. Food processing such as thermal and non-thermal processes can be thought of as altering the natural structure and the composition of food materials. Moreover, to improve on the quality of dried foods, micro-structural analysis is very necessary. This is because some of the structural elements contributing to the desirable properties of foods are below the range of 100µm range. Scanning electron microscopy (SEM) is a very useful tool to visualize food structure. Finally, the strength properties of foods play an important role in textural evaluation as well as in the selection of the correct equipment in operations involving the deformation of foods. The amount of energy that is absorbed by food before it fractures is determined by its hardness and tendency to crack (friability) which in turn depends on the structure of the food. Harder foods absorb more energy and consequently require a greater energy input to create fractures. The more line of weakness in a food, the lower is the energy input needed fracturing. The objective of this study was to use microscopy and universal testing machine to study the influence of different extrusion conditions and ingredients on food structure and strength.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Cassava tubers (Crantz) TMS 30572, were sourced from experimental plots at the Federal College of Agriculture, Akure and processed into flour within 48 hr of harvesting. The materials were passed through a 300µm sieve separately and the proximate analysis and moisture contents of samples were determined as described by AOAC (1995) approved method.

2.2 Experimental Procedure and Data Collection

A locally developed extruder was used in this study (Figure 1 and 2). The extruder screw is of single flight, increasing diameter and tapering/decreasing pitch with (L\D-12:1, CR – 4.4:1, die diameter 6mm and 12 mm) configuration. More details of the extruder can be found in Fayose et al 2017.Samples were fed into the extruder at a constant feed rate 10kg/h, 27 ^{o}C room temperature and screw speed of 150 rpm until steady state. The extrudates were extruded as ribbons and later cut manually to a length of 10 cm each. Samples were collected until 30 minutes at every 3 minutes duration. Samples were thereafter dried in a dryer to safe moisture content of 12% d.b. and stored. The temperature of extrusion is built up with extrusion time by viscous dissipation.

A JSM 7600F Jeol ultra-high-resolution field emission gun scanning electron microscope (FEG-SEM) equipped with energy dispersive spectroscope (Figure 3) was used to study the microstructure and elemental composition of the cassava flour. The EDS of sample show the elemental composition of the samples Samples were dried and cut, grinded and attached to SEM stub with a carbon tape. The samples on the stub were coated with platinum and examined using the SEM at 15kV at different magnification (between 100-5000). However, due to electron charging of some of the samples, they were observed at 3.0 kV. Also, cassava flour samples were mixed with proven ingredients used in Nigeria for compounding fish feed (Gbadamosi et al, 2006) for comparison of results.

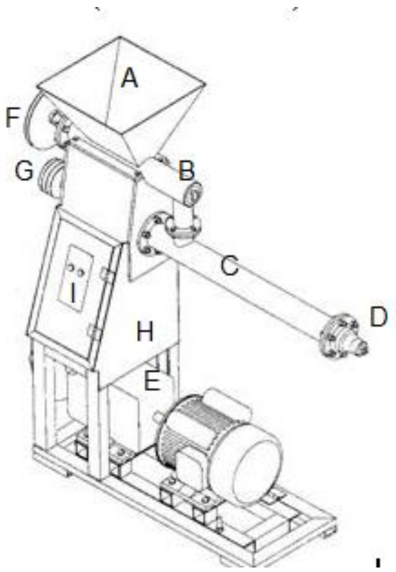

FIGURE 1: Isometric drawing of the extruder used- LEGEND A- Hopper, B- Feeding Conveyor, C- Extruder worm, D- Die Unit, E- Power train, F- Conveyor pulley, G- Extruder pulley, H-Extruder Housing, I- Control switch.

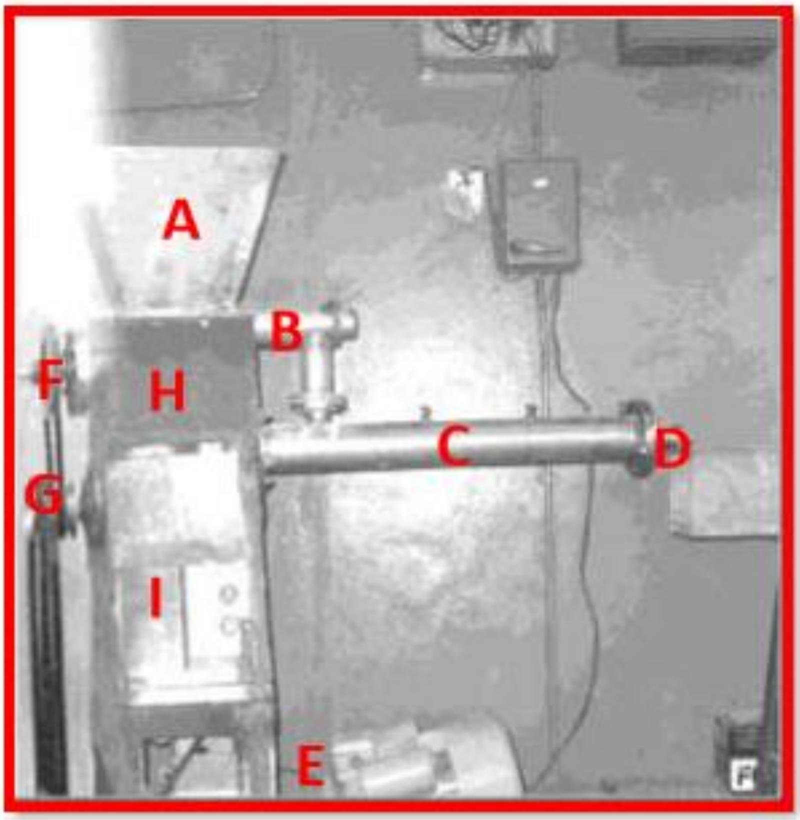

Figure 2: The picture of the extruder used.

Figure 3: The SEM used for the study

Compression forces, was measured using the Testometrics Universal Testing machine 500-532 at the Material Testing Laboratory of the National Centre for Agricultural Mechanisation (NCAM), Ilorin – Nigeria. (Figure 4) Dried strands of extruded products

20mm long with carefully aligned out surfaces were added in compression using the compression jaw/rig (plate) of the UTM at a loading rate of 1cm/min until failure occurs according to Guan and Hanna (2004). The peak load was reported as the compressed strength. The peak force was defined as the height of the first peak. The peak force represents the resistance of extrudate to initial penetration and is believed to be the hardness of extrudate Each sample was measured three times and reported as an average of three readings.

Figure 4: Testometric Universal testing machine

3. RESULTS AND DISCUSSION

The representative SEM micrographs of the extruded products are presented in Figures 5 to 10. The result indicated that melting of the starch samples- an indication of gelatinization, increased with increase in extrusion time. Low degree of gelatinization results in the presence of particles in extrudates. Also, extruded cassava flour samples have stronger cell walls than samples mixed with other ingredients. More gelatinization evidenced was observed in samples extruded with 6mm die than those with 12 mm die. This shows that smaller dies gave more gelatinization than bigger dies under the same conditions.

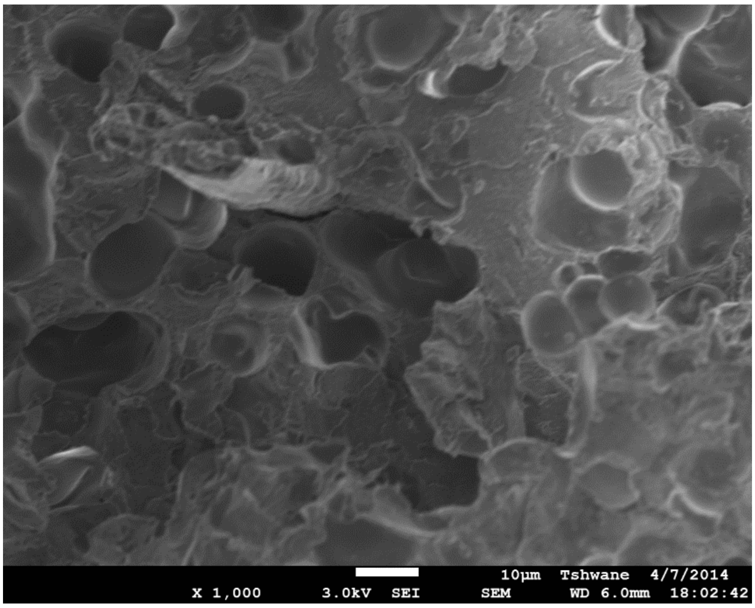

Figure 5: Extrudate with 6mm die θ at early extrusion showing unmelted starch particles

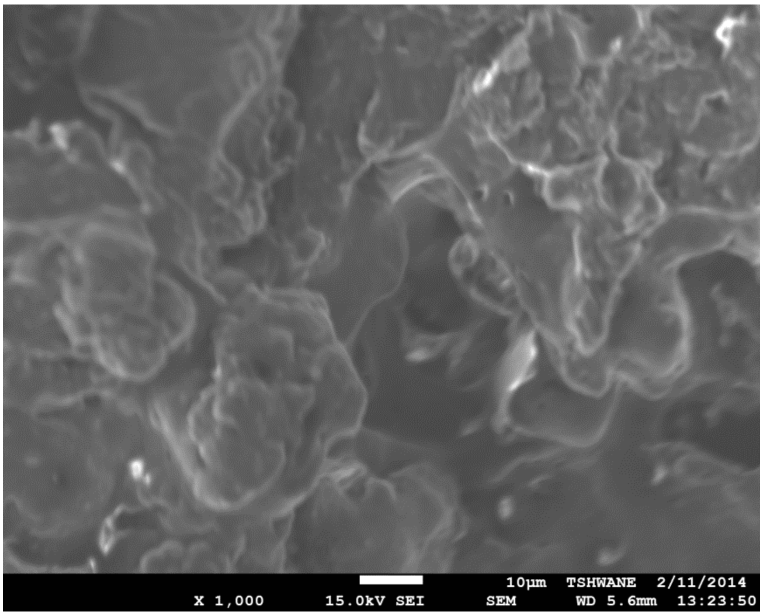

Figure 6: Exrudate extruded with die 12mm at 30 mm extrusion time showing unmelted starch particles

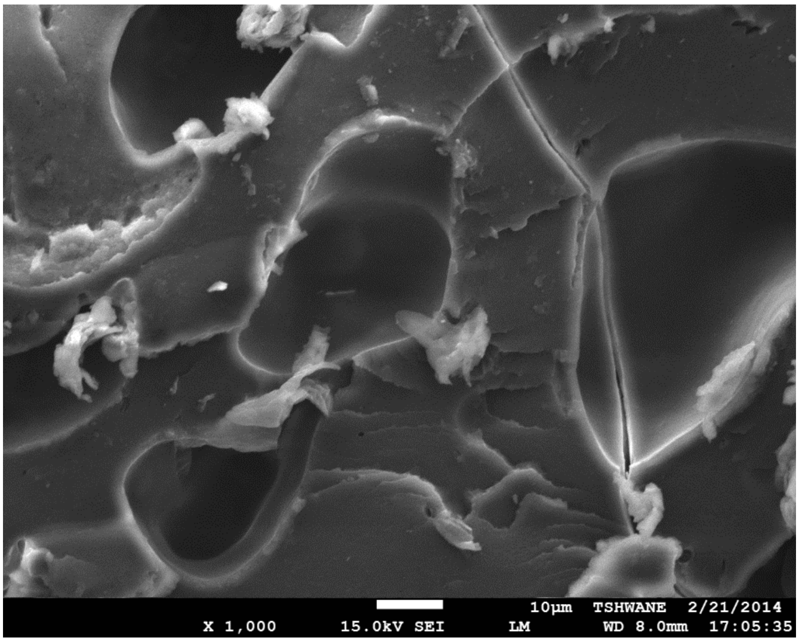

Figure 7 Extrudate with 6mm die θ at 30 minutes duration of extrusion showing melted starch particles

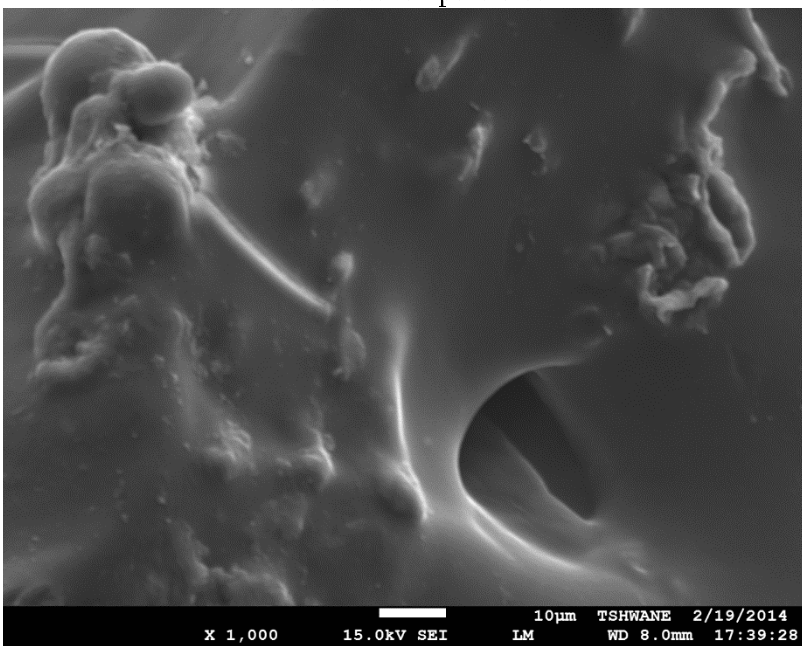

Figure 8: Extrudate with 6mm die θ at 21 minutes extrusion showing unmelted starch particles. However, the degree of melted starch particle is higher than that of Figure 1

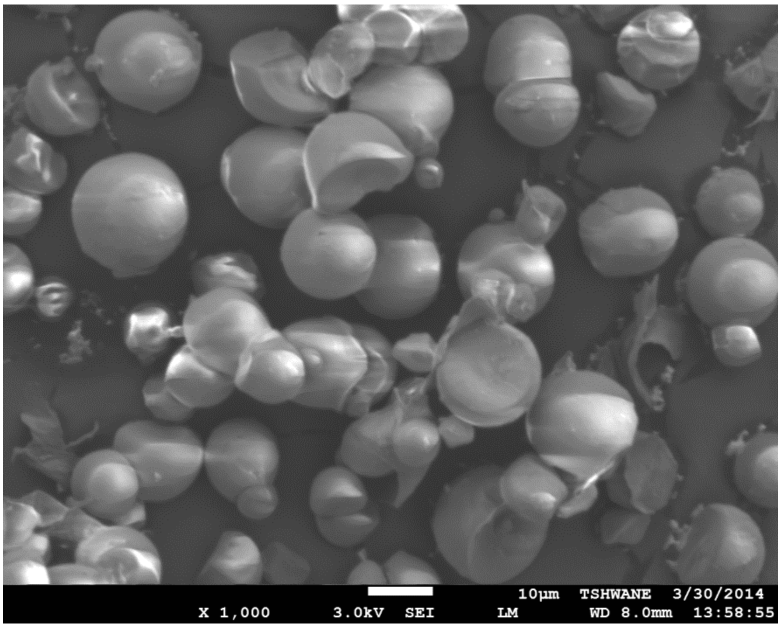

Figure 9: Raw cassava flour

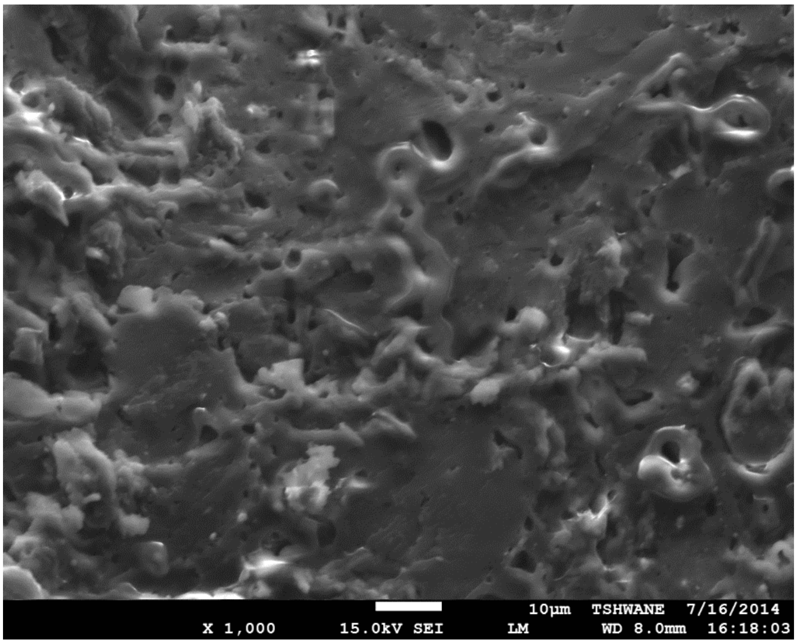

Figure 10: Cassava mixed with fish feed ingredients showing fragments

Tables 1 -3 shows the percentage by weight of the elemental composition of the cassava used for the experiment. It contains Carbon (C) and Oxygen (O). Extrusion cooking resulted in changes in percentage by weight of the C and O. As can be observed from Tables 1-3, there was increase in the percentage composition of oxygen from 26.17% to 52.12 % and 41.98% with extrusion. The reason for this observation is oxidation of the carbon content.

Table 1: EDS for raw cassava flour

Element	Weight%	Atomic%
C	47.88	55.03
O	52.12	44.97
Totals	100.00	

Table 2: EDS for Exrudate @ 15 minutes of extrusion

Element	Weight%	Atomic%
C	73.83	78.99
O	26.17	21.01
Totals	100.00	

Table 3: EDS for Exrudate @ 30 minutes of extrusion

Element	Weight%	Atomic%
C	73.83	78.99
O	26.17	21.01
Totals	100.00	

The compressive test result showed that compressive strength of cassava flour extrudates reduced with extrusion time with a maximum strength of 1098.6 N at 100 rpm extrusion speed. This result is an indication that cassava flour extrudates are hard at low temperature while they become softened with increase in extrusion temperature.

4. CONCLUSION

The strength and microscopy of cassava flour extrudates of a locally developed single screw extruder have been characterized in this study. Melting of the starch samples increased with increase in extrusion time. Also, extruded cassava flour samples have stronger cell walls than samples mixed with other ingredients. More gelatinization was observed in samples extruded with 6mm die than those with 12 mm die. Extrusion cooking resulted in changes in percentage by weight of the elements composition of cassava flour. Also, cassava flour extrudates are hard at low extrusion temperatures while they become softened with increase in extrusion temperature. These observations will assist on the use to which the products from extruder can be put.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Performance Evaluation of a Hydraulic Press for Oil Palm

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ABSTRACT

The traditional method of palm oil extraction is not only a health hazard to the processors but is inefficient, as a lot of oil is left trapped in the mixture as an emulsion. Mechanical hydraulic press of different varieties have been designed and fabricated locally by the research engineers to solve the problems of oil extraction, but some of these mechanical devices are low in efficiency due to poor feeding rate. The performance evaluation of an existing palm oil hydraulic press was carried out with a view of increasing the quality and the quantity of oil extraction. Fresh palm kernel fruits were harvested from Igbo Oloogun in Saki, Saki Oyo state, Nigeria. The fruits were sterilized; digested and known weight of the palm kernel mesh was taken and subjected to pressing. The capacity of the press is 5.0 kg/h. Feeding of 2.0, 2.5, 3.0,
3.5, 4.0, 4.5 and 5.0 kg/ batch were tested. The result indicated that the oil yield increased from 42 to 55% as the feed rate increased from 2.0 to 3.5 kg/batch. However, the oil yield decreased from 55 to 35 % as the feed rate increased from 4.0 to 5.0 kg/batch. The highest oil yield was achieved at 3.5 kg/batch feed rate.
Key words: Oil palm, Feed rate, Hydraulic press, Digested mesh and Oil yield.

1. INTRODUCTION

Oil palm (*Elaeis guineensis*) is a perennial plant generally agreed to originate in the tropical forest of West Africa (FAO, 2004). It is a single, indispensible tree with many vital by-products. The products include palm oil, palm kernel oil, palm kernel cake, fibre, palm wine, fatty alcohol, broom, and wood plank. Many have called it the richest productive plant in the plant kingdom (Kheiri 1985, Kurki *et al*., 2008). The oil palm gives the highest yield of oil per unit area compared to any other crop and produces two distinct oils - palm oil and palm kernel oil - both of which are important in world trade (FAO, 2004). Processing of palm fruit to obtain oil involves five basic operations which are fruit threshing, fruit sterilization, digestion, oil extraction, cooking and oil clarification (Owolarafe *et al*., 2009). Nigeria, Palm Oil extraction is mostly done traditionally by squeezing and mashing the pulp fruits of the oil palm nut which results to waste of time, high low output, and the high level of drudgeries involved in the process requires great concern. Mechanical expression by hydraulic or screw press is common in modern palm oil production. However, hydraulic press is common in small scale processors because it is less capital intensive in terms of initial and maintenance costs (Adeeko and Ajibola, 1990; Owolaafe *et al*., 2002). Different types of mechanical press have been developed. These feature spindle presses inform of threaded shaft carrying a piston and a perforated cage and many more. Apart from the fact that the presses are manufactured locally due to the simplicity of the design and maintenance is very easy. However, some of these existing mechanical oil presses are operating under poor processing conditions resulting to low efficiency and high percentage of oil losses. Hence, there is need for performance evaluation of an existing hydraulic oil press machine with a view of increasing the output, reducing the operation time and eradicate drudgeries encountered in the traditional extraction of palm oil.

2. MATERIALS AND METHOD

This section presents the test materials used, description of the exiting machine and the experimental procedure in carrying out the performance evaluation of the existing oil press.

2.1.1 Source of Test materials

Freshly harvested palm kernel fruits (tenera species) were used as a test material. The oil palm fruits were harvested from a private Farm at Igbo Ologun, a village nearby Saki, OyoState, Nigeria. The bunches were carefully harvested and manually threshed from the spiklets to avoid mechanical damage such as brushing and abrasion which may affect the quality of oil extracted.

2.1.2 Machine

The existing hydraulic oil press in the storage and processing laboratory of the Agricultural Engineering Department of the Oke-Ogun Polytechnic was used as a test machine to carry out the performance evaluation of the hydraulic press.

2.2 Experimental Design

Performance evaluation was carried out at different moisture contents (22.30, 24.75, 45.76, 41.23 and 42.34%), loading of mash per batch (2.0, 2.5, 3.0, 3.5 and 4.0 kg/batch) and level of hydraulic jack pressure (90, 95, 100, 105 and 110 kPa). The levels of the processing parameters were chosen in accordance with the suggestion of Owolarafe *et al*. (2007b).

2.3. Test Procedure

The machine was evaluated by determining its extraction efficiency and the percentage of oil losses. Freshly harvested fruits were sterilised for 90 minutes and digested for 10minutes based on the previous experiment carried out by Babatunde *et al*. (1988) and Owolarafe *et al*. (2007b). Known weight of palm kernel mash was taken from the digester mash and subjected to pressing at different loading rate, level of hydraulic jack and moisture content. The choice of the quantity of mass was based on the practice in the use of hydraulic press by processors and the capacity of the press.

The oil yield was determined as the percentage of mass of oil recovered from the total mass of the mass as given below:

$$.Oil\ yield\ (\%) = \frac{W_M - W_P}{W_M} \times 100 \qquad 1$$

Where:

Wm = Weight of mash before extracted of oil

Wp = Weight of pressed cake after extraction of oil.

The extraction efficiency of the machine was determined as the ratio of oil yield (%) to oil content of the fruit. The extraction efficiency is thus given below as:

$$Extraction\ efficiency = \frac{oil\ yield}{oil\ content}\ x\ 100 \qquad 2$$

$$Machine\ throughput\ capacity = \frac{mass\ of\ paste}{pressing\ duration} \qquad 3$$

3. RESULTS AND DISCUSSION

The result of the performance evaluation of an existing manually hydraulic oil palm press at different loading rate, level of hydraulic jack and moisture contents in terms of percentage oil yield, extraction efficiency, machine throughput capacity and percentage of oil losses is presented and discussed in this section.

3.1.1 Performance evaluation of hydraulic press at different processing conditions

The result of the performance evaluation of the hydraulic press at different processing conditions sis presented in Table 1. The highest oil yield (55%) is obtained at 3.0kg loading rate, 45.76% moisture content and hydraulic jack of 100 kPa. While the lowest oil yield (35.01%) is obtained at a moisture content of 42.34%, 4.0 kg loading rate and hydraulic jack level of 110 kpa. However, the oil yield decreased from 55 to 35% as loading rate increased from 3.5 to 5.0 kg/batch. The increase in oil yield with pressure is in line with the previous findings of Owolarafe *et al* (2002) and Baryen (2001) on palm oil extraction. It also agrees with the earlier work of Ajibola *et al* (1992) on sesame seed oil extraction. The increase in oil yield with pressure may be attributed to the fact that the breaking of oil cells and flow of oil is enhanced with increase in pressure.

The effects of hydraulic jack pressure on extraction efficiency are also presented in Table 1. An extraction efficiency of about 62% was obtained at hydraulic jack pressure of 100 kpa while the least extraction efficiency of 50% was recorded at a hydraulic jack pressure of 110 kpa. This value is an improvement over that record on the hydraulic press or screw alone as reported by Owolarafe (1999). This efficiency also compares favourably well with most motorised screw presses.

3.1.2 Effects of loading rate on throughput capacity

The effect of loading rate on throughput capacity of the hydraulic press is presented in Figure 1. It could be seen the Figure that the throughput capacity of the machine increased as the loading rate increased from 2.0 to 4.0kg of the press capacity but decreased as the loading rate increases from 4.0 to 5.0kg. This may be as a result of the capacity of the hydraulic press used.

Table 1: performance evaluation of a hydraulic press at different processing conditions

Moisture content (%)	**Loading/ batch (kg)**	**Hydraulic pressure (kPa)**	**Pressing duration (min)**	**Weight of mash extracted (kg)**	**Oil yield (%)**	**Extraction efficiency (%)**
22.30	2.0	90	2.45	10.21	42.00	50
24.75	2.5	95	3.21	13.45	47.91	57
45.76	3.0	100	4.00	16.05	51.00	62
41.23	3.5	105	3.98	14.98	55.00	53
42.34	4.0	110	4.01	14.78	35.01	52

4. CONCLUSION

The performance evaluation of the hydraulic oil palm press was carried out. The highest oil yield (55%) was achieved at 3.5 kg/batch feeding. An extraction efficiency of 62% was obtained at hydraulic jack pressure of 100 kPa while the least extraction efficiency of 50% was recorded at a hydraulic jack pressure of 90 kPa.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Effect of Solar Drying Methods on Drying Time and Proximate Composition of *Brycinus nurse* Dried During the Wet Season

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ABSTRACT

Fish can be classified as highly perishable product and drying is one of the methods normally employed to reduce its spoilage and increase the shelf life. There are different fish drying techniques and this study was conducted to investigate the effect of different solar drying methods on the drying time and proximate composition of *Brycinus nurse* dried during the wet season. The study was carried out in Maiduguri, North Eastern Nigeria, to take advantage of its abundant solar radiation. Conventional Solar Dryer (CSD) and Hybrid Solar Dryer (HSD), with the dimensions of 1550 x 800 x 109 mm were used while sun drying (SD) served as control. The CSD and SD utilised solar energy, while charcoal was the additional heat source in HSD. The thermal profile for each of the dryers was conducted. About 2400 g fish was spread in thin layer in triplicates on drying trays in the drying chamber and were dried in the solar drying chamber. Weighing of fish samples and temperature readings were carried out with respect to time as follows: 10, 30, 50 up to 240 minutes and subsequent measurements and readings continued hourly until three consecutive readings gave identical weights. The drying was then terminated, the time taken was recorded and proximate composition (%) of fresh and solar dried *Brycinus nurse* was investigated for moisture, protein, fat and ash contents, crude fibre and dry matter using the AOAC standard. Data obtained were subjected to statistical analysis using one way analysis of variance (ANOVA). Results show that the average minimum and maximum temperatures (^{0}C) were 31.3±1.03 and 85.2±4.40 for CSD; 32.7 ±1.72 and 89.7±1.86 for HSD and 31.0±1.41 and 45.0±2.83 for SD. Average drying time for fish in CSD, HSD and SD was 2580, 2460 and 3480, respectively. The moisture content of fresh *B. nurse* was 71.36±8.1e^{-5} while for fish dried in CSD, HSD and SD, was 4.42±0.01, 11.48±0.05 and 8.02±0.12, respectively. Crude protein was 14.00±0.01 for fresh and fish dried in CSD, HSD and SD, was 18.47±0.02, 19.52±0.03, and 15.67±0.02, respectively. Fat content for fresh fish was 23.00±0.01, while fish dried in CSD, HSD and SD was 21.00±0.07, 11.00±0.06 and 17.00±0.02, respectively. Crude fibre for fresh *B. nurse* was 23.00±0.08, while the fish dried in CSD, HSD and SD was 31.00±0.012, 28.00±0.02 and 34.00±0.03, respectively. The dry matter content of fresh *B. nurse* was 28.60±0.08 while that of the dried fish was 86.30±0.09, 87.90±0.21 and 76.50±0.37 in CSD, HSD and SD, respectively. The ash content for fresh had 1.50±0.16 and the fish dried in CSD, HSD and SD was 4.00±0.11, 2.00±0.01 and 2.00±0.08, respectively. Drying time differed significantly with solar drying methods (p>0.05). The proximate composition of fresh fish was not significantly different from that of fish dried in solar dryers. Proximate composition of dried fish was significantly different with respect to solar drying methods (p<0.05). Conclusively, solar drying methods, had effect on drying time and proximate composition of *B. nurse* dried during the wet season.

Keywords: Moisture, Protein, Wet season, *Brycinus nurse*, Maiduguri

1. INTRODUCTION

Fish is an important protein source available in the tropics, and it represents about 14% of all animal protein on a global basis (Abolagba and Melle, 2008). Fish has been widely accepted as a good source of protein and other elements necessary for the maintenance of healthy body (Adebayo-Tayo *et al.,* 2012). Fish is an excellent low fat source, providing many benefits, such as low cholesterol and an excellent source of livelihood (Charlton *et al.,* 2016). It is a rich source of essential requirements for supplementing both infant and adult diets (Phiri *et al.,* 2013). It constitutes a very important component of the diet for many people and often provides the much needed nutrients unlike cereal-based diets (Ali, 2013; Ekunke *et al.,* 2017). The importance of fish to man cannot be overemphasized (Udeze *et al.,* 2012).

Fish is an important commodity in the international trade, however they deteriorate rapidly due to high ambient temperature. It is estimated that one-third of fish produced worldwide is lost and or wasted (Affognon *et al.,* 2015). Fish is a very perishable commodity and hence susceptible to high post-harvest losses. Both physical and quality losses are high in fisheries sector. These translates into losses, in nutritional contribution of fish to the total diet and health of the populace (Kabahenda *et al.,* 2011). Very high levels of post-harvest loss occur during handling, processing, storage and transportation of fishery products (Rahman *et al.,* 2013). Post-harvest fish losses are commonly caused by: discarding of bye catch at sea because the fishes are too small or not valuable enough for sale, poor processing techniques damaging fish, animal predation, insect infestation, inadequate packaging and storage facilities, leading to damage of the end product (Yvette, 2011). Post-harvest loss in fish products, is a nuisance to the Nigerian fish industry particularly at the artisanal level. Post-harvest losses occur at various level of production from capturing method to marketing channels (Idakwo *et al.,* 2016).

Solar-drying of agricultural products in enclosed structures by forced convention is an attractive way of reducing post-harvest losses and low quality of dried product associated with traditional open sun-drying method (Jain and Tiwari, 2003 as cited by Prakash and Kumar, 2014). In many rural locations in most developing countries, grid-connected electricity and supplies of other non-renewable source of energy are unavailable, unreliable, or too expensive. Bello *et al.* (2011) revealed that solar dried fish were neater, odourless, with no contamination from stones, dust, and no insect infestation observed and were fit for prolonged storage. Therefore, this study aimed to determine effects of solar drying methods on drying time and proximate composition of *Brycinus nurse* dried during the wet season.

2. MATERIALS AND METHODS

The study was carried in Maiduguri in North-Eastern Nigeria. The fish species, *Brycinus nurse* used in this study was procured from Alau Lake. Alau Lake is the second largest lake in Borno state, Nigeria. It is located between latitude 12°N and 13°N and longitude 11°E and 13°E with total surface area of 56 km. The climate is sahelian with two distinct seasons. The wet season starts from June to September, with a mean rainfall of about 600 mm, and a dry harmattan period precede the rainy season from October to February. (Idowu *et al.*, 2004). The sampled fish was identified using standard taxonomical key (Fish Base, 2012). The conventional solar dryer (CSD) shown in Figure 1, which had three main compartments: the drying chamber, the collector area and the dryer tool frame was used. The materials used in the construction of the conventional solar dryer was obtained from the local market. The CSD uses only natural convention to remove moisture from the fresh fish and dry the product to a lower or safe moisture content level. Drying chamber of the CSD was rectangular in shape, it had double walls made up of plain galvanized alloy steel sheet (gauge 16). The outer structure was 1550 mm x 800 mm x 109 mm, in length, breadth and width, respectively. The inner structure was made of aluminium sheet (0.7 mm thickness), measuring 1470 mm x 700 mm x 105 mm length, breadth and width, respectively. In between the outer and the inner structure was a 40 mm space, which served as the lagging interval for insulation. As shown in Figure 2, the hybrid solar dryer (HSD), comprises of four main compartments: the drying chamber, solar collector, the dryer tool frame and the combustion chamber. The HSD has same components with the conventional solar dryer except the external heat source combustion chamber. The combustion chamber for alternative source of energy used to enhance further drying of product during the rainy/cloudy days and sunset. A no-load test was conducted for the thermal profile in each of the dryers for 3 days between sunrise and sunset (6am-6pm). The temperature of the drying chamber and the ambient temperature were measured using laboratory type, mercury-in-bulb thermometer (accuracy ±0.5°C) at the regular interval of one hour between the hours of 6.00 and 18.00 local time for a period of three days. This idea was borne out of minimum and maximum drying temperature 60°C and 90°C considered suitable for drying fish by (Rahman, 2006).

The fish species of 2400 g was weighed and divided into three equal parts of averagely 800 g each. The 800 g fish was spread in thin layer and the three trays were placed in the drying chamber and was firmly closed to avoid escape of heat. Through the inlet, air enters the chamber, which was heated up by the collector, and the air moved over the fish to remove moisture and the moist-laden air was raised and moved out of the

chimney. Changes in fish weight were monitored throughout the experiment by weighing periodically using an electronic balance (model MS2000). Weighing of fish samples and temperature readings were carried out with respect to time as follows, 10, 30, 50… 240 minutes (20 minutes interval) and subsequent measurement and readings continued hourly until three consecutive readings gave identical weights. The drying was then terminated, the time taken was recorded. Intermittent turning of the fish was also carried out to ascertain effective drying and moisture removal. The fish was carefully removed from the different trays and packed in a labelled plain polythene bag for laboratory analysis.
This drying process continued for the different drying methods. Except in the hybrid dryer, 2 kg of charcoal was introduced into the stove and already ignited charcoal was introduced into the middle to ignite other charcoal for gradual burning and the opening for the stove was carefully closed. The charcoal was allowed to burn all through the night until it got exhausted to continue the drying process.
The moisture content, crude protein content, fat content and ash content of the products was determined according to the (AOAC, 2006). All samples were analysed in triplicates and data were subjected to one-way analysis of variance (ANOVA). Post hoc analysis was done by the use of Duncan’s Multiple Range Test and means were separated at $P<0.05$ using the Statistical Package for Social Scientists computer software package (IBM, 2012).

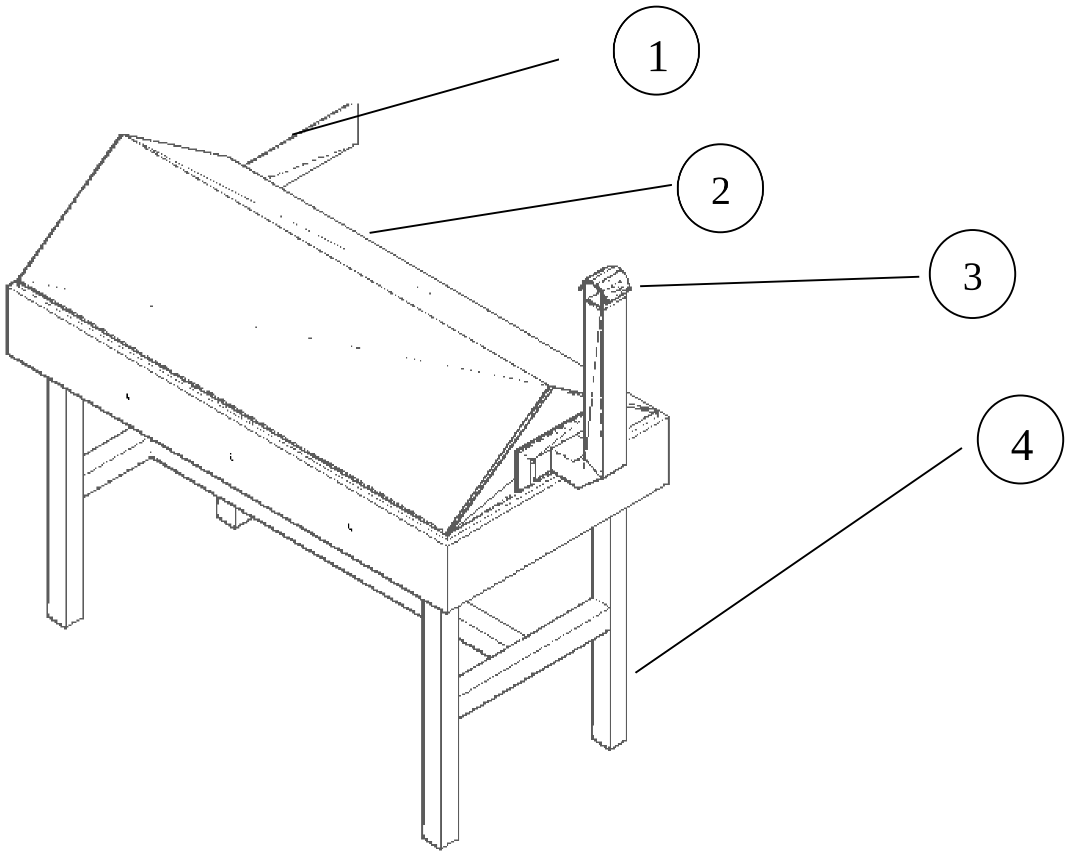

Figure 1: Conventional solar dryer

Part list

1. Inlet 2. Glass cover 3. Vent 4. Stand

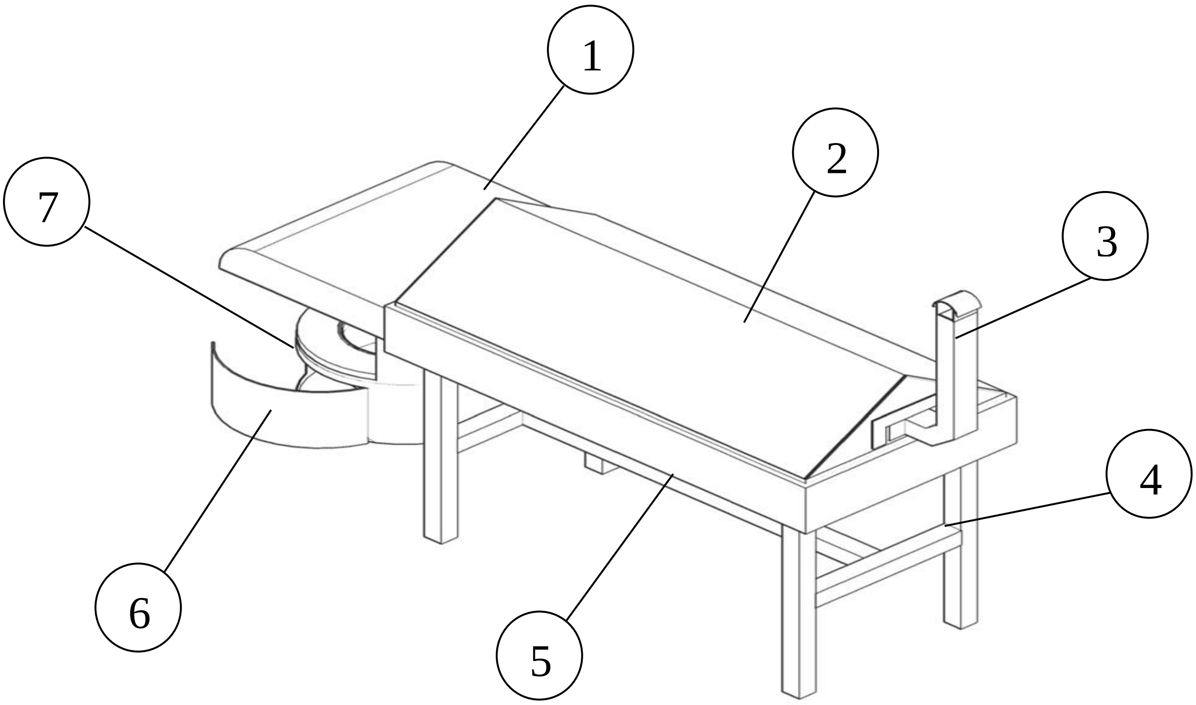

Figure 2: Hybrid solar dryer

Part List

1. External heat source 2.Glass cover 3. Vent 4. Stand 5. Drying chamber 6. Lid for the power source 7.Internal compartment for the stove

3. RESULTS

The mean unloaded temperature reading within the solar-drying compartments and ambient temperatures (°C) is presented in Table 1.

Table 1: Mean unloaded temperature reading within the solar-drying compartments and ambient temperatures (°C)

Time (hour)	Conventional solar dryer	Hybrid solar dryer	Ambient
6am	31.3±1.03	32.7±1.72	31.0±1.41
7	36.7±1.97	36.8±1.94	32.5±0.72
8	33.3±2.42	52.7±3.20	38.0±2.83
9	63.0±3.90	62.5±3.56	39.0±4.24
10	73.8±4.996	75.1±3.92	41.5±2.12
11	81.7±3.67	83.5±3.78	44.0±1.41
12	85.2±4.40	89.7±1.86	45.0±2.83

13	82.7±1.15	88.5±6.63	44.5±2.12
14	78.7±3.78	80.8±2.71	43.0±2.83
15	75.0±3.29	74.8±4.12	42.5±2.12
16	58.5±1.52	59.8±2.04	41.5±0.71
17	48.8±2.04	49.8±2.04	40.5±0.71
18	44.0±0.63	44.0±1.26	40.0±0.01

The variation of drying time and moisture content with respect to *B. nurse* in the wet season is presented in Table 2.

Table 2: Variation of drying time and moisture content with respect to *B. nurse* in the wet season

Drying Methods	Moisture content (%) Initial	Final	Drying time (minutes)
CSD	71.36±0.01	4.42±0.01	2580
HSD	71.36±0.01	11.48±0.05	2460
SD	71.36±0.01	8.02±0.12	3480

The mean proximate composition of *Brycinus nurse* and standard deviation is as shown in Table 3.

Table 3: Mean proximate composition and standard deviation (%)

Dryer type	Moisture content		Crude protein		Fat content		Crude fibre		Dry matter		Ash	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Conventional solar dryer	71.36^{a} ±0.01	4.42^{c} ±0.01	14.00^{c} ±0.01	15.67^{c} ±0.02	23.00^{a} ±0.01	21.00^{a} ±0.07	23.00^{a} ±0.08	31.00^{b} ±0.012	28.60^{a} ±0.08	86.30^{ab} ±0.09	1.50^{b} ±0.16	4.00^{a} ±0.11
Hybrid solar dryer	71.36^{a} ±0.01	11.48^{a} ±0.05	14.00^{c} ±0.01	18.47^{ab} ±0.02	23.00^{a} ±0.01	11.00^{c} ±0.06	23.00^{a} ±0.08	28.00^{c} ±0.02	28.60^{a} ±0.08	87.90^{ab} ±0.21	1.50^{b} ±0.16	2.00^{bc} ±0.01
Sun-drying	71.36^{a} ±0.01	8.02^{b} ±0.12	14.00^{c} ±0.01	19.52^{ab} ±0.03	23.00^{a} ±0.01	17.00^{b} ±0.02	23.00^{a} ±0.08	34.00^{a} ±0.03	28.60^{a} ±0.08	76.50^{c} ±0.37	1.50^{b} ±0.16	2.00^{bc} ±0.08

Means with different superscript within the same column are significantly different ($p<0.05$)

4. DISCUSSION

The results in Table 1 was in line with the claims of Bolaji and Olalusi (2008), in which the peak of hottest in the dryer was achieved at mid-day when the sun is overhead. It also buttress the results of Oparaku (2010), which stated that the highest mean temperature attained in the dryer was 70 °C, while the ambient temperature was 33.5 °C at the insolation of 857.6wm^2. Bello *et al*. (2006) revealed that unloaded solar dryer had higher mean temperature of 50.4 °C compared to sun-drying, which was 36 °C.
The results in Table 2, indicate that as the temperature of the drying chamber increased, there was decrease in moisture content of the fish. This was in line with Dilip *et al.* (2002) who observed that the moisture content of anchovy was reduced from 49.59% (db) to 17% (db) in 15days for the shade-drying, 7 days for the open sun drying while the solar-drying, took only 4 days. Oparaku (2010) reported that the moisture content of the solar dried *Heterotis niloticus* was 21% that of the sun-dried *Heteretis niloticus* was 26% while solar-dried *Clarias lazera* was 17%, and that of sun-dried *Clarias lazera* was 28%.

The results in Table 3, for the proximate composition agreed with the findings of Bello and Oyelese (2016), that proximate composition of fresh *Brycinus nurse* from Alau Lake was varied seasonally for different period of the year. Agbabiaka *et al.* (2012), reported that characteristic weight of *Clarias gariepinus* smoked with *Anthonatho macrophylla* wood had average moisture loss of 63.34% from the smoked catfish which was similar to the value of less than 65.00% recommended by Cardinal *et al.* (2001).

The results obtained by Obande *et al*. (2012) indicated that the moisture contents of the fresh fish of 67.43% was reduced to 19.51% for fish smoked using firewood and 20.00% for fish smoked using charcoal. Generally, the main aim of smoking or drying fish, according to Clucas (1982), Tobor (1995) and Eyo (1998; 2001) is to reduce the moisture content of fish to 15-20%. This is to make the conditions in the fish that allows for spoilage organism and chemical activities in the fish to be reduced to minimum. As averred by Obande *et al*. (2012), fish smoked with charcoal and firewood, will reduce spoilage and subsequently prolong the shelf-life of the fish. Fish at 10-15% moisture content reportedly had shelf-life of 3-9 months when stored properly (Jallow, 1995). Modibbo *et al.* (2014) reported that there was reduction in moisture content, and an increase in crude protein.

The crude protein formed the largest quantity of the dry matter in all the fish samples. This is in line with the report that protein forms the largest quantity of dry matter in fish (Daramola *et al*., 2007). Dried fish had higher protein than fresh fish. Increase of protein may be due to the dehydration of water molecule present between the proteins, thereby causing aggregation of protein and resulting in the increase in protein content of dried fishes (Ninawe and Rathnakumar, 2008).

Ash content of dried fish was higher than that of fresh fish. Clucas and Ward (1996) reported that the inorganic content remain as ash after the organic matter was removed by incineration. Dried fish had higher fat content than fresh fish. After drying, there

was an increase in fat content and this variation could be the result of evaporation of moisture content, which is in agreement with (Ogbonnaya and Shaba, 2009).
Crude lipid and ash, with low moisture content is an indication that the dried fish samples have a tendency to be very stable. El- Gamal (2001) also agrees with the above. Ninawe and Rathnakumar (2008) reported that dried fish had higher protein content than fresh fish.

Oladipo and Bankole (2013) stated that the proximate analysis showed that dried *C. gariepinus* had higher fat content (11.02%) and also had the highest protein content (42.88%). Fresh *O. niloticus* had the highest moisture content (71.11%), whereas dried *O. niloticus* had the highest crude fibre and ash content (4.79% and 20.00%) respectively. Ash content of dried fish was higher crude fiber and ash content (4.79% and 20.02%, respectively). Ogbonnaya and Ibrahim (2009) studied the effects of drying methods on proximate composition of Catfish (*Clarias gariepinus*) and found that the changes in moisture protein, lipids energy value, vitamin A and phosphorus content were found to be significant for the two drying methods, Ash, Fibre, carbohydrate, vitamin C and potassium contents showed no significant difference for the two drying methods used.

Tao and Linchun (2008) and Ogbonnaya (2009) stated that decrease of moisture and increase of protein, lipids, vitamin A, potassium and phosphorus contents were the most prominent changes in *O. niloticus* fish after drying. Moisture, protein lipids and vitamin A contents increased significantly in processed samples ($p<0.05$). Puwastein *et al.* (1999), Gokoglu *et al.* (2004), Tao and Linchun (2008) and Ogbonnaya (2009) reported that the significant increase in protein levels ($p<0.05$) in dried *O. niloticus* fish, when compared with the raw fish, suggested that protein was not lost during drying. There was no significant difference between smoking kiln-drying and electric oven-drying for protein, ash, fibre, carbohydrate, potassium and phosphorus contents.

After drying, there was a significant increase in lipids content. Smoking kiln-dried samples retained higher lipid content than electric oven-dried samples ($p<0.05$). It indicates that fat loss phenomenon was more intensive in the electric oven-dried than in smoking kiln-dried samples. Fat may exude with moisture evaporation during electric oven drying and that seems to enhance the phenomenon of lipid loss.

Conclusively, the unloaded temperature reading, inside the drying chamber was higher than the ambient temperature during most hours of the daylight which made the dryers acceptable for fish drying. Increase in temperature reduced the drying time and moisture content of the fish but sun-drying had slightly higher moisture content. Also, solar drying in the conventional and hybrid solar dryers for *Brycinus nurse*, quality parameters were within the acceptable range and better proximate composition. Further research should be carried out on using the dryers for different fishes available in the area.

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Construction of Storage Structures for Onion Bulbs for Food Security

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ABSTRACT

The impacts of climate change on natural disasters, infra-structure and livelihood, infers that the implementation of climate change adaptation strategies in developing countries needs to be practically addressed. Among other factors, inter-annual rainfall variations, excessive rainfall which causes flood and drought cause great stress to the farming activities, crop production and crop yield. During these periods there is food scarcity due to lack of storage infrastructure that can make food to be available throughout the year. Large quantities of harvested produce are wasted due to deterioration during the peak of harvest. To ensure food security and to reduce wastage, the adoption of an effective storage condition is necessary. This paper presents the analysis to set up proper storage medium for onion bulbs to make the crop available when it is off season. A storage shed was constructed and some storage cabinets were kept inside for storing onions and compared with open storage of onion bulb on concrete floor. The storage shed was built with concrete blocks and covered with corrugated iron sheet. The storage cabinet was constructed with wood which was divided into three portions and the sides were covered with thin wire mesh. The onion bulbs were measured, graded into small, medium and big sizes and arranged in each portion (A, B and C) of the cabinet, respectively. The temperature and relative humidity inside the storage medium were measured three times daily. Analysis of variance was used to determine effect of storage period on weight of the onion bulbs. The comparison of open storage and storage was done using T-test analysis. The area of the entire storage shed was 25 m^2 and each storage cabinet was 2.25 m^2 and each portion of the cabinet was 0.25 m^2.The diameter of the onion bulbs ranged from 3.2 to 5.98 cm (small), 6.01 to 7.09 cm (medium) and 7.39 to 9.27 cm (large). The result of experimental values showed that the rate of deterioration varies with the sizes of the onion. Analyses of variance results indicated that moisture (weight) loss increased as storage period increased. The rate of deterioration of onion bulbs in storage cabinet is minimal. The effect of temperature and relative humidity is significant at 95 % confidence level on stored products which necessitates the prolonged shelf life. The designed wooden storage cabinet for homestead storage of onion bulb is recommended for domestic use to ensure food security and safety.

Keywords: Onion bulb, storage cabinet, food security, weight loss, climate change

1. INTRODUCTION

1.1 Agronomy of Onion

Onion (*Allium cepa*) is an edible bulb composed of a fleshy tight concentric leaf based having a pungent odour and taste, it is a bulbous plant cultivated worldwide as a vegetable, a cool season biennial onion of Asiatic origin and belonging to the plant order lilalies. The Onion is grown for its edible bulbs other species are leek, garlic, welsh onion and shallot (Brewster, 1994). Onion is the queen of the kitchen (Selvaia, 1976), the onion is preferred mainly because of its green leaves immature and mature bulbs are either eaten raw or cooked as a vegetable, its varieties are classified mainly according to pungency (mild or pungent) or use (dry bulb of green bunching). Bulb may be white, red or yellow. They generally have a papery outer skin over a fleshy, layered inner conie used worldwide for culinary purposes; they come in a wide variety of forms and colours (KTBL, 1993).

In this light of the day, hybrid varieties with increased disease resistance, longer storage life and improved quality are rapidly displacing older varieties; Texas, New York and California are important producing status (Bruce et al., 1991). Onion (Allium cepa) in general sense can be used for any plant in genius but used without qualifias usually mans. It is also called the garden onion (usually but not exclusively the bulbs) are edible with a distinctive strong sweetened by cooking.

The underground bulbs, like lily, are priced around the world for the magic it makes in multitude of dishes with its pungent flavor and odour. There are two main classification of onion, green onion (also called scallions) and dry onion which are simply matured onions with a juicy flesh covered with dry papery skin. Dry onion comes in a wide range of sizes, shapes and flavours, among those that are mild flavoured are the white or yellow Bermuda onion which is usually yellow skinned from August to May and red or Italian onion which is available year round. The primary center of origin of onion is central Asia with secondary centre in Middle East and the Mediterranean region, from these centers, onion has spread widely to many countries of the world. Onion is different from other edible species of Alliums for its single bulb and is usually propagated by true botanical seed. (Dahlgren *et al.*, 1985). Onion is one of the oldest cultivated vegetables and has been in cultivation for more than 4000 years, the earliest records came from Egypt, where it is cultivated at the time of the old kingdom. Carvings of onions can be seen on the walls of pyramids in the 3rd and 4th dynasties. A global review of major vegetables show that onion ranks second to tomatoes in area under cultivation. (Dahlgren et al., 1985)

1.2 Climate Change and its Impact on Onion Bulb Availability in Nigeria

There was problem of flood in Nigeria in 2010 which eroded onion plants and bulbs away and this led to loss of products. In other words, there is a lot of wastage of onion due to deterioration when the product is at the peak of harvest. During the off season there is scarcity of onion bulb and the available ones are expensive. These problems arise from improper storage methods or lack of storage facility for onion bulbs. This study is targeted to getting a suitable storage medium and condition to make the product available at cheaper cost throughout the year in Nigeria. Therefore, proper storage of onion bulbs will encourage farmers for more production and this will improve the economy of the nation. The aim of this work is to construct an underground pit and shelves for storing onion bulbs and determine effect environmental factors on the deterioration rate of the onion bulbs.

2. RESEARCH METHODOLOGY

The materials used for the construction of the underground storage pit and shelves were such that could make it to be easily maintained, repaired, and obtained at relatively lower costs. The materials used are such that can withstand humidity, heat and prevent rodent attack. Some of the materials used are cement, sand, gravel, wood, wire mesh net and corrugated iron sheet.

2.1 Design consideration of the storage pit

Some factors were considered in the design of storage pit of onion bulb in order to produce high quality and large quantity of products to be dried. The factors considered are as follows:

- The availability and cost of materials required (relatively cheaper than imported ones),
- Ease of operation
- Can be operated by one person
- Size of the shelves and storage structure
- Ease of Maintenance
- Safety

2.2 Description of the underground pit

The underground pit consists of the following: foundation, wall, roof, floor and shelves. The foundation of the pit was made; a piece of land was pegged to give a rectangular shape of 3 m by 3 m. This was sited and constructed at the workshop of the Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. The foundation was dug until sub soil was got. The concrete was pounded in the trench, and then five layers of block were laid and join together by mortar from foundation to make the underground pit with 1 m depth. The floor was filled with a concrete mixture of ratio 1:3:6. The floor was reinforced to ensure adequate strength and firmness. The overall materials were; 16 bags of cement, 155.5 kg of sand and 352 kg of gravel. The wall support was constructed with 3 by 4 hard wood and the four sides were covered with chicken net and mosquito net to prevent insect and rats from entering the barn and also allow free movement of air in the barn. The roof is covered with galvanized sheets and the areas of the roof and storage pit are 2 m^2 and 9 m^2, respectively. Figures 1and 2 show the design diagrams of the storage shed. The storage cabinet was made of wood divided into three portions with chicken wire mesh net. The cabinet is rectangular in shape, with length of 0.5 m, thickness of 0.5 m and breath of 0.5 m. Fig. 3 shows the storage cabinet constructed.

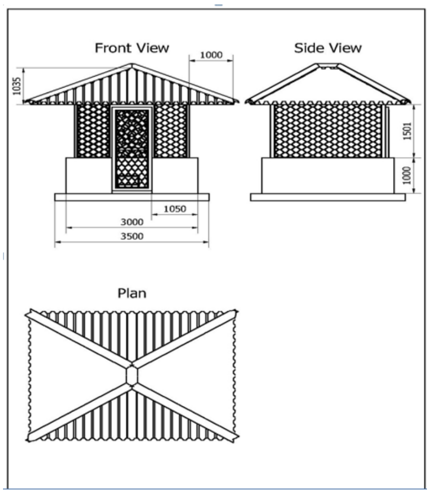

Fig. 1: Plan of the storage shed

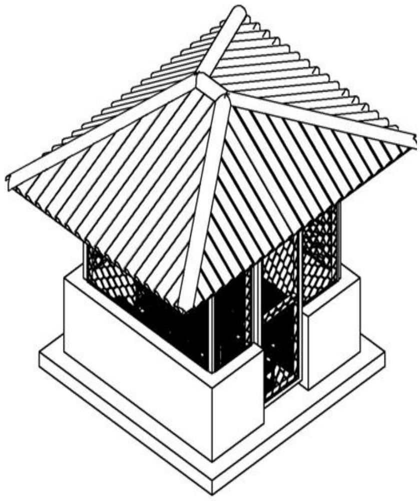

Fig.2: Design of storage shed for onion bulbs

Fig. 3: Storage cabinet for onion bulbs

2.3 Sample Preparation and Measurement of Onion bulbs

Some onion bulbs were purchased from Sabo market in Ogbomoso. The onion bulb sampling experiment was carried out and the onions were grouped into three different sizes; small, medium and large. A vernier caliper was used to measure the width of the samples. The diameter of the onion bulbs ranged from 3.2 to 5.98 cm (small), 6.01 to 7.09 cm (medium) and 7.39 to 9.27 cm (large). The grading of sample was necessary to compare the rate of deterioration among the different sizes.

Ninety onion bulbs were arranged on each portion of the cabinet; thirty small onions, thirty medium onions and thirty large onions as shown in Figure 4. The onions were checked carefully for damages and ensure that their body covers were intact (unremoved) before storage. The onions were arranged randomly on the storage cabinet and not touching one another. The temperature was taken three times daily inside the room at 7:00am, 12 noon and 6:00pm, each onions were labeled and the weight were taken before storage and at the end of the week for a period of eight weeks(two months). The significant losses were being determined using T-test and also the effect of the week and losses were determined using analysis of variance (ANOVA).

Figure 4: cabinet storage of onion bulbs

3. RESULTS AND DISCUSSIONS

The results of the average weight loss of onions are presented in Fig. 5. It was observed that the weights of the onions reduced as the weeks advanced for the period of 2 months. The environmental factors which were wet bulb temperature, dry bulb temperature and relative humidity played a significant role in the weight loss and deterioration of the onions. It was observed that there was weight loss in the onions as the weeks progressed. The variance in the weight of onion is due to the hygroscopic nature of the crop; so when it increases it has absorbed moisture and when it decreases it loses moisture as presented in Table 1.

From the Fig 5.1 it was observed that there were more weight losses in the onions as the weeks progressed. The variance in the weight of onions is due hygroscopy, that is when it increases it absorbes moisture and when it decreases it loses moisture. From Table 2, It was observed that the F calculated (3.558676 and 8.636586) is greater than the F critical (2.591094 and 3.633716), this implies that there is a great significance in the weeks and the losses, hence making all the environmental factors have an effect on the small, medium and big size of the onions. Figure 5.2, 5.3 and 5.4 shows that small onions, medium onions and big onions results have the same pattern because each one has its losses increasing by the week. Further investigation was carried out on the result using the T-test statistical analysis. Table 3, 4 and 5 shows the confident limit of the small, medium and big onions at 95%.

From Table 3, the value of t-stat (1.01142E-05) is less than tcritical one-tail and t Critical two-tail (1.795883691 and 2.200986273) respectively. This implies that there is a significant difference. Table 4 shows that the value of t-stat (-1.66907E-06) is less than t Critical one-tail and t Critical two-tail (1.745884219 and 2.119904821) respectively. This implies that there is no significant difference. Table 4 shows that the value of t-stat (-1.34821E-06) is less than tcritical one-tail and t Critical two-tail (1.745884219 and 2.119904821) respectively. This implies that there is no significant difference.

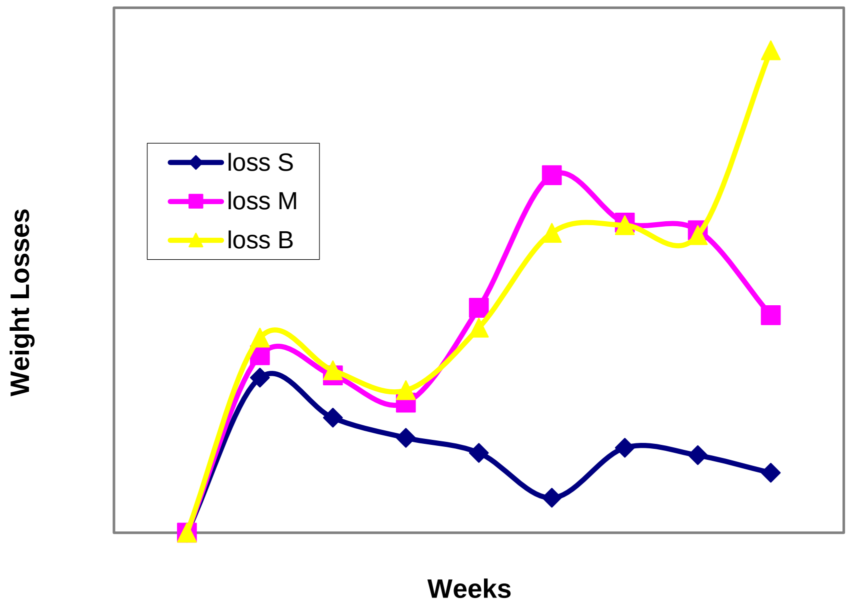

Fig. 5.1 Graph of weeks against weight losses for all the three sizes of onions

Table 1: Analysis of variance of the weeks and losses of the three sizes of onion

Source of Variation	Sum of Square	Degree of freedom	Mean of Square	F Calculated value	P-value	F standard value
Weeks	26.45926	8	3.307407	2.754189	0.040264	2.591094
Losses	22.11654	2	11.05827	9.208595	0.002182	3.633716
Error	19.21383	16	1.200864			
Total	67.78963	26				

The regression equation for loss S = - 19.1 - 0.094 WK - 0.000 WT + 0.456 DT + 0.100RH

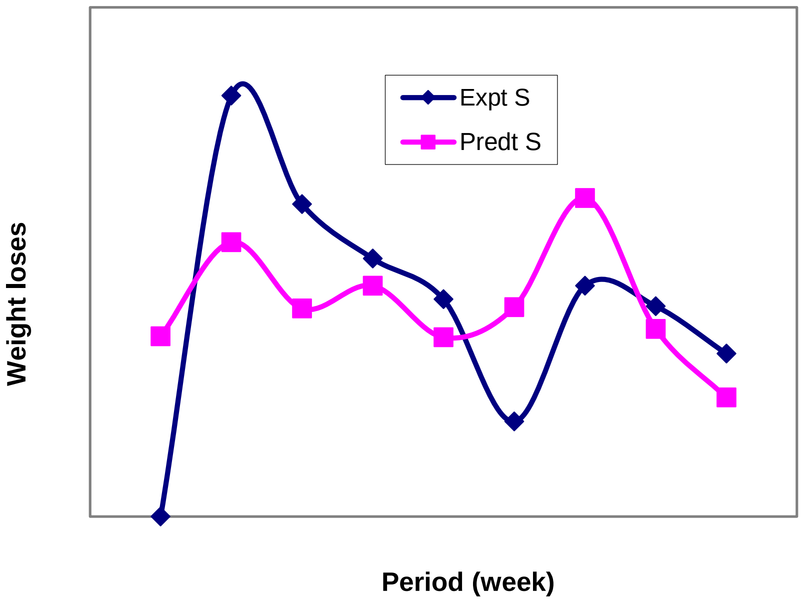

Fig. 5.2 Graphical comparison of experimented and predicted results for small onions

The regression equation for loss M = - 18.6 + 0.424 WK + 0.584 WT - 0.035 DT + 0.073RH

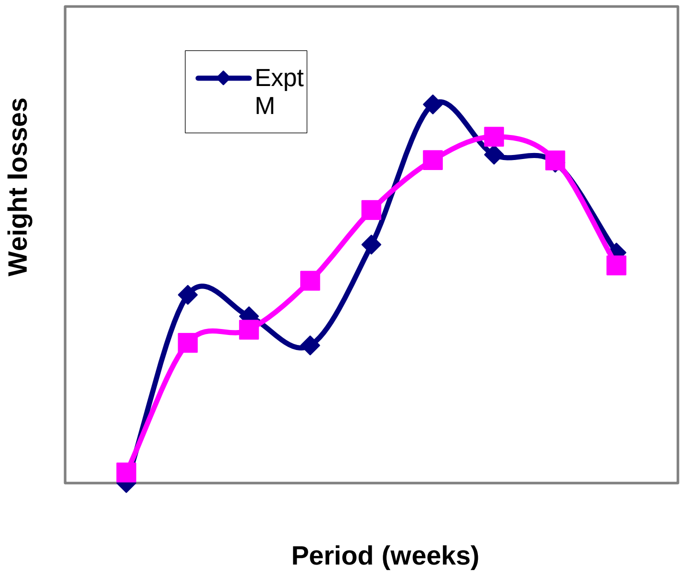

Fig. 5.3 Graphical comparison of experimented and predicted results of medium onion

The regression equation for loss B = - 6.9 + 0.387 WK + 0.033 WT + 0.377 DT - 0.034RH

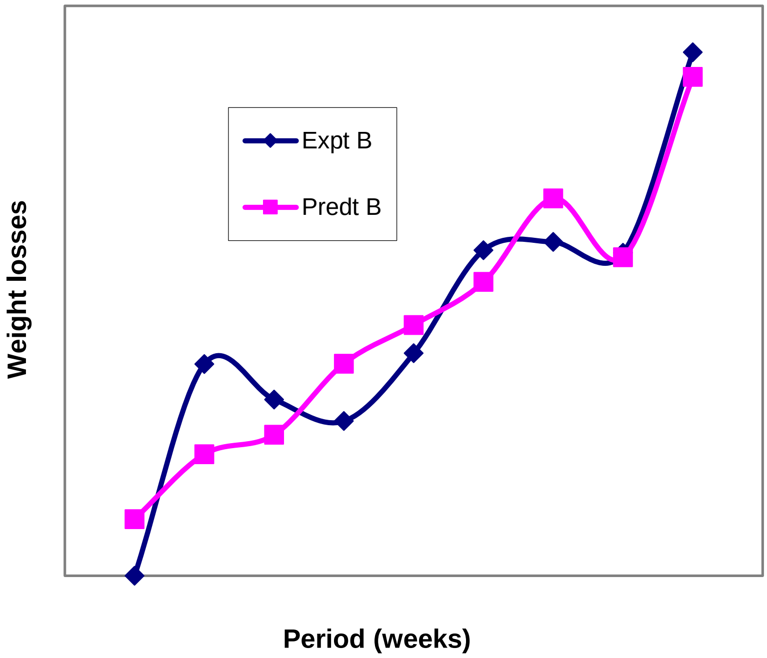

Fig. 5.4 Graphical comparison of experimented and predicted result of big onion

Table 2: T-test analysis results for experimented and predicted values of small onions

	Experimented values of Small	**Predicted values of Small**
Mean	1.040741111	1.040738889
Variance	0.35327171	0.081192757
Observations	9	9
Hypothesized Mean Difference	0	
Degree of freedom	11	
t Stat	1.01142E-05	
P(T<=t) one-tail	0.499996056	
t Critical one-tail	1.795883691	
P(T<=t) two-tail	0.999992111	
t Critical two-tail	2.200986273	

Table 3: T-test analysis results for experimented and predicted values of medium onions

	Experimented values of Medium	Predicted values of Medium
Mean	2.781481111	2.781482222
Variance	2.108641988	1.879829919
Observations	9	9
Hypothesized Mean difference	0	
Degree of freedom	16	
t Stat	-1.66907E-06	
P(T<=t) one-tail	0.499999345	
t Critical one-tail	1.745884219	
P(T<=t) two-tail	0.999998689	
t Critical two-tail	2.119904821	

Table 4: T-test analysis result for experimented and predicted values of big onion

	Experimented value of Big	Predicted value of Big
Mean	3.1	3.100001111
Variance	3.247219694	2.86561904
Observations	9	9
Hypothesized Mean Difference	0	
Degree of freedom	16	
t Stat	-1.34821E-06	
P(T<=t) one-tail	0.49999947	
t Critical one-tail	1.745884219	
P(T<=t) two-tail	0.999998941	
t Critical two-tail	2.119904821	

4. CONCLUSIONS

Ninety onion bulbs (small, medium and big) were stored at room temperature for a period of eight weeks (two months). The weight loss of each onions were studied against the week and the environmental conditions. The results showed that each onions has its own experimented and predicted value and has a significant difference at 95% confident limit and the rate of deterioration onions varies with the size of the onion bulbs. The onions stored in cabinet had high rate of deterioration than those stored in storage shed built with underground pit filled with sawdust. Therefore, storage shed is recommended for storing onion bulbs for food security.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Some Physical, Mechanical and Chemical Properties of Loofah Gourd Seed (*Luffa cylindrica*)

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ABSTRACT

Information on physical, mechanical and anti-nutritional properties of the loofah seed will promote utilisation. Therefore, oil content and effect of moisture content on physical and mechanical properties of the loofah seed were determined using standard methods. Also determined was anti-nutritional factor. The seeds were conditioned into five moisture content levels (7, 12, 17, 22 and 27% w.b). Oil content of the whole seed, cotyledon and the shell of the seed were 21.65, 37.35, and 5.00% respectively. The length, breadth, thickness, geometric mean , aspect ratio, sphericity , mass of 100 seeds , porosity , true and bulk density of the *Luffa cylindrica* seed ranges from 9.38 – 11.47mm, 6.15 – 8.46mm, 2.25 – 2.71mm, 5.15 – 5.97mm , 61.19 -79.99%, 52.14 - 57.75% , 7.30 – 10.40g , 84.06 - 105.45% , 0.52 – 0.70g/cm^3 , 0.41g/cm^3 – 0.58g/cm^3 respectively. There was significant difference ($p<0.05$) in length, breadth, geometric mean, mass, porosity, true and bulk density of the luffa seeds. There was no significant difference ($p>0.05$) in thickness and shape. Force at peak, break and yield, energy to peak and break, and Young modulus of the seed decreased with increase in moisture content. The range of deformation at peak, break and yield of the luffa seed were 1.43 – 2.39mm, 1.48 – 4.38mm and 0.79– 2.94mm respectively. Anti –nutritional factors (phytate, saponin, tannin and phytin phosphorus) were more concentrated on the shell than the cotyledon of the luffa seed.

Keywords: *Luffa cylindrica* seed, Moisture content, Mechanical properties, Physical properties, Anti-nutritional content

1. INTRODUCTION

Loofah gourd *(Luffa cylindrical)* is a member of the family *cucurbitaceae*. It is a running vine with round leaves and yellow flowers. It is an herbaceous plant and thrives commonly with tendrils (Ajiwe *et al.*, 2005). *Luffa cylindrica* produces berry- like fruit whose colour at tender stage is green and yellow at maturity. The fruit is smooth and cylindrical in shape with of length 30.38 - 60.90 cm and edible when young (Abitogun and Ashogbon, 2010). Factors such as high surface area per volume, strong and durable structure, low specific gravity and reasonable cost are characteristics of *Luffa cylindrica* making it suitable alternative for use as a packing medium in an attached growth system (Mazah and Alves, 2005). The fibrous vascular system flesh and seeds can be used as a sponge, as component of shock absorbers, as a sound proof lining, as packing materials, for making crafts, as filters in factories and as a part of soles and shoes (Bal *et al.,* 2004). The sponge in the whole fruit holds about 20-30 seeds.

Seeds of loofah contain oil with high percent of free fatty acids. In the pure state, the oil is colourless, liquid at room temperature and can be used as food (Hussein *et al.*, 2006). Nutritionally, research has shown that *Luffa cylindrica* seed contains a high percentage of carbohydrates, protein, fats and minerals such as potassium, sodium, zinc, iron, magnesium, phosphorus, calcium and manganese (Dairo *et al.*, 2007). Also, the oil extracted from the seed is finding increase use in the production of biodiesel (Ajiwe *et al.*, 2005). In solving problems associated with development of agricultural machine and equipment for post-harvest operations data on some engineering properties of agricultural materials are important (Akinoso and El-alawa, 2013). Information on these properties is useful in development of handling, processing, packaging and storage equipment for crops. Findings from previous researches clearly showed that engineering properties of biomaterial significantly depend on treatments such as crop variety, moisture content, temperature, storage duration and cooking duration (Akinoso and Lasisi, 2013). Therefore, this work was deigned to generate data on some physical, mechanical and chemical properties of *Luffa cylindrica* seed.

2. MATERIALS AND METHODS

Preparation of samples

The loofah seeds sourced from a local market in Nigeria were manually cleaned to remove foreign materials such as stones, broken seeds and dust. The initial moisture content of the seeds was determined using moisture analyzer (Mettler Toledo HG 63 Halogen). The desired moisture content levels were achieved by adding calculated volume of distilled water as obtained from equation 1. Each sample was sealed in a separate polyethylene bag for 12 hours to equilibrate.

$$Q = A(b-a) \Big/ (100-b) \ldots\ldots\ldots\ldots\ldots\ldots 1$$ (Akinoso *et al*, 2006)

Where A is Initial mass of the sample (kg), a is Initial moisture content of the sample (% wet basis), b is final (desired) moisture content of sample (% wb) and Q is mass of water to be added (kg).

Mass, size and shape

Unit mass of the seed was determined by direct measurement on electronic digital balance (Scout™ Pro OHaus model SPU401, Germany) with accuracy of 0.001g. Length and thickness were measured using digital vernier calliper (Cappera precision, China) with 0.01mm accuracy. The mean values of the length and diameter for the samples of 25 seeds were determined. Equations 2, 3 and 4 were used for computation of geometric mean (Razavi *et al.*, 2009), surface area and sphericity of the fruit (Mohsenin, 1986), respectively.

$$D_g = (LD^2)^{1/3} \qquad (2)$$

$$S_A = \pi D_g^2 \qquad (3)$$

$$\Phi = (LD^2)^{0.333}/L \qquad (4)$$

Where,

L is length (mm)

D is diameter (mm)
D_g is geometric mean diameter (mm)
ɸ is sphericity (%)
S_A is surface area (cm^2)

Density and porosity

Bulk density of the seed was obtained by filling a container of 129.40 mm height and 98.03 mm diameter with seeds (Aremu and Fadele, 2011). Ratio of mass to volume was recorded as density. True density was determined by displacement of a *Luffa cylindrica* seed. The ratio of the weight of seed to volume of the displaced ethanol gave the true density (i.e., Equation 5). The porosity is the ratio of bulk density and true density (i.e., Equation 6) (Mohsenin, 1986).

$$\textit{True density} = \frac{\textit{Mass of the fruit submerged in g}}{\textit{Volume of water displaced in cm}^3} \quad (5)$$

$$\textit{Porosity} = \frac{\textit{true density} - \textit{bulk density}}{\textit{true density}} \times 100 \quad (6)$$

Determination of mechanical properties

Mechanical properties viz: force at break, deformation at break, energy to break, , force at peak, deformation at peak, energy to peak, force at yield, deformation to yield and energy to yield were determined using Testometric AX Type DBBMTCL 2500 kg (Rochdale, England). These tests were carried out using Akinoso and Raji (2011) reported method. A unit *Luffa cylindrica* seed from the samples was placed between the compressions plates of the testing equipment. Each seed was compressed at a constant deformation rate 10.00 mm/min., and readings were made using data logger. The procedures were repeated in 50 replicates.

Determination of fat content

Fat content analysis was carried out on different components of the loofah gourd seed viz; shell, cotyledon and whole (unshelled) seed. The samples (shell, cotyledon, and unshelled seeds) were ground into powder form using coffee grinder. The fat content was determined using soxhlet extraction method (AOAC, 2005).The fat was extracted in a soxhlet apparatus using petroleum ether (40-60°C). Five grams of each of the samples were weighed into previously dried fat free thimble. Previously dried and fat free round bottom flask were weighed and filled with petroleum ether (40-60°C) up to 2/3 of the flask. The soxhlet extractor was then fitted up with reflux condenser and placed on a heating mantle. The heat mantle was adjusted so that the solvent boils gently, it was then left to siphon over several hours (6-8 hrs). After this, the thimble was then removed and the apparatus fitted back to recover the solvent. The flask containing the extracted fat was then dried in an air oven at 105°C for 2hrs, allowed to cool in desiccators and weighed. Oil yield in percentage was calculated using equation 7.

$$Oil\ yield\ (\%) = \frac{weight\ of\ extracted\ oil}{weight\ of\ seed}\ x\ 100 \quad (7)$$

Determination of tannin content

Tannin was qualitatively determined as reported in the manual of food control (AOAC, 2005). The 0.5g sample were weighed into test-tubes and mixed with 10ml of distilled water. This was shaken and allowed to stand for 1hr, 1ml of the extract was pipette into another test-tube. This was followed by the addition of 5ml of distilled water and two drops of Ferrichloride in 0.1M HCl was added. It was shaken to mix properly and about 4 drops of potassium Ferrocyanide was also added, the absorbance of the portion of mixture was read at 620nm using spectrophotometer.

Determination of saponin content

The spectrophometric method of Brunner (1984) was used for saponin analysis. Finely ground sample (0.5g) was weighed into 200ml test-tubes and 10ml of 80% ethanol was added. The mixture was shaken on a shaker for 5hrs to ensure uniform mixing. Thereafter, the mixture was filtered through a Whatman No 1 filter paper into a 100ml beaker and 200ml of 40% saturated solution of magnesium carbonate added. The mixture obtained with saturated $MgCO_3$ was again filtered through a Whatman No1 filter paper to obtain a clear colourless solution. 1ml of the colourless solution was pipette into 50mls volumetric flask and 2ml of 5% $FeCl_3$ solution was added and made up to mark with added distilled water. It was allowed to stand for 30 minutes for blood colour to develop. 0-10ppm standard saponin solutions were prepared from saponin stock solution. The standard solutions were treated similarly with 2mls of 5% $FeCl_3$ solution as done for 1ml sample 3 above. The absorbance of the sample as well as standard saponin solutions were read after colour development on spectronic 21D spectrophotometer at a wavelength of 380nm.

Determination of phytate content

Extraction of phytate from the sample was carried out following a modified procedure of Harland and Orberleas (1977). The principle of this method relies on a conversion of free phytic acid and a colorimetric measurement of the liberated organic phosphorus. Sample (2.0g) was extracted with 40ml of 2.4% of HCL (68.6ml of 35% hydrochloric acid in total volume of 1 litre of H_2O) under constant shaking at room temperature (25^oC) for 3hrs. All extracts were then filtered using Whatman No.1 filtered paper. The content of phytate was determined by spectrophotometric method with an absorbance (A) wavelength at 640nm, outlined in AOAC (2005).

Determination of phytin phosphorus content

Sample (2.0g) was extracted by a solution containing 0.6% hydrochloric acid and 0.03% ammonium sulfocyanate. It is then titrated against standard ferric chloride solution in 0.6% hydrochloric acid , the solution containing from 0.05 to 0.2% Fe, until the supernatant liquor above the whitish iron precipitate develops a pale red colour persisting for 5 minutes. One mg Fe corresponds to 1.19mg phytin phosphorus (AOAC, 2005).

Statistical analysis

Mean values of replicates were recorded as data. This was subjected to ANOVA, and means were separated using Duncan multiple range rest. In addition, regression analysis of the models generated was done. For all the analysis, level of significant was accepted at 5%. SPSS 16.0 version software was used to run statistical analysis and developed mathematical models.

3. RESULTS AND DISCUSSION

Size

The Length, breadth and thickness of *Luffa cylindrica* seed ranged from 9.38 to 11.47mm, 6.15 to 8.46mm and 2.25 to 2.71mm respectively. Fig. 1 is a plot of size against moisture content which shows that all the dimensions increased with increase in moisture content. This is in agreement with Hosain Darvishi (2012) report on white sesame seed. The length was constant between 12% and 17% moisture content. The breadth and thickness was highest at 27%. The significant effect of moisture content on the size was due to moisture uptake in the intracellular spaces within the seed. Akinoso and El-alawa (2013) reported that the size of a seed is an important parameter in processing. Moisture content has no significant difference ($p>0.05$) on seed thickness.

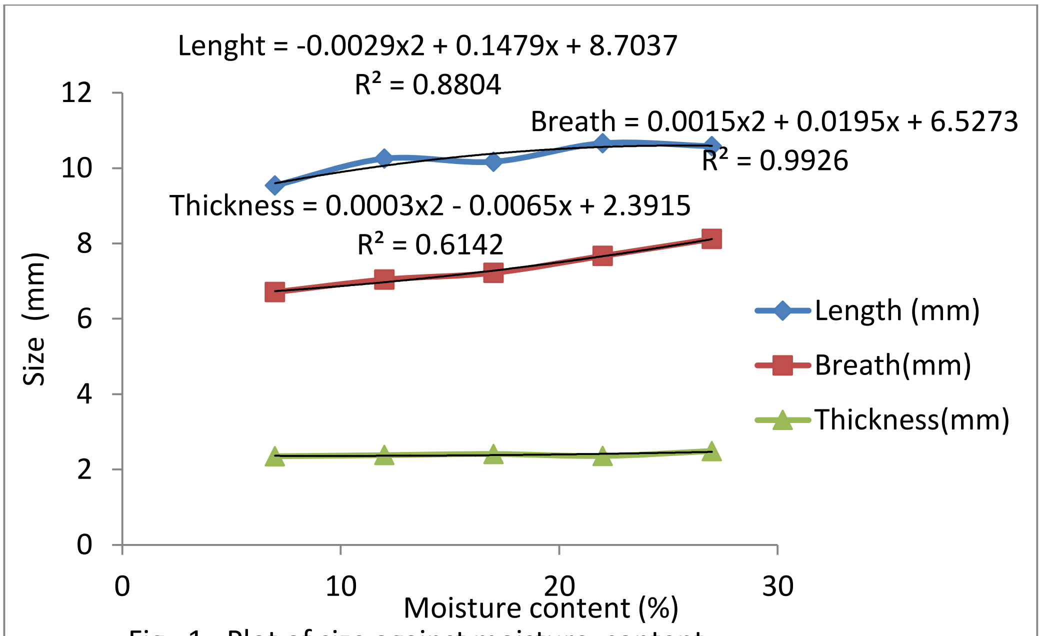

Fig . 1. Plot of size against moisture content

Density

The bulk density decreased with increase in moisture content while the true density increased with increase in moisture content (Fig. 2). Bulk density decreased from

0.50g/cm^3 to 0.41g/cm^3, true density increases from 0.53g/cm^3 to 0.68g/cm^3. This was in agreement with Kibar *et al.* (2010) for sorghum seeds. The true density of the seeds is lesser than the density of water. This explains why *Luffa cylindrica* seed floats on water. The principle of floatation can be applied in cleaning and separation of the seed. Moisture content significantly influence true and bulk density.

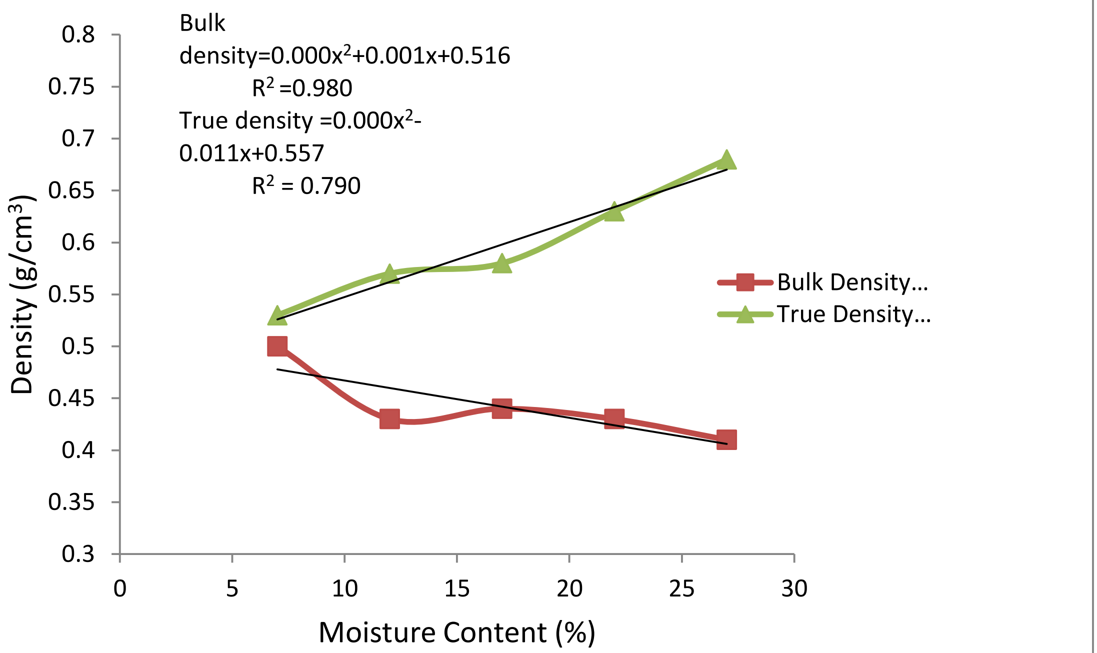

Fig. 2: Plot of density against moisture content

Shape and Porosity

Aspect ratio and sphericity were highest at 27% moisture content (Fig. 3). Aspect ratio and sphericity increased with increase in moisture content. The shape of *Luffa cylindrica* seed was not significantly affected by moisture content. Porosity decreased with increase in moisture content from 93.44% to 86.60% (Fig. 3). This was in agreement with Fathollazadeh *et al*. (2008) for apricot kernel. Highest porosity was recorded at 12% moisture content.

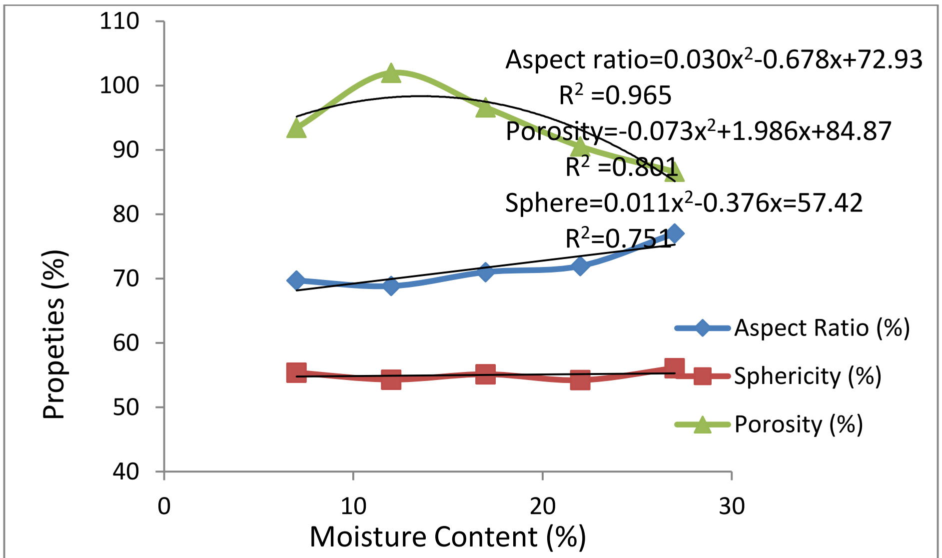

Fig. 3: Plot of shape and porosity against moisture content

Mass and Geometric mean

Figure 4 is a plot of mass and geometric mean moisture content. The mass significantly increased with increase in moisture content. This was in agreement with what Phillip and Atiko (2012) report on acha varieties. The same trend was reported for apricot kernel (Fathollazadeh *et al*.,2008). Geometric mean varied from 5.15 to 5.97mm

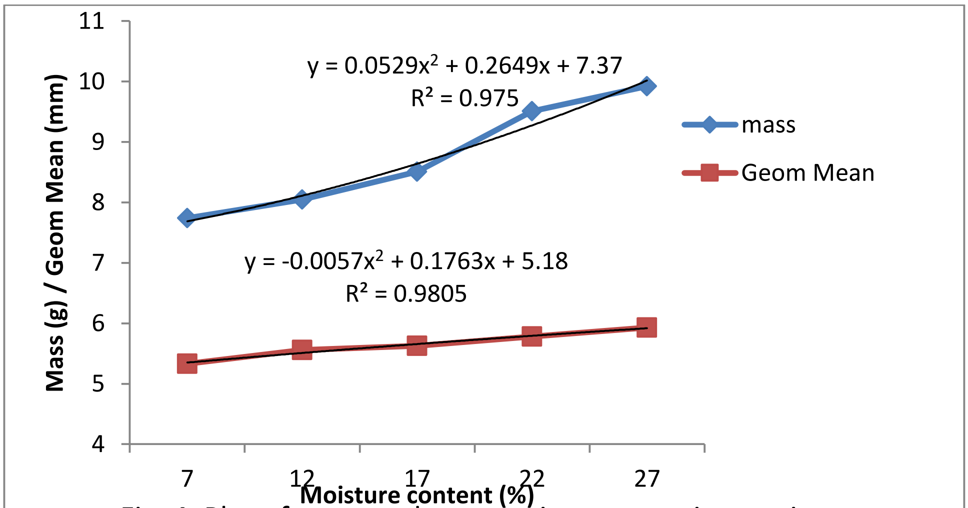

Fig. 4. Plot of maas and geometric mean against moisture content

Force at peak, break and yield

The force at peak, break and yield were highest at 7% moisture content. Force at break was constant between 17 and 17% moisture content and force at peak and yield were equal at 12 and 17% moisture content (Fig 5). Force at yield, break and peak decreased significantly with increase in moisture content, this was in agreement with Gorgi *et al.* (2010) report on soybean grains. This could be due to a higher binding force within the molecules of the seed which require more force to break. This means that the hardness of the *Luffa cylindrica* seed decreases as the moisture content increases.

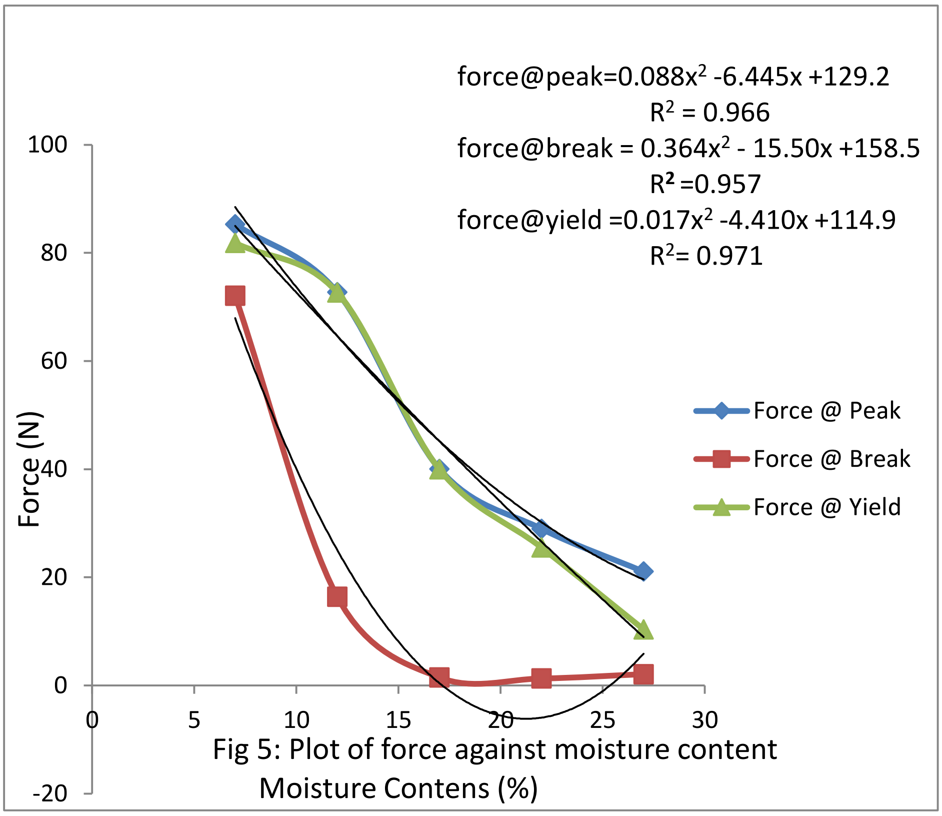

Fig 5: Plot of force against moisture content

Deformation at peak, break and yield.

The range of deformation at peak, break and yield of *Luffa cylindrica* seeds were 1.43mm-2.39mm, 1.48mm-4.38mm, 0.79mm-2.94mm respectively. The deformation at peak and yield was highest at 17% moisture content. Deformation at break was highest at 27% moisture content (w.b) (Fig 6). Deformation at peak, break and yield increased with increase in moisture content. Bamgboye and Adejumo (2011) reported similar trend on rubber seed and roselle seeds respectively.

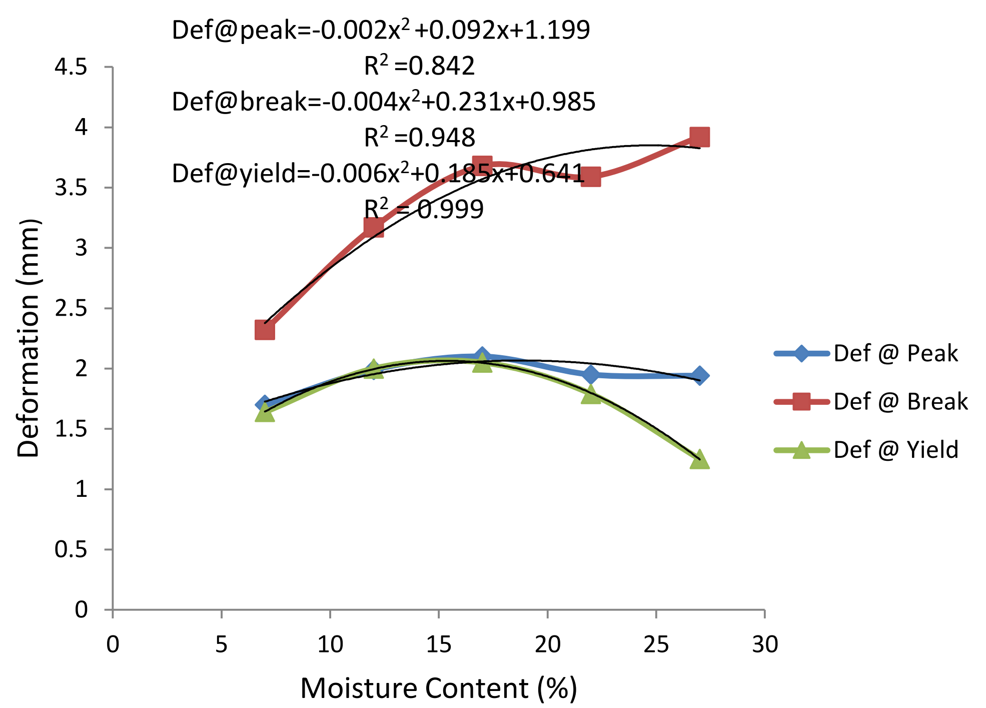

Fig. 6: Plot of deformation against moisture content

Energy to peak and break

The energy to peak and break decreased with increase in moisture content (Fig. 7). This was also due to higher binding force within the molecules of *Luffa cylindrica* seed due to low amount of water present. More energy and force were required to break the bond. Energy to peak and break was highest at 7% moisture content. This was in agreement with what Awolu and Oluwafemi (2013) report on Dika (*Irvingia gabonensis*) nut. Akinoso and El-alawa (2012) also reported similar trend on cooked locust bean seed.

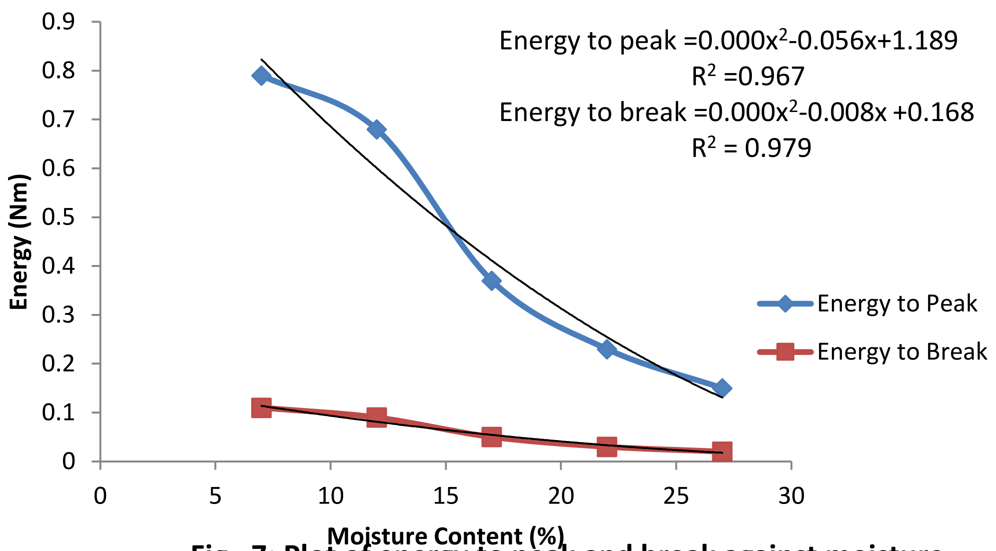

Fig . 7: Plot of energy to peak and break against moisture content

Young modulus

The range of young modulus of *Luffa cylindrica* seed was 6.46N/mm^2 – 99.20N/mm^2. Young modulus was constant between 22 and 27% moisture content (Fig. 8). Young modulus of *Luffa cylindrica* seed decreased with increase in moisture content. This was in agreement with what Gorgi (2010) reported on wheat kernel. Young modulus is often used by engineers as an index of product firmness. There was no significant difference ($p>0.05$) in Young modulus *Luffa cylindrica* seeds compressed at 22 and 27% moisture contents. .

Oil content

Table 1 shows the oil content in whole seeds, cotyledon and the shell of *luffa cylindrica* seed. The cotyledon has the highest oil content (37.35%) which is higher than oil content of soybean (20%), locust bean (22%), rice bran (16%) but less than groundnut (50%), coconut (48%), palm kernel (45%) and sesame seed (53%), all of which are classified as oilseeds (Akinoso , 2006). The shell has the least oil content (5.00%). The oil content of the shell is higher than 0.38% reported for *Luffa cylindrica* seed shell by Hussein et al; (2006).

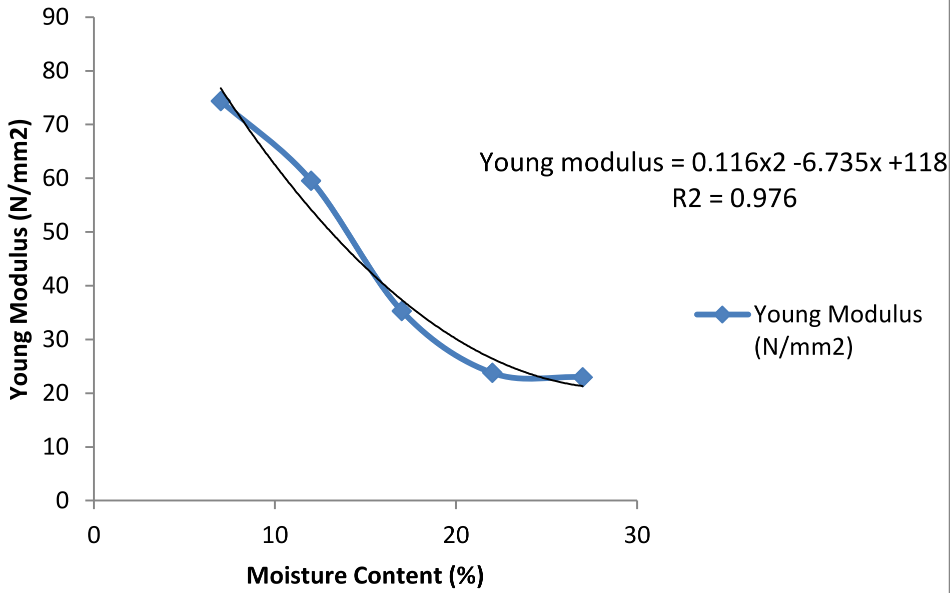

Fig . 8: Plot of Young Modulus against Moisture Content

Table 1: Some chemical properties of *Luffa cylindrica* seed

Parameters	Whole seed	Cotyledon	Shell
Oil content	21.65	37.35	5.00
Phytate (mg/g)	-	0.45 ± 0.1	0.94 ±0.1
Phytin phosphorus (mg/g)	-	0.12 ± 0.1	0.25 ± 0.1
Tannin (mg /g)	-	0.43 ± 0.1	0.92 ± 0.1
Saponin (mg/g)	-	0.03 0.01	0.92 ± 0.01

Anti-nutritional factors

Concentration of some of the anti-nutritional factors present in shell and cotyledon of *Luffa cylindrica* seed are shown in Table 1. High proportions of the anti-nutritional factors (phytate, saponin, tannin and phytin phosphorus) were found in the shell as compared to the cotyledon. Deshelling can therefore be employed as a means of reducing anti-nutritional factors in *Luffa cylindrica* seed. This is in agreement with Dairo *et al*. (2007). The anti-nutritional factors in *Luffa cylindrica* seed were relatively low when compared with *Luffa aegyptiaca* and other oil seeds (Elemo et al., 2011). The low level of anti-nutritional factors in *Luffa cylindrica* seeds make guarantee bioavailability of nutrient if consumed.

4. CONCLUSIONS

The following conclusions are drawn from the investigation on some physical, mechanical and chemical properties of loofah gourd (*Luffa cylindrica*) seed. Increase in moisture content significantly increased the breadth than the length. Bulk density and porosity decreased with increase in moisture content. Increase in moisture content significantly reduced force at peak, break and yield, and young modulus than energy to peak and break. Increase in moisture content of the seed had little effect on the deformation at peak, break and yield. There was low concentration of anti-nutritional factors (phytate, tannin, saponin and phytin phosphorus) in the *Luffa cylindrica* seed. Anti-nutritional factors are more concentrated on the shell. The seed contains a high percentage of oil and can be classified as oil seed. The oil content of the whole seed is lower than that of the cotyledon. Hence, deshelling helps to get maximal oil yield.

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Preliminary Assessment of Construction Material of Furniture Items for Display of Fruits, Vegetable and Meat offered for Sale at Bodija Market

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ABSTRACT

There are wide ranges of materials available for producing furniture items employ for display of fruits, vegetables and meat during selling activities. This study examined the status of wood as raw material for constructing this category of furniture used for selling activities at Bodija market, Ibadan, Oyo State, Nigeria. A survey conducted between June and August, 2018 focused on furniture used by retailers for the display of Tomatoes, Pepper, Okra, Vegetables, Oranges, Pineapples and Meat during sale. The survey tools used include on-the-spot assessment, oral interview and structured questionnaire. Food materials retailers (45) and 30 potential producers of the furniture items were randomly selected for the study. The data was analyzed using descriptive statistical tool. Result revealed that the display furniture were made using metal (), wood (), calabash (), plastics () and palm product, rattan and paper ().Availability, suitability and relative cheapness of the cost of wood made it the most patronized construction material. Engineered and reconstituted wood products are yet to be introduced into the list of materials used. Ficus mucuso, Alstonia boonei, Symphonia globulifera, Daniella oliveri, Albizia lebbek, Detarium spp, Kola nitida, Chrysophyllum albidum, Mallaotus oppositifolius, Pyananthus angolensis and Pterygoat marcrocarpa are lesser known species that are now being used for display furniture production. This study recommends the need to investigate the chemical characteristics of these wood species to ascertain the presence or otherwise of volatile substance that can migrate to food items displayed on them.

Keywords: Agricultural products, Display furniture, Construction materials, Wood-based products, Lesser known species

1.0 INTRODUCTION

Wood is still relevant in food materials handling and marketing. Wooden packaging is now extremely popular and used by a variety of different industries. Around 95% of pallets are made from wood, including hardwood, softwood, a mixture of them both or a composite wood such as plywood. Each one of them has their unique advantages for packaging, but generally wood is inexpensive, durable and can be recycled when no longer needed and both softwood and hardwood species have been used with varying benefits (Fellows, 2011; Akande, 2008 and Chiellini, 2008) Wood might have traditionally been used for centuries in food materials packaging, storage and transportation, the resentment for wood usage for the purpose is been erroneously conceived. The mis-placed perception is that wood utilization for these purposes call to question the integrity of the food hygiene due to wood absorbency and porosity natures. Advancement in knowledge and technology had brought about development of several products from wood. The advocacy is on for the use of wood products as viable substitute for conventional materials in construction of furniture items due to their benefits (FAO, 1991 and European Commission, 2013). However, there are a number of factors that may guide the selection of types of wood and its products patronized from place to place, especially for the handling and marketing of food items due to some reasons. The major reason(s) guiding the selection of what is used in any location will also be dependent on number of factors.

Nigeria is undoubtedly blessed with abundance tree species with the wood and many wood products available for potential users (Adewole and Olorunnisola, 2010). Bodija market is reputable as one of the biggest leading markets in Nigeria where people come from all over Nigeria and West African Coasts for trading in food materials and general products (Adewole and Oyewole, 2016). It has also in its vicinity a popular plank market with section of area where wood products are sold. Despite these opportunities, there are dearth of information on the status of patronage of wood products as material for producing facilities use in supporting fruits, vegetables and meat handling and sales at the popular Bodija market. The availability of this information is essential to determining the challenges to the uptake of adopting these wide ranges of wood products for use for the identified purposes for their numerous benefits

2.0 METHODOLOGY

A survey was conducted in June to August, 2018 to ascertain the characteristics of wood-based material used in the construction of the furniture items used for displayed of selected food items at Bodija Market, Ibadan, Oyo State, Nigeria. The focus is on retailers of Tomatoes, Pepper, Okra, Vegetables, Oranges, Pineapples and Meat. Structured questionnaire was administered on forty-five (45) food materials sellers and thirty (30) carpenters (workshops were located not beyond 1000 meter radius from the market, including plank selling section). Though mode of selection of respondents was random, gender and size of the wares displayed was considered in selecting food materials sellers. Where it was difficult to retrieve information with questionnaire, oral interview and on-the-spot assessment tools were used. A 13 pixel Cameral phone was used to capture images of the wood-based facilities for further investigation and analysis. The information gathered was analyzed using descriptive statistics.

3.0 RESULTS AND DISCUSSION

3.1 Characteristics of Sellers and Food Materials Considered During the Study

The study noted that male and females were actively involved in retailing of Tomatoes, Pepper, Okra, Vegetables, Oranges, Pineapples and Meat at Bodija market. The age of retailers of the selected food items ranged from 13 to 70years. More than 94% of the total respondents preferred to display their food products outside of the lock-up shops to attract potential buyers and to reduce the cost of facilities to support their business during operation. This may be one of the criteria for using portable furniture piece for the food item display. Respondents indicated that an average fruit and vegetable retailers at the study location requires a minimum of two thousand naira (#2000) to start business. There is no obvious form of cartel once the seller is ready to pay a toking of fifty to one hundred and fifty naira only (#50-#150), depending in the size of the ware, to Local Government Tax collector daily. Same fee holds for the out of stall retailers of meat that are also shown in Plate 1 except that the starting capital may be as high as thirty thousand naira (#30,000).

The starting capital of category of meat sellers who display their wares under open stall is about fifty thousand naira (#50,000) on average while a form of cartel exists in the group. None of the respondents had post-secondary education and refrigerator owned by stall owner is the common storage system used by meat sellers while vegetable and fruits seller depends largely on cool night hours to preserve their wares. This must have been responsible for the high rate of spoilt recorded (Ryall, and Pentzer, 1982) because fruits and vegetables will transpire and respire at high rates at field (market) temperatures as reported by many literatures (Harvey and Harris, 1986; d'Sousa and Ingle, 1989; Robbins and Moore,1992).

Plate 1: Food Materials Retailers who displayed their Wares out of Stall

3.2 Construction Materials for Display Furniture Items Used for Food Materials Display

It was evidenced from an on-the-spot assessment and responses by the respondents that there are wide range of materials that are available for use in display of fruits, vegetable and meat for sales. Investigation revealed that metal, wood, calabash, plastics, palm product, rattan and paper were the sources of materials for producing the furniture items used for displaying food materials of concern at the Bodija market. The ratio of use of the constructional materials is depicted in the pie chart presented as Figure 1. The overriding reason advances by the respondents for the choice of materials used for the construction of display furniture item are cost and their perceive suitability for the work characteristics, environment and availability.

Almost all respondents (98%) were of the opinion that no material will be able to displaced wood as material of construction if cost and suitability for their job nature is to be considered. However, for meat retailers, the tables, stool and counter top used for display were mostly made from solid wood as shown in Plate 2. Although in some instance, nylon is used to cover or used as the base of the wooden tray by hawkers to prevent dropping of meat juice on the hawker. Aside from solid wood that was used to manufacture the displayed furniture items, no reconstituted (Hardboard and Fiberboard, Medium Density Fiberboard, Particleboard, Wafer-board and Oriented Strand-board etc.) and engineered (Wood Plastics, Plywood, Laminated Veneer Lumber 'LVL' , Laminated Strand Lumber 'LSL', Parallel Strand Lumber 'PSL' Glue-laminated 'Glulam') wood were used. The chief reasons adduced were cost, availability, knowledge of their suitability and work demand.

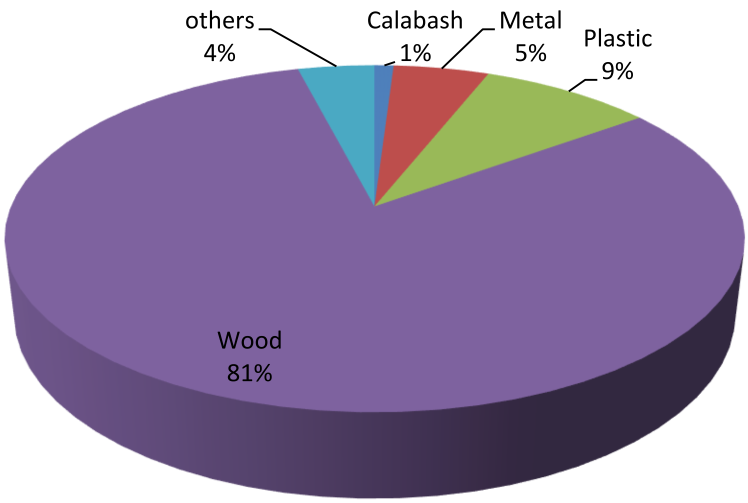

Figure 1: Materials of Construction of Furniture Items Used for the Display of Food Materials at Bodija Market

Plate 2: Wood as Major Materials for Making Meat Display Furniture at Bodija Market

3.3 Factors Guiding Selection of Wood Species Used for Display Furniture Manufacturing

Investigation revealed that no scientific reason is adduced as guide for the selection of the wood species used for constructing the display furniture. Availability and cost of the wood species were the major reasons guiding the selection by the producers who largely determine the species. However, USDA (2016) observed that the structure of wood is not only the criterion of differentiation in their response to pollution, since the presence of certain molecules and the chemical composition is even more than a factor in this differentiation. Less familiar wood species have flooded Bodija plank market located in the vicinity of the Bodija market in recent time. And there is dearth of information on the chemical characteristics of these lesser known wood species. Response of the carpenters involved in the study revealed that about eleven lesser known species indicated in Table 1 have been used for producing wooden trays and table tops.

Table 1: Some Lesser Known Wood Species That have been Introduced into the Production of Display Furniture at Bodija Market

S/N	COMMON NAME	BOTANICAL NAME
1	Obobo	*Ficus mucuso*
2	Ahun	*Alstonia boonei*
3	Epu	*Symphonia globulifera*
4	Eya	Daniella oliveri
5	Acacia	*Albizia lebbek*
6	Ogbogbo	*Detarium spp*
7	Obi	*Kola nitida*
8	Agbalumo	*Chrysophyllum albidum*
9	Orokoro	*Mallaotus oppositifolius*
10	Akomu	*Pyananthus angolensis*
11	Oporoporo	*Pterygoat marcrocarpa*

There is possibility that they may have chemical constituent in form of extractives that may migrate to the food items displayed on them thereby impacting on quality of the wet agricultural produce and animal products.

There is no doubt that wooden boxes, trays and crates protect foods materials against crushing, are easy to stack and have a good weight-to-strength ratio. This must have been why it is widely used for handling fruits and vegetables during sale at Bodija market to prevent damage by crushing. However, other wood and bamboo products had been used in the construction of this category of furniture item. The products are been used in many countries to produce furniture employed for food materials display and packaging without compromising the quality of the food materials/items as shown in Plate 3.

Plate 3: Wood Products Used as Material for Display Furniture

There is need to encourage the use of this products to lessen the use of solid wood and to encourage production of these wood and bamboo products at even cottage level. With patronage of the use of other wood products, particularly the engineered wood and bamboo products capacity can be developed to create secondary raw materials from numerous lignocellulosic wastes. Such raw materials can be used to produce display furniture that will guarantee needed environment that will produce appropriate rate of cooling (Nunes *et al*, 2009) for the products that may be major challenge of the other conventional materials as shown in the rate of cooling time predicted in equations presented in Thompson et al. (1998)

4.0 CONCLUSION AND RECOMMENDATION

This study was able to identify the material of construction of furniture items that were used for fruits, vegetable and meat display for sale at Bodija market in Ibadan, Oyo State, Nigeria. The materials of construction ranged from metal, wood, calabash, plastics, palm product, rattan and paper. Wood is most patronized construction material because of availability, suitability and relative cheapness of the cost. Engineered and reconstituted wood products are yet to be introduced into the list of materials used for the category of furniture production. Eleven lesser known wood species have been introduced into the wide range of familiar species that are known for making the furniture items. These new species are *Ficus mucus, Alstonia boonei*, *Symphonia globulifera, Daniella oliveri, Albizia lebbek, Detarium spp, Kola nitida, Chrysophyllum albidum, Mallaotus oppositifolius, Pyananthus angolensis* and *Pterygoat marcrocarpa.* This study recommends the need to investigate the chemical characteristics of these wood species should be carried out to determine the presence or otherwise of volatile substance that can migrate to food the food items displayed on them. Aside this, the use of wide range of wood products materials should be encouraged in the manufacture the category of furniture items under consideration to enhance capacity development in the production.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Extraction of Vegetable Oils from Agricultural Materials: A Review

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ABSTRACT

Extraction is an important unit operation in crop/food processing; involving the recovery of a material of interest from a parent material. Vegetable oil extraction has presented a lot of challenges, which border on developing appropriate equipment/technology, improving the efficiency of available equipment, ensuring good quality and safety of the product, and minimizing the adverse environmental effects of oil extraction technology. In line with this, various researches have been carried out to understand the properties of oleaginous crops and to find solution to the challenges associated with oil extraction. Some research works are also focused on improvement of process conditions and development of models able to explain observed phenomena during extraction. This paper provides a comprehensive review of vegetable oil extraction, both from the standpoint of research advances and industrial application. The paper reviews works on the theory as well as the methods of vegetable oil extraction. The objective of the paper is to present the technology situation and to provide an overview of the state-of-the-art in vegetable oil extraction research and development as well as their application.

Keywords: Extraction, Vegetable oil, Methods, Technology, Oleaginous, Equipment

1. INTRODUCTION

The crop/food processing research sector is seeking ways to find solution to various problems in order to ensure availability of high quality food and other products to the ever-growing population. In the area of vegetable oil extraction, a lot of challenges need to be overcome in order to ensure availability of the product. These challenges are associated with the crop, the methods/technology needed to obtain the desired product (vegetable oil), the quality of the product so obtained, as well as environmental concerns (such as those posed by the chemicals used in solvent extraction). Various researches have been carried out to understand the properties of oil-bearing crops and to find solution to the challenges associated with oil extraction. Mariana *et al*. (2015) noted that for centuries, various methods have been adopted for oil extraction from oilseeds and that the purpose of those extraction methods is to optimize the process by collecting the maximum quantity of the existing oil in oilseeds with the minimum costs. The tissues of plants bear varying quantities of vegetable oils. Mariana *et al*. (2015) named the parts of crops in which oils are concentrated to include the seeds, pulp, stone fruits, and in the tubers or sprouts. The source added that oil can be obtained from different categories of plants: plants with oil concentrated in seeds (sunflower, soybean, rapeseed etc.), plants producing oleaginous fruits (olive, coconut and palm), plants producing oleaginous tubers (peanuts) and plants producing oleaginous germ (corn). Major oil crops include Oil Palm (palm fruit and palm kernel), Soybean, Canola, Sunflower, Linseed, Coconut, Palm kernel (Dyer *et al*., 2008).

Extraction is an important unit operation in crop/food processing involving the recovery of a material of interest from a parent material. Techniques to extract oil from crops have existed for decades; and was majorly based on the Traditional Hot Water Floatation (TWF) Method. This method have been used for low-scale oil extraction as it is tedious and time-consuming. (Alenyorege *et al*., 2015).

However, due to high demand of vegetable oils, there was need to develop other techniques such as solvent extraction, mechanical extraction and other advanced oil extraction methods such as supercritical fluid extraction. Avram *et al.* (2014) predicted that the worldwide oil seed production will face an increasing demand in the next thirty years. This necessitates increased interest in vegetable oil extraction research and development.

Oil extraction from crops present some problems that warrant continuous research and development. For instance, the challenge that goes with variations in oil content is that the oil content in some crops is too little, making extraction uneconomical, while crops with abundant oil content may present structures that make oil extraction extremely difficult (Mariana *et al*., 2015). Alonge and Olaniyan (2007) presented the various problems of shea butter extraction and recommended that engineers should intensify efforts at developing more efficient systems for shea butter processing. Generally, agricultural materials present the problem of enormous variability. Consequently, an extraction method/equipment developed for a particular crop may not be amenable for oil extraction from another crop.

The above and other situations have prompted research and development of technologies for extraction of oil from specific crops. In recent years there has been widespread studies and researches aimed at developing improved technologies for oil extraction from agricultural materials (Avram *et al.*, 2014). In this paper, a comprehensive review of the recent studies and works on vegetable oil extraction is presented. The paper reviews works on the theory as well as researches on vegetable oil extraction. The objective of the paper is to present the technology situation and to provide an overview of the state-of-the-art in vegetable oil extraction research and development.

2. VEGETABLE OIL AND ITS USES

Vegetable oils are biological mixtures derived from plants. They are triglycerides, consisting of ester mixtures of fatty acids and glycerol. They also contain traces of monoacylglycerols and diacylglycerols, as well as variable amounts of other components such as phospholipids, free and esterified sterols, triterpene alcohols, tocopherols and tocotrienols, carotenes, chlorophylls and other coloring matters, and hydrocarbons as well as traces of metals, oxidation products, undesirable flavors, and so on (Anna et al., 2012).

Vegetable oils are useful both for the food and non-food industries. The food uses of vegetable oils include direct consumption, production of margarine, canned foods, bakery, confectionery, fried foods, etc. The non-food uses include production of detergents, paints, special varnishes, fatty acids, pharmaceuticals and cosmetics products, biodiesel production, lubricants and painting (Mariana *et al*., 2015; Dyer *et al*., 2008). In food products, vegetable oils play important functional and sensory roles, acting as carriers of fat-soluble vitamins (A, D, E, and K). They also provide an essential linoleic and linolenic acid, responsible for growth (Kostik et al., 2005).

2.1 Oil Extraction Parameters

Parameters used to test the performance of an oil extraction system include Extraction Yield, Extraction Efficiency and Extraction Loss (Alenyorege *et al.*, 2015).

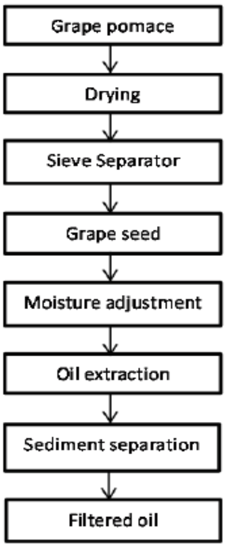
Extraction Yield is the amount of oil derived from a certain quantity of oleaginous material in a certain extraction process, expressed as a percentage.
Extraction Efficiency is the ratio of the amount of oil extracted to the amount of oil present in the oleaginous material, expressed as a percentage.
Extraction Loss is the weight of material that cannot be accounted for at the end of the extraction operation, either as oil recovered or the residual cake, expressed as a percentage of the total weight of material before extraction.

3. VEGETABLE OIL EXTRACTION TECHNOLOGIES

Certain extraction methods are applied as a unit operations in the oil extraction process, which basically involves seed/material preparation, actual extraction and post-extraction operations/treatment. For example, Venkitasamy *et al.* (2014) presented the flowchart they employed in extraction of oil from grape-seed (Fig. 1a). The simplified flowchart for three routes of mechanical extraction of palm kernel oil is shown in Fig. 1b. Route (A) is for direct screw-pressing without kernel pre-treatment; Route (B) is for partial kernel pre-treatment followed by screw-pressing; and Route C is for complete pre-treatment followed by screw-pressing (FAO, 2015).
Technologies for extraction of oils from agricultural produce have been developed over the years. The goal of a particular technology for oil extraction is to obtain high quality oils optimally (achieve the highest possible extraction yields with the lowest possible costs).

The oldest method of vegetable oil extraction is the traditional hot water floatation (THW) method. Another common traditional method is manual kneading. Mariana *et al*. (2015) stated that there are currently four vegetable oil extraction technologies, which include mechanical extraction, chemical extraction, supercritical fluid extraction and steam distillation.

Fig.



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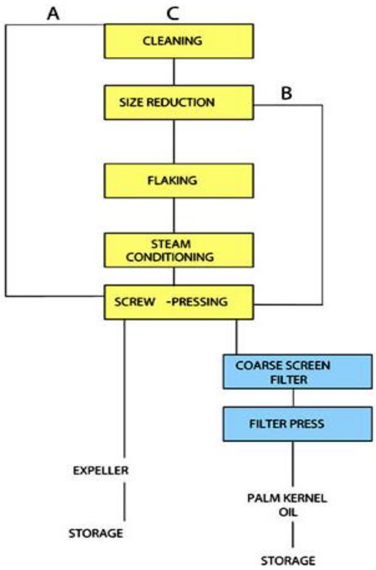


Flowchart for Oil Extraction from Grape-seed
Fig. 1b: Mechanical Extraction of Palm Kernel Oil

3.1 Traditional Hot Water Floatation (HWF) Method

This method of vegetable oil extraction is also called aqueous extraction or wet extraction method. It involves the use of a large amount of water such that the extracted oil floats on the water surface. The hot water floatation method is traditionally applied for small scale extraction of oil from oil seeds. The extraction process comprises five fundamental steps: thermal conditioning of the seeds; milling; extraction by boiling; oil recovery; and drying. The method is reportedly applicable to most oilseeds with varying degrees of oil yield (Alenyorege *et al*., 2015).

Head *et al.* (1995) explains that the process involves heating and then grinding the oil seed kernels, followed by suspending in boiling water for at least 30 minutes. This causes mass transfer of oil from the solid phase (ground seeds) to the liquid phase (water). The oil then floats to the surface of the water. According to the source, water may be further added after boiling to replenish evaporated water, and to enhance displacement of oil to the surface. A shallow dish is used to scoop out the oil and residual moisture is separated by evaporation.

The hot water floatation method is cheaper to carry out, compared to solvent extraction as it does not involve the use of chemicals. It is also considered environmentally safe (Mariana *et al*., 2015). The method however proves to be tedious and time consuming, and often offers low oil yields.

Alenyorege *et al.* (2015) conducted a research to determine the Extraction Yield, Extraction Efficiency and Extraction Loss associated with the traditional Hot Water

Floatation method of oil extraction from *Allanblackia floribunda* seeds. The quantity of seed used was 50 Kg. The method reportedly yielded 21.1 kg of oil (42.2% Extraction yield), a residual cake of 26.2 Kg and a process loss of 2.7 Kg at a moisture content of 13.1%. Thus, the Extraction efficiency was 58.6% while 5.4% Extraction loss was recorded. They concluded that the yield exceeded the minimum oil yield for commercial, domestic and industrial consideration.

3.2 Manual Kneading

According to Head *et al*. (1995), manual kneading is a water-assisted oil extraction method. The method is used for traditional groundnut oil extraction in West African villages. It involves adding water to groundnut paste to form a mixture, which is stirred and kneaded by hand until the oil separates.

3.3 Technological Advances in Mechanical Oil Extraction

Mechanical extraction, as the name implies, involves the application of pressure on milled/digested agricultural material to dislodge the oil from the material. The method is also known as pressing. The process involves separation of oil from the oleaginous material under the action of compressive forces produced by special machines called presses (Mariana *et al*., 2015).

The major advantage of this method is that the cost is relatively low and the extracted oil is non-contaminated. Mechanical extraction is also attractive because it does not present the environmental and health concerns associated with the use of hazardous solvents such as n-hexane.

The energy consumption and waste production is also relatively lower. Also, this method produces high-value vegetable oils, particularly for the food and cosmetics industry (Evelien and Philippe, 2017). The disadvantage is that the mechanical presses do not have high extraction efficiencies as about 8-14% of the available oil remain in the press cake (Mariana *et al*., 2015).

Mechanical extraction is also referred to as "Expression" and involves placing the material between permeable barriers (barriers with perforations) and increasing mechanical pressure by reducing the volume available for the material. This way the oil is squeezed from the material. Generally mechanical expression is only used for smaller capacity plants, specialty products or as a prepress operation in a large scale solvent extraction plant (Arișanu, 2013; Mariana *et al*., 2015).

There are two major methods of mechanical expression: screw press and hydraulic press. However, Adetola (2012) states that over the years, oil extraction presses developed (for palm oil extraction) include manual vertical screw-press, motor-jack press, motor-jack/cantilever, and combined screw/hydraulic hand press. Other methods include the wedge press, the plank press, cage presses, the bridge press, scissor press, ram press and ghani (Head *et al*., 1995).

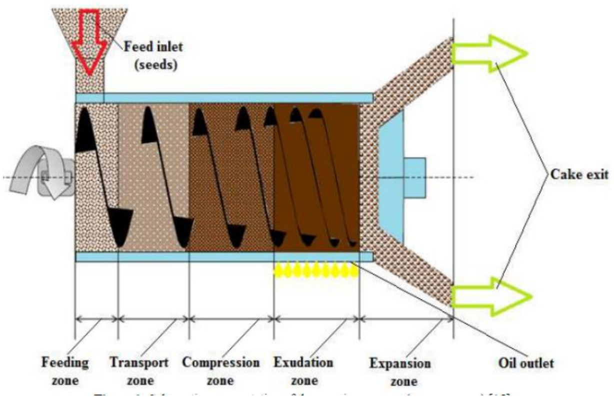
3.3.1 Screw Press

Screw presses are also called extruders or expellers. In a screw press, the pressure force is exerted by a helical body/worm which rotates in a closed space called press chamber. A screw press basically has a feed inlet, a horizontal barrel, which carries the horizontal screw, perforations for oil collection and exit for the cake/digested material. The screw is designed with an increasing body diameter, such that the highest pressure is attained at the exudation zone, which expels the oil. In a screw press the seeds are continuously fed; and the screw grinds, crushes and presses out the oil. This operation requires high friction co-efficient and it generates a high amount of heat (Khan *et al.*, 2016). When compared with a hydraulic press a screw press is more advantageous in that it has slightly higher oil extraction efficiency and allows for continuous oil extraction.

Single-screw Press

In a single-screw press, the material movement along the screw axis is achieved only through friction with the barrel wall. The pressure responsible for oil extraction is due to the flow restriction at the extruder outlet, which causes a pressure gradient that induces a pressure flow opposite to the material flow. The combination of both flows determines the feed rate, thus, the extruder throughput is dependent on the screw speed (Evelien and Philippe, 2017).

Also, since friction is the main factor, single-screw extrusion can consume enormous amounts of energy. It also has poor mixing capacity. It is noteworthy that these factors can lead to overheating and subsequent cake and oil quality deterioration (Evelien and Philippe, 2017). Fig. 2a illustrates the screw pressing process. Fig. 2b is a vertical section of a single-screw extruder.



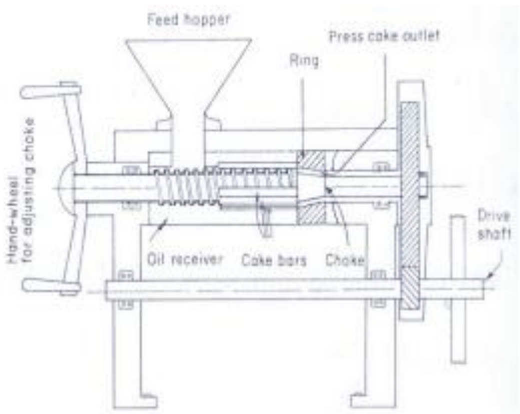


Fig. 2: Screw Pressing Process Fig. 2b: Single-Screw Press (Khan & Hanna, 1983 in Anna *et al*., 2012)
(Savoire *et al*., 2013).

[[Some researchers have worked on developing improved screw oil extractors. Some of the screw presses are developed for specific purposes. Alonge *et al.* (2004) developed a manually operated screw press for village level groundnut oil expression. The materials for construction were sourced locally. The press was tested for efficiency, throughput and durability. Test results indicated that a maximum oil yield of 24.93% was obtained at 80℃ and pressure of 42.28kPa. the oil expression efficiency was found to be 54.7%.

Adetola *et al.* (2012) developed a palm oil single-screw press for small and medium scale palm fruit processors, with the following components: standing frame, feed hopper, threaded shaft, cylindrical barrel, speed reduction gear motor, electric motor, pulley, cake and oil discharge outlets.

The principle of operation of the machine was presented by Adetola *et al.* (2012). According to them, the digested palm fruit is introduced into the machine through the hopper and is conveyed inside the cylindrical barrel with the aid of the worm shaft. The pressure buildup between the worm and the cylinder causes the crude oil to be pressed out of the mash. The crude oil extracted is drained through the oil channel into the oil tray where it is collected, while the residual cake is discharged at the cake outlet. The machine is powered by a 5hp three – phase electric motor with the construction materials being sourced locally at affordable costs. Plate 1 is a side view of the screw press.

Plate 1: Side View of the Oil Palm Screw Press (Adetola *et al.*, 2012)

Results of performance test showed that the highest oil extraction ratio (OER) of 17.90% and oil extraction efficiency (OEE) of 79.56% were obtained at the sterilization time of 60 min, digestion time of 10 min and screw speed of 10 rpm (Adetola *et al.*, 2012).

Khan *et al.* (2016) worked on design, simulation, construction and performance testing of a single-screw oil expeller press for small scale oil extraction. ASME shaft design code was used in designing the screw shaft of the press. The screw was analyzed with simulation software (ANSYS). The pressure on screw was determined & applied in the created meshed design in Ansys. A 20 HP 3-phase electric motor was used for running the machine at 140 rpm. Plate 2 shows the constructed expeller while Fig. 3 shows the ANSYS simulation of the screw.

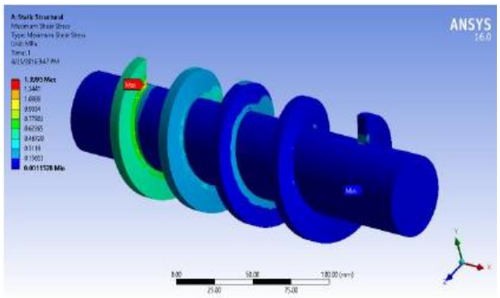


Plate 2: Screw Press (Khan *et al.,* 2016) Fig. 3: Maximum Shear Stress of Screw (Khan *et al.,* 2016)

The expeller was tested using coconut, rape seed, sesame, and sunflower seed. Structural analysis of the screw was also carried out. From the achieved stress analysis they concluded that the screw is within safety limit of stress. Also, the expeller efficiency was 68.2% and the capacity ranged between 85.22 gm/min to 98.52 gm/min (Khan *et al.,* 2016).

Twin-screw Press

Twin-screw presses/extruders consist of two intermeshing screws mounted on splined shafts and enclosed in a modular barrel. The screws may be rotating in the same direction (co-rotating screws) or in opposite direction (counter-rotation screws). Like the single-screw extruder, there is filtration module (perforations) that allow the collection of the liquid expelled from the material by compression.

When designed in the co-rotating configuration (the best design), a twin-screw extruder functions as a positive displacement pump, resulting in a throughput that is independent on the screw speed and pressure and ensuring efficient mixing and heat transfer – and higher process flexibility (unlike in single-screw extruders). Twin-screw oil expression (compared to single-screw method) could result in energy saving of 40% to 80% (Evelien and Philippe, 2017).

Further, the high flexibility and productivity inherent to twin-screw extrusion further exerts a positive impact on the economic feasibility of the process. Unlike single-screw presses (which are often dedicated to a particular crop species), twin-screw presses are amenable for universal application. Also, the non-interdependence of twin-screw extruder parameters such as throughput, oil flow rate and extraction efficiency allows for their simultaneous augmentation, and process optimization. This is not obtainable in single-screw extruders because a higher pressing efficiency and oil flow rate would result in low throughput (Evelien and Philippe, 2017).

of twin-screw presses for vegetable oil extraction.

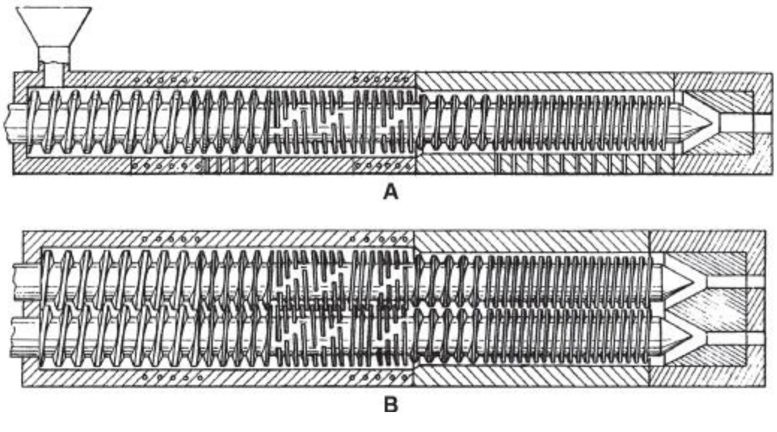


Fig. 4: Schematic representation of the twin-screw extruder design comprising two different pressing sections (Bouvier and Guyomard, 1996). A. Schematic Sectional front view; B. Schematic Sectional Plan

Evelien and Philippe (2017) stated that twin-screw extrusion has not yet found application in the oil extraction industry. However, due to its innovative and promising features, the technology has received significant research interests, which are concerned with development and improvement

Many researchers have worked on twin-screw extraction of oil from agricultural materials. They include: Amruthraj *et al.* (2014) who designed, constructed and tested a twin-screw expeller for extraction of inedible oil (for biodiesel) from *Pongamia pinnata* seeds; Dufaure *et al*. (1999) who reported the use of the twin-screw extruder for direct expression of oleic sunflower seeds; Evon *et al.* (2007) who evaluated the feasibility of an aqueous process to extract sunflower seed oil using co-rotating twin-screw extruder; Uitterhaegen *et al.* (2015) who presented an assessment of the vegetable oil extraction from coriander fruits through twin-screw extrusion, among many others.

Parameters Influencing the Screw Pressing Process

According to Mariana *et al.* (2014) the most important parameters which have to be taken into account for optimization of the oil production in screw presses include: screw speed, restriction size, hull content, moisture content, cooking process, temperature, pressure. The source gives detailed explanation of the influence of each of these parameters on the performance of screw presses, with cogent examples in published literature.

Ojomo *et al.* (2011) carried out economic analysis and effect of machine speed on the performance parameters of a locally fabricated screw press. The test results revealed that increase in machine speed resulted in increase in the feed rate, output capacity and the mass of cake produced. The extraction efficiency rose sharply and reached a maximum of 68% at 650rpm, and then decreased with higher speeds. The mass of oil yield also reached a maximum of 1.9kg and then decreased with increasing speed.

Kartika *et al.* (2010) carried out a study to evaluate the effects of screw configuration and operating parameters on oil extraction of sunflower seeds using a twin-screw extruder. Results showed that increased spacing between two screw elements and smaller pitch elements resulted in an increase in oil yield. Also, Oil yield was increased when pressing temperature, screw rotation speed and seed input flow rate were decreased. They also reported that the effect of the operating parameters on oil quality was low (mainly on acid and iodine values).

3.3.2 Hydraulic Press

Hydraulic presses are uni-axial presses which are driven by fluid pressure. According to Mariana *et al*. (2015), hydraulic expression of oil involves application of pressure through a ram to digested oleaginous material mash in a cylindrical cage. This results in axial compaction and radial oil flow through a lateral perforation. Fig. 5 shows the hydraulic pressing process.

The disadvantages of a hydraulic press compared to a screw press is that it has slightly lower oil yield and does not allow for continuous oil extraction (only batch extraction).

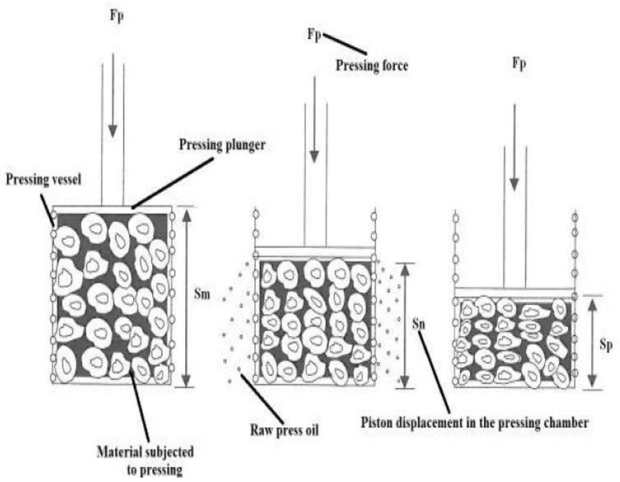


Fig. 5: Schematic Representation of a Hydraulic Pressing Process (Arișanu, 2013).

Fig. 6: Hydraulic Press (Head *et al.*, 1995)

However, Anna *et al.* (2012) stated that hydraulic presses are still needed for processing materials which require gentle handling, such as cocoa butter. Hydraulic presses have been utilized in oil extraction researches in recent times. For example, Sabarish *et al.* (2016) carried out a research which involved extraction of oil from rubber seeds through hydraulic press and kinetic study of acid esterification process. The hydraulic pressing method was compared with solvent extraction method, and they claimed that mechanical oil extraction method was superior in terms of purity of extracted oil, stages in process and cost of process. Others are Santaso *et al.* (2014), Oscar and Leonart (2013), among others.

Parameters Influencing the Hydraulic Pressing Process

According to a research carried out by Kehinde (2007) on coconut oil expression by uniaxial (hydraulic) expression, the factors which influenced coconut oil yield include heating moisture content, applied pressure, pressure duration, heating time and temperature which the samples were subjected to.

3.3.3 Cage Press

These are a form of manual presses used for small-scale vegetable oil extraction. They operate on batch mode. Head *et al.* (1995) noted that these presses are sometimes wrongly called screw presses and pointed out that this should be avoided as it can be confused with the continuous screw expeller. An example of cage press is the curb press which was manufactured in Luxembourg and which has been widely used in Nigeria for extracting palm oil.
The cage is made of two halves hinged on one side and locked together with a pin on the other. This enables the cage to be opened easily for unloading the spent material after pressing. The design makes cage presses particularly convenient for palm oil

extraction, but the central position of the screw inside the cage makes the press unsuitable for pressing other oilseeds (Head *et al.*, 1995). Fig. 7 illustrates the curb press and its use.

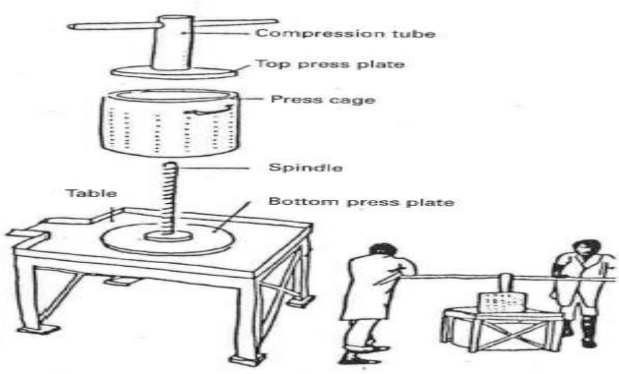


Fig. 7: Curb Press.

Alonge and Olaniya (2006) performed experiments to determine the effects of dilution volume, water temperature and pressing time on oil yield from the kernels of thevetia nuts using a laboratory cage press. They reported that oil yield increased to a maximum value when the dilution volume was increased from 5 to 15 ml after which it decreased with further increases in dilution volume. They also reported no definite pattern in the relationship between oil yield and water temperature. Also, oil yield increased progressively when the pressing time was increased from 5 to 30 minutes at all levels of dilution volume and water temperature. Alonge and Iyanda (2011) also reported that dilution volume, water temperature and pressing time had significant effect on oil yield from cashew nut (at $p<0.05$).

The effect of processing factors on oil yield of shea butter during extraction was also studied by Alonge and Olaniyan (2003). They found out that the dilution volume, water temperature and pressing time, as well as dilution volume versus water temperature all have significant effect (at 95% significance level) on the yield of shea butter. Research has also been carried out on optimization of groundnut oil expression (Alonge and Olaniyan, 2006).

3.4 Technological Advances in Chemical Oil Extraction

Chemical oil extraction can be achieved through the use of solvents (solvent extraction) or enzymes (enzymatic extraction).

3.4.1 Solvent Extraction

Solvent extraction is the most commonly used chemical method for oil extraction. It is the process of separating a liquid from a liquid-solid system with the use of a solvent. Some of the solvents used for oil extraction are light paraffinic petroleum fractions which include pentane, hexane, heptane and octanes (Mariana *et al.*, 2015). Other solvents include ethanol, methanol, and acetones (Mani *et al.* 2004).

Solvent extraction of oil is a simultaneous mass transfer process, which involves movement of vegetable oil from the solid phase (flaked material) to the liquid phase (solvent), as well as absorption of solvent by the solid phase, until equilibrium is attained. It can be a batch (e.g. Soxhlet and fixed column extraction) or continuous process (e.g. countercurrent extraction or continuous stage-wise extraction). Avram et al. (2014) mentioned that the rate of oil extraction in solvent process is dependent on the type of moisture used, the thickness and area of solid phase, temperature and moisture content. Another factor is the residence time.

The materials are first milled, then flaked in order to increase the contact area of the material with the solvent resulting in maximum oil yield. Some processes may involve cooking the flaked material to denature cell tissues for easy penetration of solvent (Mariana *et al.*, 2015). The solvent extraction process consists of five closely interrelated unit operations, namely: solvent extraction, meal desolventizing, meal drying and cooling, miscella distillation, and solvent recovery (Kemper, 2000).

Most commercial vegetable oil extraction plants employ the continuous countercurrent process in which the fresh solvent enters in one direction while the material enters in the opposite direction. The spent cake is discharged at one end while the miscella (solvent-oil mixture) is collected at the opposite end.

The solvent is separated from the oil through miscella distillation. Mariana *et al.* (2015) explains that the process involves heating the resulting miscella in evaporators at 80°C. Further, steam is injected on the shell side to vaporize and reduce the solvent to about 5% of the oil. Finally, the mixture is subjected into steam-stripping in a vacuum tower to remove the remaining solvent, at temperatures rising to a final of 110°C.

After the maximum oil has been extracted from the material in the solvent extractor, the meal is conveyed to the desolventizer toaster (DT), in order to remove the solvent from the meal fraction so that the solvent can be recovered. The material entering the DT is typically at the extractor temperature of 60°C, and it contains 25–35% (w/w) of solvent. The material leaving the DT is wet cake which is conveyed to the meal dryer cooler (DC), where the moisture in the meal is reduced to trading rule limits and to lower the meal temperature prior to storage (Kemper, 2000).

According to Kemper (2000), the solvent recovery processes include solvent and water vapor condensation as well as stripping of solvent from water and air effluent streams. The recovered solvent is usually heated prior to reuse in the extractor. The solvent vapors from the miscella distillation process are typically condensed in a common medium-vacuum condenser while the water and solvent vapors from the oil stripper and mineral oil stripper are typically condensed in a high vacuum condenser.

Solvent extraction is considered the most effective means of oil extraction in terms of oil yield and oil extraction efficiency. Commercial solvent oil extraction processes result in 99% extraction efficiency. Adepoju *et al.* (2014) gave the other advantages of solvent extraction over other extraction methods to include cost effectiveness, simplicity and short time needed for extraction. However, some limitations and disadvantages related to solvent oil extraction include the fact that chemical solvents are harmful to human health and the quality of recovered oil is lower than that of pressed oil. Thus, solvent-extracted oils may not be considered suitable for certain specialty purposes, such as food and cosmetics. Also, the highly inflammable nature of the chemicals pose danger of fire and explosion. The process also requires relatively high capital costs as well as high energy requirements (Mariana *et al.*, 2015).

Many researchers have worked on solvent extraction of oil from specific crops. One of them is Mani *et al.* (2004) who carried out a study to investigate the suitability of different solvents (hexane, petroleum ether and acetone) for oil extraction from moringa seed and to optimize the various process parameters (particle size, extraction temperature and residence time). Also, Adepoju *et al.* (2014) carried out a study which focused on optimization of oil extraction from Soursop oilseeds using Box-Behnken design, and also examined the physicochemical properties and fatty acid profile of the oil. Avram *et al.* (2014) built up an experimental bench-scale plant based on percolating procedure, in order to investigate the solvent extraction for oil separation from ground rapeseed, soybean and sunflower.

The Solvent Extraction Plant

A commercial solvent extraction plant for vegetable oils is usually a highly automated plant. In addition to the basic components described above, the plant comprises pumps, conveyors, heavy piping, heat exchangers, and process and instrumentation equipment, among others. Fig 8 shows a typical process flow diagram for solvent extraction of vegetable oil.

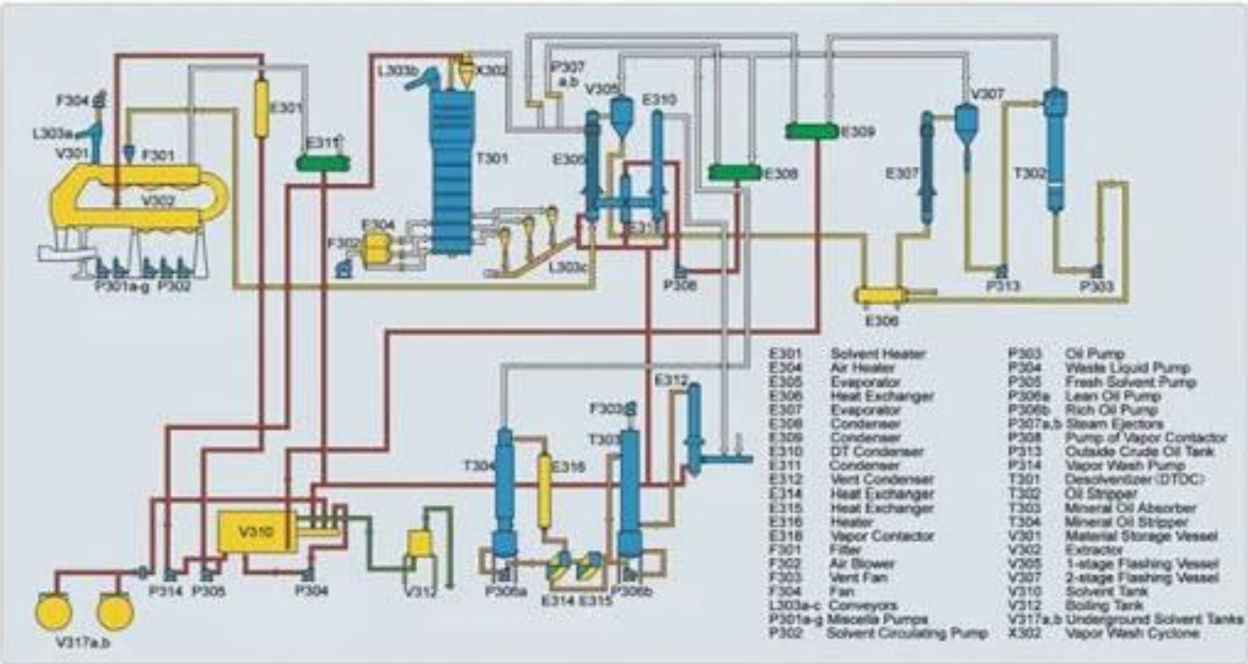


Fig. 8: Process Flow Diagram of a Vegetable Oil Solvent Extraction Plant (Source: Oil Mill Machinery).

3.4.2 Enzymatic Extraction

Enzymatic extraction is an aqueous extraction process which uses specific enzymes (depending on the type of material) to break down the tissues of oil-bearing materials, releasing oil. Ricochon and Muniglia (2010) noted that enzymatic extraction works using a phenomenon opposite to solvent extraction. Solvent extraction works by dissolution of the oil by the solvent, which results in the oil extraction, while the solids are left over as spent material. In enzymatic extraction, the non-solubility of oil in water is utilized. Here enzymes are used to hydrolyze/facilitate dissolution of the different constituents of cell walls (cellulose, hemicellulose, pectins, proteins, etc.) and the oil is liberated. Thus, in enzymatic extraction, knowledge of the structure and component of the crop cell wall is important for proper selection of enzymes, as well as the selection of the right physico-chemical parameters required for optimum yields.

Depending on the component of the crop cell wall, enzymes that may be used include cellulase, β-glucosidase, Xylanases, β-Mannanases, -L-Arabinofuranosidases, Polygalacturonases (PG), Pectin ester hydrolases, Polymethylgalacturonases (PMG), proteases etc. (Ricochon and Muniglia, 2010). The role of most carbohydrate enzymes such as cellulases and pectinases is to break the structure of cotyledon cell walls and the action of proteases is to hydrolyze the protein in the cell membranes as well as the inside cytoplasm (Wang et al., 2008). Different enzymes can be combined to form an enzyme mixture suitable for a particular cell wall composition. This will facilitate hydrolysis of the tissues, partly due to the fact that one enzyme may release a useful substrate needed for another to function.

A number of factors influence the performance of an enzymatic process. These include: grinding (type of crusher, speed, humid or dry); degree of inactivation of endogenous enzymes (equipment, pH, humidity, temperature, time); water quantity and mixture (water/solid ratio, equipment, speed rate, time); enzymatic hydrolysis (time, agitation, enzyme/substrate ratio, pH, temperature, sort of enzyme); inactivation of exogenous enzymes (temperature, pH, time, equipment); and oil recovery (Centrifugation, filtering, speed rate, time, pH, temperature) (Ricochon and Muniglia, 2010).
Enzymatic extraction is considered an eco-friendly method of oil extraction, which can better protect the health of employees and the environment – compared to solvent extraction. It also results in better oil quality. Thus, this method of oil extraction has been explored by many researchers. Wang et al. (2008) developed an aqueous enzymatic extraction process to recover oil and protein hydrolysates from blanched peanut. The enzyme type and enzyme concentration for the most efficient extraction were selected.

Beatriz *et al.* (2003) investigated the effect of relevant operational parameters including enzyme concentration, incubation time, pH and substrate/ water ratio on coconut protein and oil extraction yield. They found out that pH was the most meaningful parameter on oil and protein extraction yields, with a significance level higher than 90%. The maximum extraction yields of oil and protein emulsion (83%) was reached using Viscozyme L and subsequently Neutrase 1.5 MG at concentrations of 0.6% (w/w) and 0.3% (w/w), respectively, total incubation time of 60 minutes, substrate/water ratio 1:6 and pH around 7.
Other notable researchers who have worked on enzymatic oil extraction include Zhang *et al.* (2007), Aparan *et al.* (2002), Ricochon and Muniglia (2010), Li *et al.* (2014), among others.

3.5 Supercritical Fluid Extraction (SFE)

Supercritical fluid extraction is a relatively novel method of obtaining vegetable oil from agricultural material. It is, however, one of the most widely used methods in recent times. The SFE is a separation technology that uses supercritical fluid as the solvent (Xu *et al*., 2011). A supercritical fluid is a fluid which exists above the critical point and thus can be continuously transformed without phase transition into both the liquid and vapor phase.

A critical point is defined in terms of the critical temperature and critical pressure. At this temperature and pressure the phase boundaries (between liquid and vapor, for a liquid-vapor critical point) vanishes. The critical point is the end point of a temperature-pressure curve which designates conditions under which the liquid and vapor phases are indistinguishable. Xu *et al*. (2011) stated that under these conditions fluids cannot be liquefied above the critical temperature regardless of the pressure applied, but may reach a density close to the liquid state.

The advantages of SFE over conventional solvent extraction processes include excellent mass transfer properties and ease of control of solubility by operating pressure, operating temperature or polar modifier. Also, SFE yields high quality oils which, unlike solvent extraction, may not need any further refining (Salgin and Salgin, 2006; Xu *et al*., 2011). According to Xu *et al*. (2011), the main supercritical solvent used in oil extraction operations is carbon dioxide (critical conditions = 30.9°C and 7.28 MPa).

The advantages of carbon dioxide as SFE solvents include the fact that it is cheap, environmentally friendly and generally recognized as safe. Also, supercritical CO_2 has high diffusivity and its solvent strength can be adjusted to meet the extraction needs. Another advantage is that CO_2 is gaseous at room temperature and ordinary pressure, and is easily recovered from the oil and cake. Additionally, the fact that SFE with supercritical CO_2 can be operated at low temperatures using a non-oxidant medium, prevents thermal degradation and oxidation of vegetable oils. In a nutshell, carbon dioxide is considered an ideal solvent for the extraction of natural products because it is non-toxic, non-explosive, readily available and easy to remove from the extracted product. (Xu *et al*., 2011).

However, using supercritical CO_2 as an extraction solvent is not without drawbacks. The main challenge is that supercritical CO_2 has low polarity, and invariably a low solvating power. However, Xu *et al*. (2011) stated that the problem can be overcome by employing polar modifiers (co-solvents) to change the polarity of the supercritical fluid and to increase its solvating power towards the oil. Other disadvantages of supercritical fluid extraction are high investment costs for equipment acquisition and high energy demand of the CO_2 extraction unit (Cvjetko, *et al.*, 2012).

The method has received enormous research interests and special attention in the field of vegetable oil extraction. Honarvar1 *et al*. (2013), who worked on mathematical modeling of SFE of oil from canola and sesame Seeds, described the SFE process. The process involves feeding carbon dioxide from a gas tank equipped with a condenser to keep CO_2 liquefied. A pump is used to pressurize the liquefied carbon dioxide to the desired pressure. The material and ethanol (modifier) along with glass beads are loaded into a high pressure vessel in which the glass beads are used to prevent flow channeling in the packed bed. The pressurized carbon dioxide is then passed through a surge tank before feeding to the packed bed vessel. Fig. 9 is a schematic representation of the process.

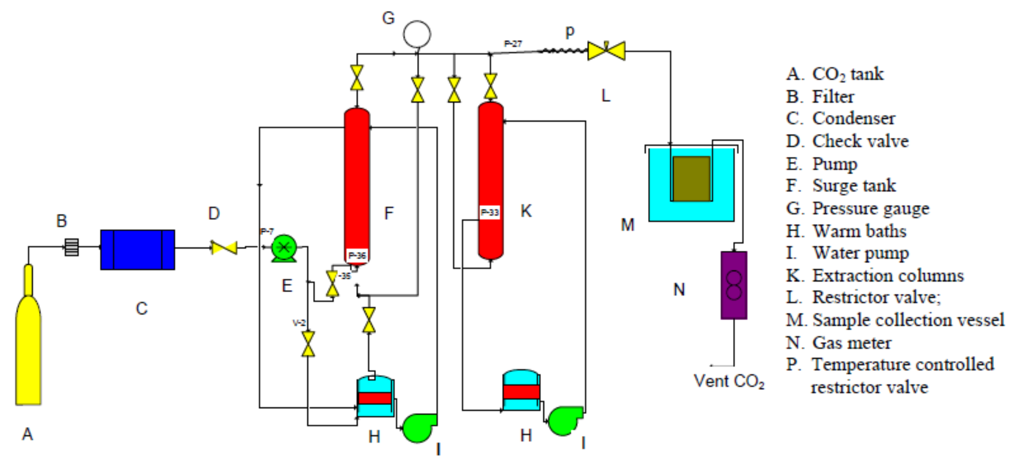


Fig. 9: Schematic Diagram of the Extraction of Oil from Canola Seed with Supercritical Carbon dioxide (Honarvar1 *et al*., 2013).

During the dynamic conditions the flow of solvent through the vessel is allowed by opening the back pressure valve, which is heated by an electrical resistance to prevent it from freezing. The extracted oil can then be obtained.

3.6 Extraction by Steam Distillation

Steam distillation is a technology used to extract essential oils in plant materials. Biorenewables Education Laboratory (2011) states that essential oils are secondary metabolites, a collection of hydrophobic compounds that can be extracted from plants and are used in perfumes, flavorings and alternative medicine techniques such as aromatherapy.

Steam distillation as a method of essential oils extraction is possible due to the volatility of essential oils (ability to evaporate) when heated with steam and their hydrophobic nature, which allows them to separate from the condensed water into an oil phase during condensation. A typical steam distillation system is a vertical unit consisting of heat source, boiler section, biomass chamber, still head, condenser and receiver.

Steam is produced in the boiler section by heating distilled water. This steam travels upward into the biomass chamber where essential oils and water-soluble plant compounds are removed into the vapor stream. The vapor stream travels through the still head, condenses in the condenser, and is collected in the receiver, where the essential oil layer phase separates. Steam distillation of biomass generally yields two products: a relatively high purity essential oil and an aqueous condensate called a hydrosol (Biorenewables Education Laboratory, 2011).

4. **CONCLUSION**

This review on vegetable oil extraction research and operations has pulled together some in-depth information from various resources. It has revealed the various technologies developed and employed in extraction of oils from agricultural materials, presenting both the older methods and recent ones. Researchers investigate the oil extraction technologies used at a particular time, in terms of their strengths and limitations. They seek ways to optimize the process in order to reduce the limitations. Others research on development of better, more efficient technologies. This evidently resulted in the vast array of research works reference in this paper.

However, it is important to research more into the effect of the processing methods and parameters on the intrinsic indices of vegetable oil quality, as well as the safety of oil produced by these methods for consumption. This presents opportunities for more research.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

The Role of Horticultural Package Vent Hole Design on Structural Performance

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ABSTRACT

Globally, ventilated paperboard packaging has been widely utilised particularly in the horticultural industry to protect packed produce against damage to satisfy consumer needs. During postharvest activities, the packages are exposed to cold environment and mechanical hazards. The mechanical hazards may result from different loadings such as drop, impact, vibration, compression or a combination of all. Designing ventilated packages should be such that they can provide uniform air distribution to cool the packed produce and protect the produce against mechanical damage. However, the presence of vent holes causes material loss of the package, thereby reducing the stacking strength of the packages and consequently resulting in produce damage. The strength of the package is crucial for preserving the produce and therefore optimising the package is essential to save time, money and resources.
This research was aimed at evaluating the structural behaviour of ventilated packages. Finite element analysis was used to create models to study the buckling of three ventilated package designs when subjected to compression load. Packages with different vent area and paperboard grades were studied. Experiments were used to quantify box compression strength. Results of mechanical strength evaluation showed a negative linear relationship between carton strength and vent area. Board thickness increased the compression strength of the packages. At 2% and 4% vent areas, packages with C flute board reduced in strength by as high as 46% when compared with the strength of the packages with B flute board. Numerical results and experimental results were in good agreement, within 12%. This study suggests the need for alternative package designs, considering the mechanical strength while still providing proper and adequate ventilation to the packed produce.

Keywords: Finite element analysis, ventilated paperboard packaging, vent hole, compression strength.

1. INTRODUCTION

Packaging is a crucial step in the long and complicated journey of fresh horticultural produce from the grower to the consumer (Fadiji et al., 2018a). The advent of ventilated paperboard packaging has been adopted globally to allow for rapid cooling, promote efficient cooling of the produce, and for proper air circulation within the package (Thompson et al., 2010; De Castro et al., 2005). However, ventilation openings adversely affect the mechanical strength of the packages, consequently resulting in the damage of the packed produce (Opara and Pathare, 2014). The structural performance of ventilated paperboard packaging is dependent on numerous factors such as quality of the cellulose fibres, strength of the paperboard components (liners and flutes), and the mechanical properties of the combined paperboard (Fadiji et al., 2018a). Furthermore, a proper package design must take into consideration different geometrical configurations of the vent such as the vent area, shape, size and location to enhance cooling while still providing sufficient mechanical strength (Pathare et al., 2017, 2016, 2012; Han and Park, 2007; Émond & Vigneault, 1998). According to Pathare et al. (2017), the strength and cooling capabilities of ventilated packages is dependent on the geometrical locations, sizes and shapes of the vent holes. To save money and resources, optimising the strength and adequate cooling capabilities is therefore crucial.

During handling of ventilated packages, they are often stacked in a pallet, resulting in increased weight on the bottom packages, which could lead to produce damage (Opara and Pathare, 2014). Box compression test (BCT) is often used as a measure to evaluate the performance potential of the packages (Pankaj et al., 2016; Fadiji et al., 2016; Markström, 1988). A decrease in carton mechanical strength was reported to be a function of increasing vent sizes (Singh et al., 2008). The compression strength of ventilated packages was influenced by package designs (Fadiji et al., 2016). Several researchers have reported the confidence of simulation techniques such as finite element analysis (FEA) and computational fluid dynamics (CFD) in replacing experimental analysis (Fadiji et al., 2018b; 2016; Pathare and Opara, 2014). Experimental and numerical analysis evaluation of the mechanical behaviour of paperboard packages was done by Biancolini and Brutti (2003). Fadiji et al. (2018b) developed a FEA model to predict the buckling of corrugated paperboard and packages. Results were validated with experimental tests and good agreement was reported. Among many factors that affect the strength of corrugated paperboard packaging, ventilation opening configurations and board grades play a crucial role. The aim of this research was to investigate the role of vent design on the structural performance of the package.

2. MATERIALS AND METHODS

a. Packaging design

Three telescopic package designs were used in this study. The Standard vent, Edge vent and the Multi vent designs. The Standard vent package is commonly used for commercial pome fruit export in South Africa (Berry et al., 2017, 2015). The Edge vent was used based on its successful application in the South African citrus industry (Defraeye et al., 2014; Delele et al., 2013a, b). The Multi vent was proposed as an alternative design to the Standard vent design. Two corrugated paperboard grades were used in this study: B-flute and C-flute. The thickness of the B and C flute paperboard grades was 2.8 mm and 3.9 mm, respectively. For each package design and board grades, two vent areas were used: 2% and 4%. Figure 1 shows the geomtry for the different package designs.

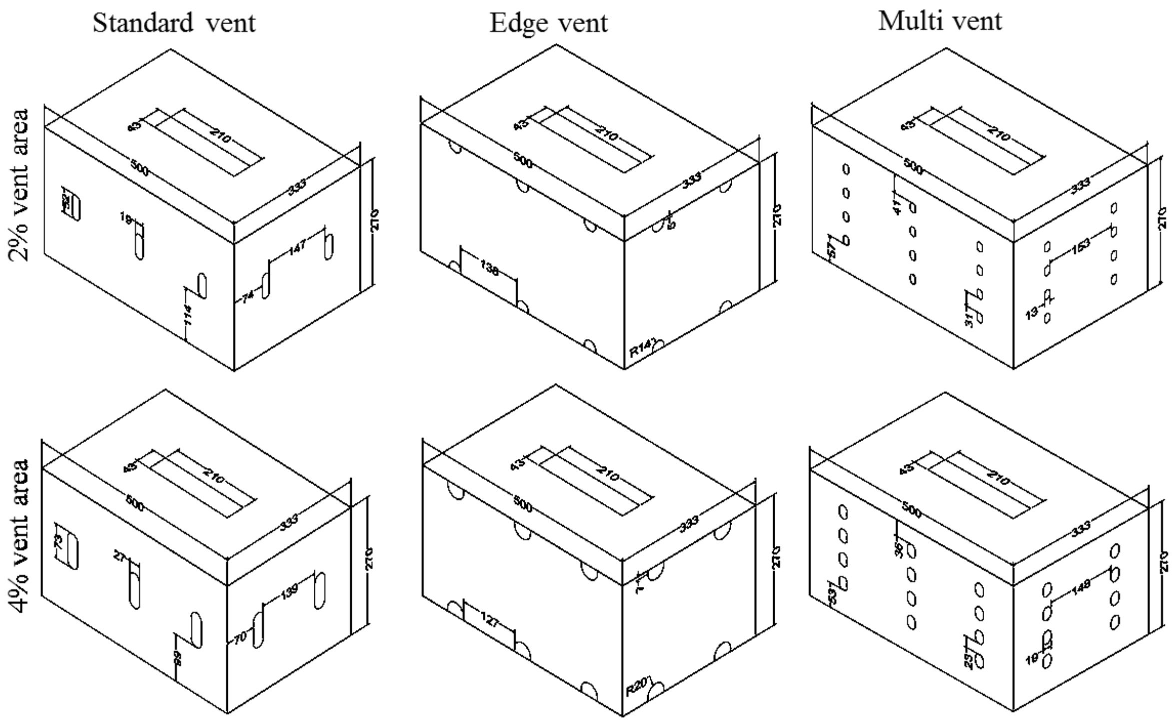


Figure 6. Geometry of the package designs. Dimensions in mm.

b. Finite element analysis

Mentat/Marc (MSC Software Corporation, California USA) was used for the FEA. The paper grammage (g m^{-1}) combination for B and C flutes was 140T2/175SC/165SC and 175T1/175SC/125FL, respectively. The thickness of the paper samples were 0.1992 mm, 0.2174 mm, 0.2646 mm, 0.2604 mm and 0.2225 mm for 125FL, 165SC, 175SC, 175T1 and 140T2, respectively. Elastic-plastic material properties reported by Fadiji et al. (2018b) were used. Due to computational time and cost, the homogenisation procedure proposed by Biancolini (2005) was used in the simulation for the package. Boundary conditions were set to represent the physical model accurately. Buckling analysis was performed on the packages to obtain the compression strength. Further details of the FEA setup can be found in Fadiji et al. (2018b).

c. Box compression strength (BCT)

BCT is a pure top-to-bottom compression load test between flat parallel steel plates that is carried out on an empty or filled sealed corrugated board package using a constant deformation speed. All compression tests were conducted using a box compression tester (M500-25CT, Testomatic, Rochdale, UK). Prior to the BCT, packages were preconditioned and conditioned according to ASTM D4332 standard. The BCT was done in accordance with the ASTM D642 Standard. A preload of 222 N was applied prior to the compression test remove initial transient effect. The fixed-platen mode of the compression tester was used to conduct all testing at a speed of 12.7 ± 2.5 mm min^{-1} until failure was observed. The compressive load and displacement are recorded continuously until collapse occurs. Statistical evaluations were performed using Statistica (v. 13.0, Statsoft, USA).

3. RESULTS AND DISCUSSION

a. Compression strength of the package designs

Figure 2 shows the compression strength and its correspnding displacements for all the package designs for both B and C flute board grades at 2% and 4% vent areas.

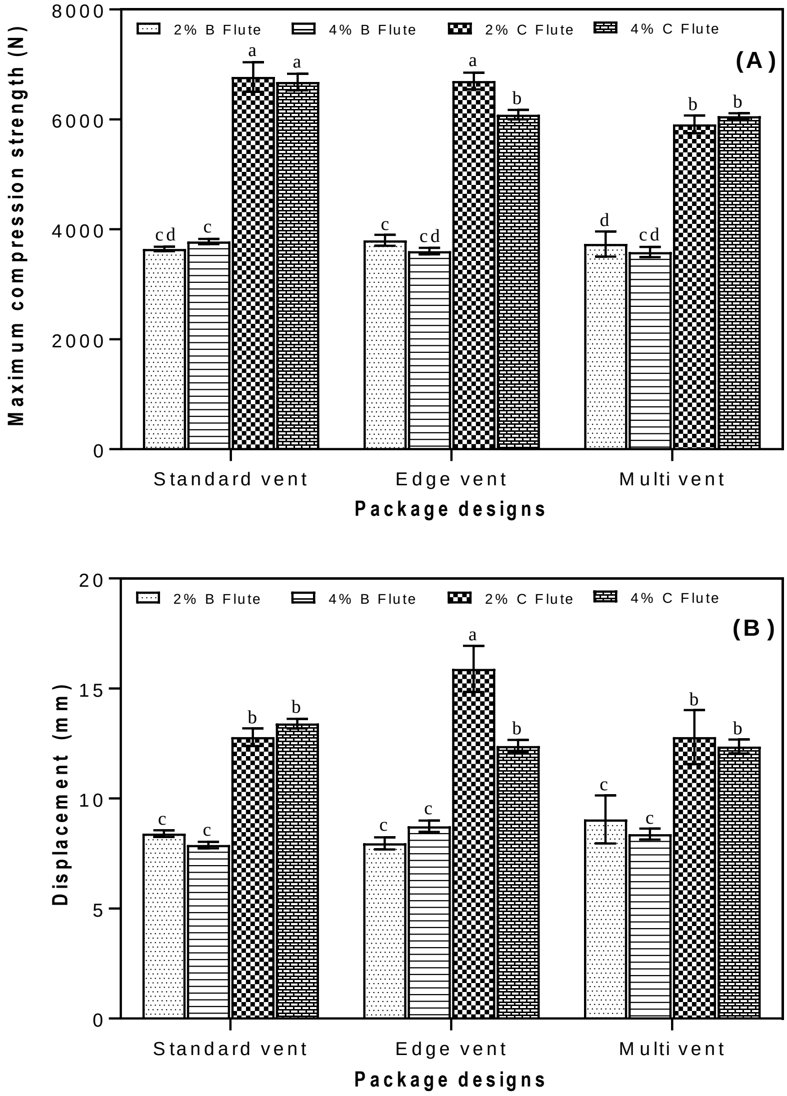
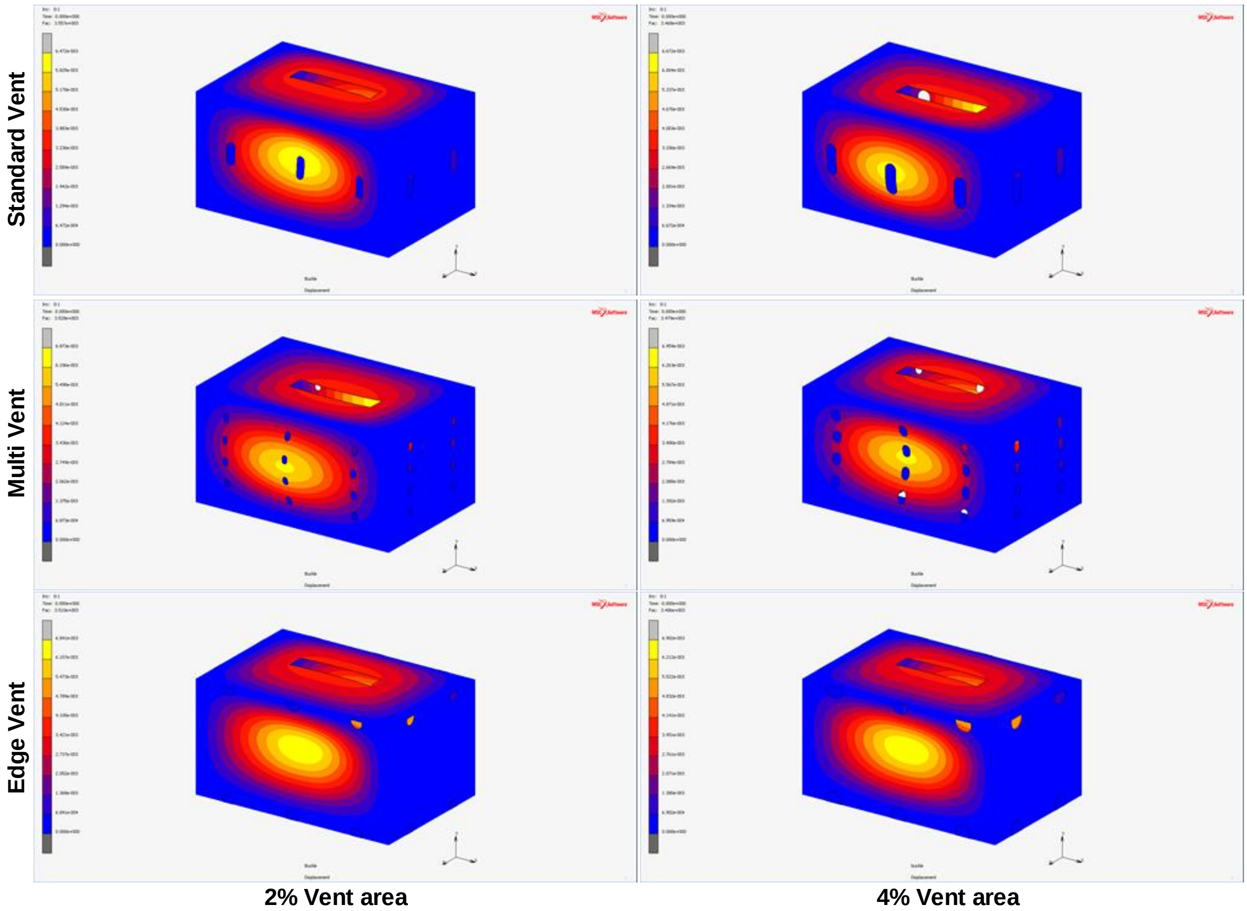


Figure 7. Bar chart showing (A) compression strength and (B) Displacements at maximum compression strength for all the package designs for both B and C flute board at 2% and 4% vent area. The letters on the error bars are used to show the statistical difference. Means with the same letters are not statistically different at P≤0.05.

From Figure 2, the compression strength of the packages with C flute board was observed to be higher than the packages with B flute board. In addition, there was a significant difference (P≤0.05) between the compression strength of the packages with B flute board and the packages with C flute board. At 2% vent area, the compression strength for the Standard, Edge and Multi vent designs with C flute board reduced by about 46%, 43% and 45%, respectively when compared with the compression strength of the same packages with B flute board. At 4% vent area, the compression strength of the Standard vent design with C flute board reduced by about 43% when compared with the compression strength of the Standard vent design with B flute board. The compression strength of both the Edge and the Multi vent designs with C flute board reduced by about 41% when compared with similar packages with B flute board. These results shows the vital role of the board grades as failure of the combined board initiates package failure (Dimitrov and Heydenrych, 2009). The combination of corrugated paperboard was reported by Biancolini et al. (2005) to be an important factor that can significantly influence the strength of paper packages. In most cases, the compression strength of the packages reduced with an increase in vent area (Figure 2A).
The compression strength at 2% vent area of the package designs was higher than the compression strength at 4% vent area for both board grades. Although, the compression strength at 4% vent area for the Standard vent and Multi vent designs with B flute board was slightly higher than the compression strength at 2% vent area. However, there was no significant difference statistically. Singh et al. (2008) reported a linear relationship between the loss in compression strength of a package and vent area, although with >40% of material removed from the package, the relationship does not stay linear. The ventilation opening on a package is a crucial factor affecting the mechanical resistance of the package, the physical support to protect packed produce against bruise damage and the cooling efficiency of the package (Defraeye et al., 2015; Pathare et al., 2012; De Castro et al., 2005; Baird et al., 1988). Therefore, there should be a compromise between the adequate cooling and the mechanical integrity of the package in designing an optimal package vent.
The corresponding displacement at the maximum compression strength for all the package designs is shown in Figure 2B. The displacement for the packages with C flute board was observed to be the highest compared to the displacement of the packages with B flute board. This indicated that the more resistance a package has to compression load, the higher the displacement. The range of the displacement for the packages with B flute board and C flute board was 7.8 – 9.1 mm and 12.4 – 15.9 mm, respectively. More deflection means that the impact of the load is spread over a longer duration, thereby reducing the intensity of the load impact (Campbell, 2010). Hence, the packages with C flute board offer better cushioning and protective ability to the packed produce, thereby minimising the mechanical damage incurred by packed produce. No significant difference (P≤0.05) in the displacement of the packages with 2% and 4% vent areas.

b. Simulation result

Typical fringe plots of the buckling behaviour of the packages with B flute board under compression load is shown in Figure 3. It can be seen that the buckling of the package



originated from the middle of the package, which is more predominant on the length side of the package. According to Panyarjun and Burgess (2001), package failure is due to the cummulative effect of the localised crushing that occur on the face of the package.Figure 8. Typical Fringe plots of the buckling of the package designs with B flute board grade.

Buckling was affected by the package designs. The length side of the Standard vent with 2% vent area buckled inward while the length side of the Standard vent with 4% vent area buckled outward.For the Multi vent with 2% and 4% vent area, the buckling on the length side of the package was outward and inward, respectively. The length side of both Edge vent with 2% and 4% vent area buckled inward. The compression strength obtained from the simulation an experimental results showed a significant dependence of the package resistance to compresion load on vent area and board grade. Both simulation and experimental compression strength agree well, within 12%.

4. CONCLUSIONS

This study evaluated the effect of package geometrical configurations on mechanical strength experimentally and numerically. Three different package designs, with two vent area (2% and 4%) and two paperboard grades (B and C flute) were used. The compression strength of the package reduced with an increase in vent area. The percentage difference in compression strength for all the packages with 2% and 4% vent area was in the range 1 – 10%. The thickness of the paperboard affected the strength of the packages. Packages with C flute board had higher compression strength than packages with B flute board. Numerical simulations were able to predict the compression strength of the packages, with good correlation, within 12% when compared with the experimental results. Results showed the importance of paperboard combination and vent hole designs to improve the structural integrity of the packages.

5. ACKNOWLEDGEMENTS

This work is based upon research supported by the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation. Experimental evaluations on cartons were conducted at the Paper Sciences Department of the Sappi Technology Centre at the Innovation Hub, Pretoria, South Africa and the authors thank the staff for their invaluable support and assistance.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Effects of periwinkle shell by-products on the behaviour of concrete: A review

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Abstract: Agricultural and aquaculture industries in Nigeria generate significant quantities of wastes and by-products during harvesting and processing of food products. Periwinkle shell is the by-product obtained after the edible part of a periwinkle shellfish has been extracted. Periwinkle shells are usually heaped in open fields and landfills which cause environmental problems. Untreated seashell wastes left for a long time leads to microbial decomposition of salts into harmful gases. Periwinkle shell by-products can possibly be used as substitute materials in concrete as a way of solving the waste management problems of periwinkle shells. Efforts have been made to utilise periwinkle shell aggregate as a partial or complete replacement of coarse or fine natural aggregate in concrete. Periwinkle shell ash has been used in experimental investigations as supplementary cementitious materials. This paper is a literature review of the effects of periwinkle shell aggregate and periwinkle shell ash on the physical and mechanical characteristics of concrete. Practical implications in the construction industry and further research suggestions are provided in the paper.

Keywords: By-products; concrete; mechanical properties; periwinkle shell; waste recycling

1. Introduction

Agricultural and aquaculture industries play a major role in the economy of nations. These industries provide food for human beings, supply raw materials for several industrial processes and also offer employment opportunities in agro- and aqua-related occupations. Owing to high demand for food by the ever-growing human population of Nigeria, significant quantities of wastes and by-products are daily generated by the agricultural and aquaculture industries during the harvesting and processing of food products. Sustainable development aims at protecting the environment for the present and future generations, and a way of ensuring environmental protection is by adopting effective waste management strategies.

Periwinkle shell is a by-product obtained after the edible part of a periwinkle shellfish has been removed. Periwinkle shells are thick, broadly ovate, and sharp-ended except when eroded. Periwinkles are found in mangrove swamps and estuarine waters. The major species found in the mudflats and lagoons of the Niger-Delta of Nigeria, from Calabar in the east to Badagry in the west, are *Tympanostomus spp.* and *Pachmellania spp.* (Agbede and Manasseh, 2009). Periwinkle is a mollusc and mollusc shellfishes contain up to 70% of inedible shell residue by weight (Martinez-Garcia et al., 2017). Periwinkle shell residues are usually heaped in open fields and landfills which create unsightly appearance and nauseating smell. Many dumpsites of seashells are seen in several towns and cities of the Niger-Delta including Port-Harcourt, Uyo, Calabar, Yenagoa, Warri and Oron (Ohimain et al., 2009). Accumulation of raw seashell wastes for a long period leads to the microbial decomposition of salts into dangerous gases such as hydrogen sulphide, ammonia and amines (Yao et al., 2014).

As a way of solving the waste management problems of periwinkle shell by-products, the shells have been utilised as recycled materials in concrete. Concrete is composed of cement, fine aggregate, coarse aggregate and water. The aggregates act as filler materials whereas the cement acts as the binding agent on reaction with water. Periwinkle shell aggregates have been used as a conglomerate in concrete by local residents in the coastal regions of Nigeria for over three decades (Agbede and Manasseh, 2009). This is because there is lack of conventional coarse aggregate (i.e. granite chippings) in most coastal regions of the country and it is expensive to transport granite aggregate to those regions, particularly localities where water transportation may be the only viable means of transportation. Periwinkle shell easily binds with cement paste, is naturally hard, and its size and shape makes it suitable for substituting normal coarse aggregate in concrete (Opara et al., 2017; Eziefula, 2018). In areas where periwinkle shells abound, the cost of periwinkle shell is cheaper than the cost of normal gravel by 10 times or more (Agbede and Manasseh, 2009). Earlier applications of periwinkle shell aggregate in simple construction works within the Niger-Delta region include residential buildings, septic tanks, soak-away pits, gutters, grave slabs and pavement slabs (Agbede and Manasseh, 2009; Ohimain et al., 2009).

Experimental investigations have been carried out on the suitability of periwinkle shell aggregate as a partial or complete replacement of natural aggregate in concrete. Periwinkle shell ash has been used in previous research as supplementary cementitious materials in concrete. This paper is a literature review of the effects of periwinkle shell aggregate and periwinkle shell ash on the physical and mechanical behaviour of concrete. Practical implications in the construction industry and further research suggestions are provided.

2. Properties of periwinkle shell by-products

2.1 Periwinkle shell aggregate

Periwinkle shell aggregate can be used as coarse aggregate (particle size retained on 5 mm sieve) or fine aggregate (particle size passing through 5 mm sieve). It should be noted that finer sizes of seashell aggregate grains generally tend to have higher water absorption, higher specific gravity and higher particle density than the coarser grains (Khankhaje et al., 2017; Martinez-Garcia et al., 2017). Table 1 shows the physical and mechanical properties of periwinkle shell aggregate. Most bulk density values for periwinkle shell fell within the range for normal weight aggregate (1280 to 1920 kg/m^3) given in the ACI (1999) code, although Falade (1995) and Agbede and Manasseh (2009) reported 694 and 515 kg/m^3, respectively. The specific gravity of periwinkle shell is low when compared with those of normal aggregate (2.30 to 2.90) but is higher than those of lightweight aggregates recommended in ACI (2003) i.e. ⅓ to ⅔ of normal weight aggregates. Periwinkle shell exceeded the 8% maximum absorption value recommended by ACI (1999). Periwinkle shell possesses the typical values for surface moisture content recommended by ACI (1999), although the 8.32% obtained by Falade (1995) was above the normal limit.

Table 1: Physical and mechanical properties of periwinkle shell aggregate

Property	Value
Uniformity coefficient	1.14-1.23
Specific gravity	2.05-2.07
Loose bulk density (kg/m^3)	514
Compacted bulk density (kg/m^3)	515-1353
Moisture content (%)	1.1-8.32
Water absorption (%)	9.03-12.99
Aggregate impact value (%)	32.5
Aggregate crushing value (%)	59.6
Los Angeles abrasion value (%)	45.73

(Sources: Falade, 1995; Adewuyi and Adegoke, 2008; Agbede and Manasseh, 2009; Osarenmwinda and Awaro, 2009; Falade et al., 2010; Ayegba, 2013; Eziefula et al., 2017)

The mechanical properties – aggregate impact, aggregate crushing and Los Angeles abrasion values – measure the toughness, strength and hardness, respectively. Periwinkle shell aggregate failed to meet up with the BS requirements for aggregate impact value for wearing surface concrete (maximum value ≤ 30%) but achieved the specifications for normal non-wearing concrete (maximum value ≤ 45%). The crushing values of periwinkle shell aggregate were more than the recommended value of ACI (2003) for normal concrete by 30%. Periwinkle shell satisfied the hardness requirement for only non-wearing surface concrete (maximum of 50%). The range reported for aggregate impact and aggregate crushing values (10 to 35%) of some natural aggregates by Shetty (2012) suggests that periwinkle shell aggregate is weaker and less shock-resistant than natural aggregates.

Molluscan shells are largely comprised of around 95 to 97% $CaCO_3$ with a small amount of chlorides, sulphates and organic substances (Yao, et al., 2014; Olivia et al., 2017). Malu and Bassey cited in Ohimain et al. (2009) reported that periwinkle shell contains CaO (38.4%), MgO (18.7%), Al_2O_3 (0.211%), Fe_2O_3 (0.019%) and SiO_2 (0.014%). Their findings thus suggest that periwinkle shell contains minute traces of silica which will not cause destructive alkali-silica reaction when mixed with cement paste.

2.2 Periwinkle shell ash

Periwinkle shell ash behaves like a pozzolanic material. Pozzolanic materials are siliceous or aluminous and siliceous materials which have little or no cementitious value but will possess cementitious properties in finely divided form when mixed with water (Shetty, 2012).

When a pozzolanic material is blended with Portland cement, it reacts with the deleterious calcium hydroxide ($Ca(OH)_2$) in cement and produces additional quantities of the valuable calcium-silicate-hydrate (C-S-H) which is the main cementing component (Ettu et al., 2013a). Regulated proportions of pozzolanic materials help to reduce the heat of evolution, enhance the durability of concrete, and produce stronger concrete at later curing ages (Shetty, 2012).

The performance of ashes as pozzolanic materials depends on the ash particle size, burning temperature and burning duration. Periwinkle shell ashes are first cooled, pulverised and sieved to very fine particles. Periwinkle shell ashes for pozzolanic use were generated at temperatures ranging from 600 to 1000 ^{o}C (Etuk et al., 2012; Olutoge et al., 2012; Umoh and Olusola, 2012; Umoh and Femi, 2013). The main chemical compounds of Portland cement (CaO, SiO_2, Al_2O_3 and Fe_2O_3) are present in periwinkle shell ash as shown in Table 2.

Table 2: Some chemical components of periwinkle shell ash

Chemical constituent	Weight (%)		
	(Etuk et al., 2012)	(Olutoge et al., 2012)	(Umoh and Olusola, 2012)
CaO	55.53	44.26	40.84
SiO_2	26.26	3.56	33.84
Al_2O_3	8.79	2.28	10.20
Fe_2O_3	4.82	1.75	6.02
MgO	0.40	8.98	0.48
Na_2O	0.25	1.41	0.24
K_2O	0.20	5.90	0.14

3. Behaviour of concrete containing periwinkle shell by-products

3.1 Workability

Slump was the main workability property used to assess the behaviour of fresh concrete in the previous investigations. Slump decreases as the aggregate replacement with periwinkle shell aggregate increases. At 100% coarse aggregate replacement, the reduction in slump of concrete ranged from 55 to 99% when compared with control concrete (Falade, 1995; Agbede and Manasseh, 2009; Adewuyi and Adegoke, 2008). The reduction in slump was attributed to bigger specific surface area (Falade, 1995; Adewuyi and Adegoke, 2008), rough texture and elongated shape of the periwinkle shells (Agbede and Manasseh, 2009).

Slump also decreases with increase in cement replacement by periwinkle shell ash (Olusola and Umoh, 2012; Olutoge et al., 2012). This is attributed to the higher specific surface owing to high fineness of the ash particles (Olusola and Umoh, 2012).

3.2 Density

Density slightly decreases when the coarse aggregate replacement with seashell aggregate increases. The density of 28-day concrete containing between 30 to 50% inclusion of coarse periwinkle shell aggregate for most mix ratios is greater than 2100 kg/m^3 and thus can still be regarded as normal weight concrete (Figure 1). The reduced density is connected with the comparative lower specific gravity and bulk density of periwinkle shell aggregate.

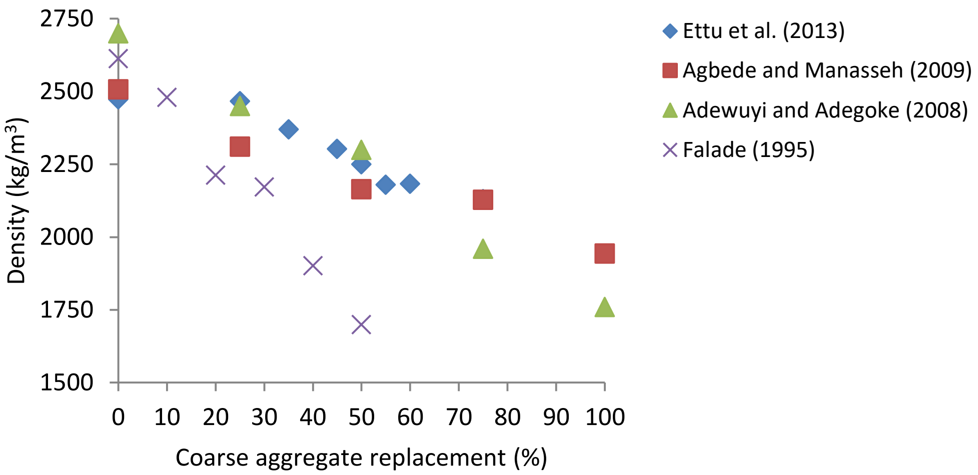

Figure 1: 28-day density of periwinkle shell aggregate concrete at various replacement levels

The density of 28-day ternary blended cement concrete incorporating periwinkle shell ash and bamboo leaf ash gives lower density as the ash content increases beyond the optimum content i.e. 20% cement substitution (Umoh and Femi, 2013). On the other hand, the density of concrete for the 20% replacement of cement was heavier than the control value.

3.3 Compressive strength

Inclusion of periwinkle shell aggregates generally reduces the compressive strength of concrete, especially at higher replacement percentages. The influence of periwinkle shell content is more remarkable in concrete mixes having high aggregate/cement ratios (Falade, 1995). Soneye et al. (2016) observed that when sand is partially replaced with crushed periwinkle shell aggregate at 10 and 50% replacement levels, the 28-day compressive strength of control concrete reduced by 5% and 27%, respectively. When normal coarse aggregate is wholly replaced with periwinkle shell aggregate, the loss in concrete compressive strength at 28 days of curing ranged from 65 to 75% (Ekop et al., 2013; Adewuyi and Adegoke, 2008). There is between 5 to 20% drop in 28-day compressive strength at 25% replacement level (Ekop et al., 2013; Ettu et al., 2013b; Adewuyi and Adegoke, 2008). For most mix ratios and replacement percentages, the compressive strength of granite-periwinkle shell aggregate concrete exceeds the BS 25 N/mm^2 target for structural concrete (Figure 2). When subjected to 800 °C/h, concrete made with periwinkle shell as complete replacement of coarse aggregate loses between 24% and 40% of its unheated compressive strength, depending on the mix ratio and curing age (Falade et al., 2010).

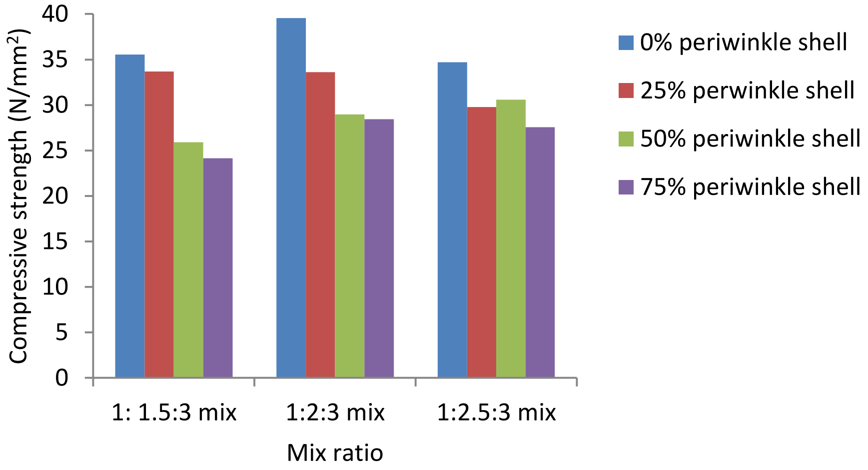

Figure 2: 28-day compressive strength of periwinkle shell aggregate concrete for a range of mix ratios and replacement percentages (Source: Ettu et al., 2013)

The compressive strength of periwinkle shell ash blended cement concrete is generally lower than the control but there is a continuous strength development comparable with that of the control. The optimum level of periwinkle shell ash substitution is 10% replacement level, attaining 102% of the control strength at 28 days (Umoh and Olusola, 2012). Use of periwinkle shell ash and bamboo leaf ash in ternary blended cement concrete of 1:2:4 mix at 20% cement replacement (10% each) gives higher strength of concrete (Umoh and Femi, 2013). This increment in compressive strength is 4.6% for 28 curing days and 9.6% for 56 curing days.

3.4 Other properties

Just like compressive strength, adding periwinkle shell aggregate in concrete has a similar influence on the flexural strength; higher ratio of periwinkle shell leads to lower flexural strength. Falade (1995) obtained 28-days results ranging from less than 1.0 N/mm^2 to values slightly above 3.0 N/mm^2 using various mix ratios and replacement percentages. The relationship between the flexural strength and compressive strength of *Pachymelania Aurita* periwinkle shell concrete is shown in Figure 3. The lowest ratio of flexural strength to compressive strength for 28-day *Pachymelania Aurita* periwinkle shell concrete obtained by Ekop et al. (2013) was 7% for 50% replacement, whereas the successive highest flexural/compressive strength ratios were 11% for the control concrete and 10% for the wholly-replaced sample.

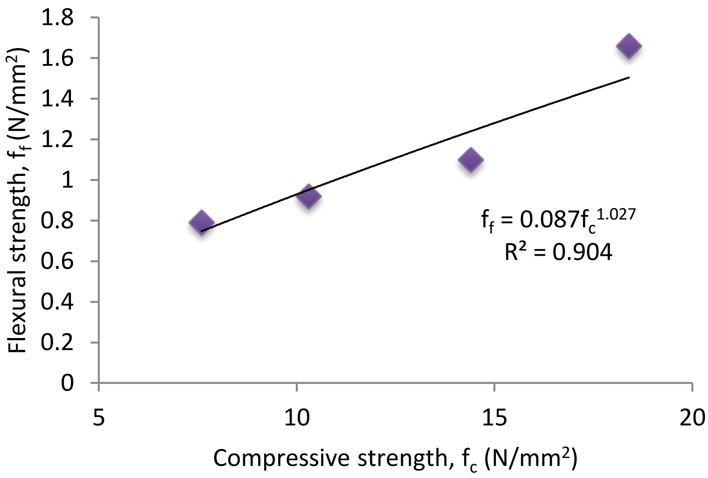

Figure 3: Relationship between flexural strength and compressive strength of periwinkle shell aggregate concrete (Source: Ekop et al., 2013)

A higher percentage of periwinkle shell ash substitution (beyond 10% replacement percentage) leads to decrease in splitting tensile strength (Olusola and Umoh, 2012). The ratios of tensile splitting strength to compressive strength of periwinkle shell ash blended cement concrete lies between 0.10 and 0.14 for 0 to 40% substitution. According to Olusola and Umoh (2012), the relationship between the compressive strength and splitting tensile strength is comparable with that of conventional concrete,

The static modulus of elasticity of the control concrete specimens is greater than those of the cement concrete blended with periwinkle shell ash (Umoh and Olusola, 2012). However, there is a continuous improvement with mixes containing 20% (or less) periwinkle shell ashes for all the curing ages.

The water absorption and porosity of ternary blended cement concrete incorporating periwinkle shell ash and bamboo leaf ash generally increases with percentage replacement concrete (Umoh and Femi, 2013). However, mixes containing 20% replacement (10% each) show lower porosity and water absorption values in comparison with the reference concrete (i.e. the 20% cement replacement mix is less permeable than the control concrete). The higher values of mixes greater than 20% cement replacement is attributed to the greater volume of pores created in the other mixes which could be due to the extra ashes that were not consumed during the pozzolanic reaction, thereby forming permeable spots for water penetration. (Umoh and Femi, 2013).

The behaviour of periwinkle shell aggregate concrete at elevated temperatures shows that minor cracking and spalling occur between 300 to 400 ^{o}C, major cracks are seen at 400 to 600 ^{o}C and smoke is emitted from 700 ^{o}C (Falade et al., 2010). Bond properties of periwinkle shell aggregate concrete matrix decreases with rising temperature due to the near-smooth surface of the shells and weakening of shell strength at high temperature (Falade et al., 2010).

4. Practical implications in the construction industry

Using periwinkle shell by-products as substitute materials in concrete can improve certain properties of concrete. This also leads to environmental and economic benefits in the society such as effective waste management of agricultural and aquaculture by-products, preservation of natural aggregate resources and cheaper construction costs. There are practical applications of periwinkle shell by-products in concrete and other cement-based construction materials. Some of the possible applications in concrete structures are hereby stated below:

i. Using periwinkle shell aggregate as a partial coarse aggregate replacement at lower substitution levels (around 30 to 50% replacement) can produce normal-weight concrete possessing satisfactory compressive strength (equivalent to 60% or more of the corresponding control strength of conventional concrete). Such periwinkle shell aggregate concrete can be utilised in cases where lower self-weight of concrete is desirable and lesser strength is acceptable. Promising applications include foundation blinds, insulating concrete and pavement slabs. If appropriate concrete mix design and higher quality control measures are adopted, it will also be possible to use such concretes in medium-strength structural applications such as lightly-loaded slabs and lean concrete bases. The reduced self-weight of concrete will invariably decrease the dead load which is an advantage in structural design.
ii. Periwinkle shell ash has the potential of being utilised as a pozzolanic material in binary and ternary blended cement concrete. At 10% cement replacement by weight, optimum strength can be realised particularly at later curing ages. Periwinkle shell ash will have beneficial functions in concrete structures where low strength at early curing ages is passable and low heat of evolution is important. Examples include precast concrete units and mass concrete works.

5. Conclusions

i. The few studies on the mechanical characteristics of periwinkle shell aggregate suggest that periwinkle shell aggregate is weaker and less shock-resistant than natural aggregate. Nevertheless, periwinkle shell aggregate satisfies the toughness and hardness requirements considered necessary for the production of non-wearing surface concrete.
ii. The chemical composition of periwinkle shell ash is similar with those of ordinary Portland cement. The major elemental oxide present in periwinkle shell ash is CaO.
iii. The inclusion of periwinkle shell aggregate as partial replacement of aggregate in concrete generally reduces the workability, density and strength characteristics, particularly at higher replacement percentages.
iv. Substituting between 30 to 50% of coarse aggregate with periwinkle shell aggregate yields normal-weight concrete of satisfactory compressive strength.
v. The optimum content of periwinkle shell ash in blended Portland cement concrete is 10%.
vi. Concrete containing periwinkle shell aggregate as complete replacement of coarse aggregate should not be exposed to temperatures higher than 300 ^{o}C.

6. Recommendations for further research

i. More detailed studies should be conducted to find out the pozzolanic characteristics of periwinkle shell ash for various burning methods, burning temperatures and burning durations.
ii. Further investigations should be carried out to firmly confirm the mechanical properties of coarse periwinkle shell aggregate.
iii. Long-term physical and strength properties of concrete containing periwinkle shell by-products should be observed.
iv. The effects of supplementary cementitious materials from agro-wastes (like, rice husk ash, coconut husk ash and palm bunch ash) on the properties of concrete having periwinkle shell aggregate should be studied.
v. In-depth research is required on the durability-related properties e.g. fire resistance, abrasion resistance, slip resistance, chemical attack resistance, shrinkage and water absorption of concrete containing periwinkle shell by-products.
vi. The structural behaviour of reinforced concrete slabs, beams and columns constructed with periwinkle shell aggregate as partial replacement of coarse aggregate at different substitution levels and mix proportions should be studied. The ultimate and serviceability limit states such as deflection and cracking need to be checked and compared with those of traditional reinforced concrete.
vii. Detailed cost analysis of concrete containing various forms of periwinkle shell by-products should be determined for various replacement percentages and mix ratios.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Dynamics of pomegranate fruit weight loss during precooling and ambient storage: a spatial and temporal analysis

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ABSTRACT

In this paper the spatiotemporal profile of weight loss of pomegranate fruit (cv. Wonderful) was investigated during precooling and simulated shelf conditions. The effects of relative humidity (RH) inside the cold room, polyliner inside the packaging and stack orientation on fruit weight loss were studied. Weight loss during the precooling operation ranged from 0.17 to 0.25% of the initial fruit weight and was highest during precooling of stack without liner and inside non-humidified room (0.25%). It was observed that fruit weight loss in liner-based packaging was almost equivalent to room humidification. Results of the shelf life study demonstrated the importance of room humidification to preserve fruit quality. Storing fruit in a room at 95% RH minimised weight loss and best maintained fruit colour, firmness, size and chemical quality attributes of pomegranates. On the other hand, fruit stored at ambient condition (65% RH) up to 30 days had excessive weight loss (up that 29.13±1.49%), which led to shrivel, deformed appearance and considerably reduced overall visual quality.

Keywords: Punica granatum, humidity management, cold chain; moisture loss; liner; market conditions; quality

1. INTRODUCTION

Rapid moisture loss is among the main quality problems affecting postharvest life of pomegranate fruit (Fawole & Opara, 2013; Arendse et al., 2014). On top of losing marketable fruit weight, fruit that lose moisture above 5% will shrivel, this reduces their visual appeal and commercial value. Weight loss in fruit is mainly due to transpiration and to a relatively small extent due to respiratory activity (Waelti, 2010). Large vapour pressure deficit (VPD) between fruit surface and the surrounding air leads to increased rate of moisture loss.

Cooling pomegranate fruit preserves quality, but weight loss remains a challenge during cold storage (Arendse et al., 2014). Humidification of the storage room, packaging fruit in plastic films, fruit coating, shrink wrapping are some of the practiced mitigation measures to moisture loss. However, humidification can also cause several storage problems affecting fruit. For instance, during cold storage of table grapes, humidification increased stem dehydration, browning of berries, increased the incidence of SO2 injury and package wetting (Ngcobo et al., 2013).

Temperature and humidity control in a stack of fruit is normally based on measurements taken from specific locations in the storage room. However, these have been reported to be spatially non-uniform in fruit pallets (Ambaw et al., 2017; Mukama et al., 2017). The amount of weight loss and the degree of spatial variation in the precooling process of pomegranate fruit are not clearly understood. Therefore, the objectives of this study were to: 1) measure the spatial and temporal weight loss profile during precooling of pomegranate fruit, 2) study the effects of internal packaging, humidification, and package orientation on the moisture loss, and 3) investigate the physico-chemical quality attributes of pomegranate fruit stored at different shelf conditions.

2. STUDY DESCRIPTION

2.1 Fruit

Pomegranate fruit (cv. Wonderful) were harvested at commercial maturity from Merwespont farm in Bonnievale (33°58’12.02” S, 20°09’21.03” E), Western Cape, South Africa and transported in an air-conditioned vehicle to Postharvest Technology Research Lab at Stellenbosch University.

2.2 Package materials

In this study, corrugated fibreboard carton box (CFC) was used to contain the pomegranate fruit. The box had 6 semi-circular vent-holes on the long side located at the top and bottom rim of the side, 2 semi-circular vent-holes at the top rim of the side and 5 circular vent-holes on the bottom side. Each box contained 12 fruit with average weight of 4.32 ± 0.39 kg per carton. Fruit weight loss during precooling of two different package designs were investigated: package with internal polyliner and another without polyliner. Plastic wrapping was done by placing pomegranates in a single non-perforated 10 µm thick high density polyethylene (HDPE) plastic film.

2.3 Air suction equipment (ASE)

The ASE was a box with suction fan attached to one end. The suction was generated by using a centrifugal fan (KDD 10/10 750W 4P-1 3SY, AMS supplies, Sandton, South Africa). The stacked fruit, as covered with plastic sheet, was placed in front of the ASE so that air was drawn horizontally through it.

2.4 Cold storage room

The ASE/stack assembly was placed inside a 20 m3 cold storage room equipped with a cooling unit and a humidifier. The cooling unit had three evaporator fans each creating an air circulation rate of 1290 m3 h-1. Cold room humidity was controlled using Aqua

Room-2 humidifier (Miatec Inc. 9480SE, Lawnfield Road, Chackamas OR 97105 USA) with 1.4-2.1 bars pressure capacity, 2 L h-1 liquid capacity, 10 µm droplet size and digital hygrotransmitter sensor (0-100% RH).

2.5 Experiments

2.5.1 Precooling experiments

70 cartons were stacked (7 layers of 10 cartons) on an ISO standard pallet (1.2 m × 1.0 m × 0.1 m). The stack was first equilibrated to ambient air conditions (≈ 17 °C and 65% RH) before being placed inside the cool storage room. The sides and top of the stack were covered with plastic sheet so that chilled air was horizontally sucked through the stack by the ASE. Two different pallet orientations with respect to the ASE were considered: pallet with its 1.2 m side perpendicular to the air flow and pallet with the 1.0 m side perpendicular to the air flow. Due to difference in vent-hole proportion between the long and short side of the box, the vent area along the flow direction of the two different orientations are dissimilar. For the 1.2 m oriented stack, the vent-hole ratio along the flow direction were 9.45% and 2.15% at inlet and outlet, respectively. The 1.0 m orientation had vent-hole ratio of 4.24% at both the inlet and outlet end.

All precooling experiments were from the initial ambient condition (≈ 17 °C) down to 7 ± 1.2 °C. During the experiment fruit pulp temperature was monitored at intervals of 5 minutes using T-type thermocouples and a 34970a Data Acquisition/Data Logger Switch Unit (Agilet Technologies, Santa Clara CA 95051, USA). The measured temperature data was used to calculate the stack average 7/8th cooling time which determined the time to stop the precooling experiment. Additionally, fruit weight loss was measured by taking initial and final weight of sample fruit. The temperature and weight loss sampling positions were from stack levels 2, 4, and 6. A total of 24 measurements (2 pallet orientations × 2 RH conditions × 2 liner conditions × 3 repetitions) were taken.

2.5.2 Measuring the effect of humidity on shelf life of pomegranate fruit

Two groups of 216 fruit each were equilibrated to ambient condition before the start of the experiment. Group 1 were kept under high humidity condition (95 ± 1.23 %RH) and group 2 under low humidity condition (65 ± 6.79 %RH). In both cases, the room temperature was kept at 20 ± 0.36 °C. Fruit weight, colour, firmness, size, titratable acidity, total soluble solids and pH were assessed on a 3 day interval for 30 days.

2.6 Statistical analysis

Statistical analysis was done using Statistica software (Statistica version 12, StatSoft Inc., Tulsa, USA). Mixed model repeated measures analysis of variance (ANOVA) was done using the VEPAC module of Statistica 12 at 95% confidence interval. Variations in weight loss were compared between the package designs, stack levels, stack orientations and fruit position within a stack level. Statistical significance of the treatments was tested using Duncan's Multiple Range Test and means with $p < 0.05$ were considered significant.

3. RESULTS AND DISCUSIONS

3.1 Weight loss during precooling of pomegranate fruit

On average, weight loss ranged from 0.17 to 0.25% of the initial fruit weight. Clearly, fruit weight loss was highest (0.25%) for the stack without liner and in a non-humidified cool store ("None" in Fig. 1 (a)). Stack with plastic liner and in a humidified room ("Liner + Humidification" in Fig. 1 (a)) experienced the lowest weight loss (0.17%). However, the presence of liner always increased fruit cooling time (Fig 1(b)) such that stacks with liner had SECT higher than 10 h compared with less than 5 h for stacks without liner.

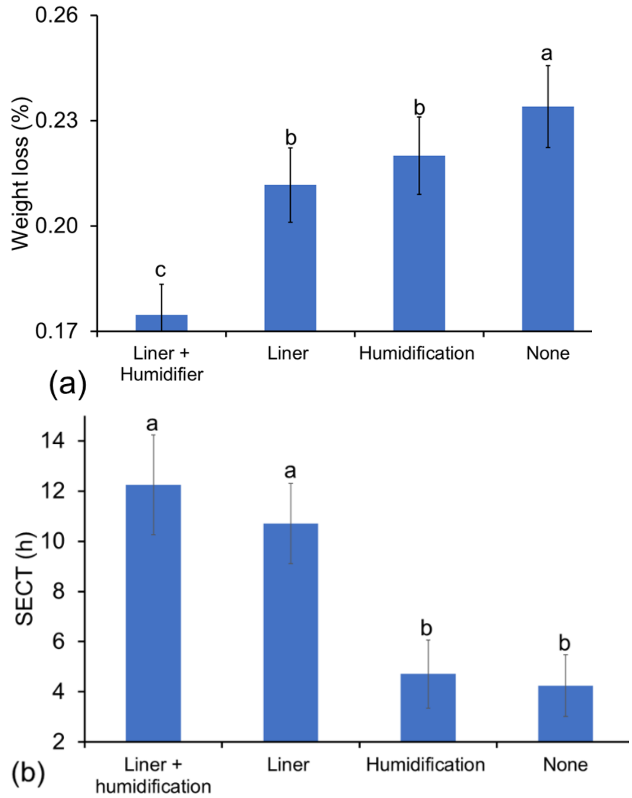

Fig. 1. Weight loss of pomegranate fruit (mean ± STDV) during precooling (a) and the corresponding 7/8th cooling time (SECT (b)). All humidification was at 95 ± 1.23 %RH. When no humidification, the cool storage room was kept at ambient humidity condition of 65 ± 6.79 %RH. The weight loss and SECT values are stack means. Means with different letters are significantly different ($p < 0.05$).

3.1.1 Effect of stack orientation

The average weight loss of precooled pomegranates in the 1.0 m orientated pallet was 0.20% while those in the 1.2 m oriented pallet it was 0.22%. The 1.0 m side of the pallet has relatively lower ventilation compared to the 1.2 m orientation as described in section 2.5.1. Low ventilation rate results in relatively lower convective mass transfer coefficient from the fruit surface to the ambient air. This leads to the observed low weight loss profile. However, this also leads to a relatively higher cooling time.

3.1.2 Spatial variation in weight loss

Spatial variability of the weight loss is important to identify the high and low weight loss regions. Fruit in the upstream region received the chilled air first, thereby subjecting them to a faster cooling rate. Increase in air temperature as it moves across a stack causes local variations in heat loss in the stacked products (Baird et al., 1988) and holding pomegranate fruit at higher temperatures for longer period causes higher moisture loss rates. There was no significant difference in weight loss between layers of the stack in all cases.

3.2 Effect of humidity on shelf life quality of pomegranate fruit

3.2.1 Weight loss and fruit shrivel

Pomegranate fruit continuously lost weight throughout the shelf life period. Till day 3, there was no significant difference between the two RH environments. However, fruit weight loss under the low RH environment became significantly higher starting from day 6, with losses reaching up to 29.13±1.49% in the low RH environment compared to 5.78±0.44% in the high RH environment. This shows that the high RH environment reduced the vapour pressure deficit (VPD) between the fruit and the environment, resulting in a significantly reduced moisture loss from the fruit (Ngcobo et al., 2013).

Shrivel was observed on fruit from the low humidity environment on day 6. At this stage the average weight loss was 5.28 ± 0.32% of its initial weight, and by day 9, the dents on the fruit surfaces were larger. Shrivel is due to loss of turgor pressure in the fruit cell walls as they continuously lose moisture (Paull, 1999). Under high humidity environment, some fruit slightly shriveled on day 24.

Changes in fruit colour, size, firmness, titratable acidity, pH, and total soluble solids were more significantly pronounced in the low humidity storage environment than high humidity environment (Fig. 2)

Fig. 2. Visual condition of pomegranate fruit 30 days under ambient humidity condition, RH ≈ 65% (top row) and under humidified condition, RH ≈ 95% (bottom row).

4. CONCLUSION

This study investigated the level of reduction of weight loss achievable by employing liner-based packaging or room humidification. This study also quantified the spatial variation in weight loss of pomegranate fruit during precooling operation. Fruit at the back of the stack had higher weight loss than those at the front. This goes in parallel with the temperature distribution in the stack as reported in previous studies (Ambaw et al., 2017 and Mukama et al., 2017). The shelf life study showed the importance of room humidification as a cold chain strategy to maintain pomegranate postharvest fruit quality. Storing fruit under 95% RH maintained fruit colour best, minimised weight loss, maintained fruit firmness, fruit size and the chemical quality attributes of pomegranates. Storing fruit under low RH ambient conditions led to excessive weight loss, which in turn resulted in excessive shrivel, deformed appearance, and reduced visual quality of fruit. These findings can be applied in efforts to establish the best storage conditions of pomegranates to maintain quality and reduce incidence of postharvest losses along the value chain from harvest to consumers.

5. ACKNOWLEDGEMENTS

This work is based upon research supported by the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation. The project was supported through contract research with Agri-Edge Ltd funded by the Department of Trade and Industry (dti) through the Technology and Human Resources for Industry Programme (THRIP). We acknowledge the award of postgraduate scholarship to Mr M Mukama by DAAD (In-Region Scholarship Programme) and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for support.

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Dry season supplemental irrigation of waterleaf crop for sustained productivity

By

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Abstract: Waterleaf crop (*Talinum triangulare*) is a highly nutritive edible vegetable crop enjoyed by most people in parts Africa and Nigeria in particular. Due to its high water use or consumptive use (CU) requirement, dry season production has been challenging and limited. Production in commercial quantity is usually limited to the rainy season (April to September) and waterleaf becomes scarce and expensive during the rest of the year due to high water requirement of the crop. This study was set-up with the view to determine the water-use requirement of waterleaf crop using lysimeter and the adoption of proper management techniques of irrigation scheduling to determine the best schedule for maximum productivity of the crop. Experiments were carried out on a sandy loam soil in Imo State Polytechnic farm during the dry season. Sprinkler irrigation method was adopted. Four (4) irrigation treatments were maintained based on the Maximum Allowable Depletion (MAD) of Available Soil Water (ASW). The treatments were 100% (T_1), 80% (T_2), 60% (T_3) and 40% (T_4) MAD of ASW during non-critical stages of crop growth. T_1 served as a control. Waterleaf crops were planted in lysimeters in order to enable irrigation scheduling, determine ET of the crop and monitor the growth and yield of the crop. After ten days of initial application at 100%, the subsequent irrigation were at 80%, 60% and 40% for (T_2, T_3 and T_4) and the growth of the waterleaf crop monitored. Growth and vegetative development of waterleaf crop at various growth stages was monitored. At maturity, the waterleaf crop was harvested and measured for leaf area index, root distribution, vegetative yield, and market value. The results obtained at this stage showed the evapotranspiration (consumptive use (CU)) of waterleaf crop from the lysimeters were 5.36 mm/day for T_2**,** 5.03 mm/day for T_3 and 5.43 mm/day for T_4. Calculated ET values from empirical models of Blaney-Morin Nigeria (BMN) for T_2, T_3, and T_4 were 4.95 mm/day, 4.45 mm/day, 4.58mm/day and 4.72 mm/day respectively, and for Blaney-Criddle (BC) for T_2, T_3, and T_4 were 5.44 mm/day, 5.95 mm/day, 6.17mm/day and 5.39 mm/day respectively. There was no significant difference between the ET calculated from the lysimeter with the BMN and BC. The growth pattern as a result of the percentage water application showed that waterleaf crop from even the 40% application did as well as the 80% application. It is recommended that farmers who apply water at 40% can also obtain as good as maximum yield as the application at 80%. This will minimize cost of irrigation water application and maximize waterleaf crop production.

Keywords: waterleaf crop, consumptive use, water use efficiency, irrigation scheduling, field capacity.

1.0 Introduction

Irrigation is the artificial application of water to the soil for the purpose of supplying water essential for plant growth. Irrigation is essentially a practice of supplementing natural precipitation for the production of crops (Michael et al., 2011). Irrigation water can come from ground water (extracted from springs or wells), from surface water (rivers or lakes) or from non-conventional sources like treated waste water or drainage water.

Effective irrigation is the water available to meet the evapotranspiration needs of the plant. The objective of effective irrigation is to increase agricultural production per unit volume of water, per unit area of cropped land in a unit of time.

In order to achieve effective irrigation, certain factors must be considered such as availability of water, when to irrigate and how much (irrigation scheduling), water quality, water location, water distribution and variation in its occurrence, climatic change or condition, nature of the soil and competing demands and socio-economic conditions (Michael *et al*., 2011).

Knowledge of the exact amount of water required by different crops in a given set of climatic conditions of a region is important in planning of irrigation scheme, irrigation scheduling, and for effective design and management of irrigation systems (Babu et al., 2015; Pandey et al., 2014; Kiwi et al., 2013; Gad et al., 2010; Manuel et al., 2009; Trajkovic et al., 2008; Sumner et al., 2005). The absence of appropriate irrigation management and wrong water estimation for crops are probably the main reasons of increasing the irrigated agriculture water use, poor growth and development of plant as well as the reduced yield. The demand for water from competing sectors/users has been on a steady increase, thereby putting pressure on our fresh water resources. There is therefore a growing concern on water use efficiency in irrigated fields (Hatfield et al. 1996 and Bakhtiari et al. 2011), particularly in semi-arid and arid regions irrigation projects. In determining the crop water need, evapotranspiration is measured. Evapotranspiration is a combined process which includes evaporation of water from the soil and plant surfaces and transpiration of water from the plant tissues (Mata, et al 2014; Pandey et al., 2014). It is the depth of water used by a crop per time, expressed in mm/day or mm/month or mm/ season.

Evapotranspiration measurements are conducted by two principal methods viz:- direct field method (lysimetric method) and indirect method (using empirical models). The choice of the method, therefore, depends mainly on its suitability for the region and, on the availability of climatic data, the reliability of the data and limitations. Empirical models, though, are considered the easiest and fastest ET measurement methods due to its simplicity and straightforwardness, especially when the required meteorological data are available, but are less accurate than the lysimetric method. According to Kiwi et al. (2013) and Mohawesh (2011), climatic data for the ET models sometimes, may not be readily available in certain locations and in some cases, the data give varying and divergent values for evapotranspiration in a given location. In view of these challenges, lysimeters are considered the reliable method for ET measurement of different crops in different climatic conditions. Egbuikwem and Obiechefu (2017) have found out that

lysimeters can be used to determine the evapotransipiration of waterleaf crop and the results they obtained were not significantly different from values calculated from some empirical models of (Blaney Criddle, Blaney Morin Nigeria, etc). A lysimeter is a tank used to measure the amount of water used in evapotranspiration (Et) on a vegetated surface. Lysimeters have been used for many years to measure and study water use rate, to calibrate reference ET methods for a local area, and to develop crop-coefficient functions for specific crops. The lysimeters are employed to measure ETo (Reference crop evapotranspiration) and ET_C (Potential evapotranspiration) directly by detecting changes in the weight of the soil/crop unit.
Irrigation scheduling is the application of irrigation water to plants at the correct frequency and duration, in order to provide the plants the needed water required for a successful crop production or to meet plant water requirement.

According to Binal (1995), irrigation scheduling refers to the actual time or stage of the crop when the irrigation should be applied to replenish the soil water already consumed by plants before they are affected by the shortage of water. Irrigation scheduling is important because it enables the irrigationist to determine when to irrigate the crop, how water to irrigate, water requirement of the water and how to minimize overflow of water. Some factors are to be considered before irrigation schedule can take place and they includes:- precipitation rate, uniform distribution of water, soil infiltration rate, topography of the land, soil available water capacity, rooting depth of the crop, amount and time of irrigation and also timing to avoid interference with other activities. The aim of irrigation scheduling is to apply enough water to fully wet the plant root zone while minimizing over watering and then allow the soil to dry out in between watering, to allow air to enter the soil and encourage root development, but not so much that the plant is stressed beyond what is allowable. Through irrigation scheduling, water can be used efficiently. Hence, an optimum irrigation schedule maximizes profit and optimizes water and energy use (Joel *et al.*, 2017).

Waterleaf (Talinum Triangulare) is a vegetable crop which originated from the tropical Africa with stems ranging from 30-100cm height. It is grown best under humid conditions at temperature of about 30^0C. Waterleaf crop is a highly nutritive edible vegetable crop enjoyed by most people in parts Africa and Nigeria in particular. Nutritionally, waterleaf is high in crude protein (22.1%), ash (33.98%), crude fiber (11.12%) and vitamin. Medically, it is used as an enema and as green forage for Rabbit feed management (Nya and Eka, 2008, Udom et al., 2013 and Uko et al., 2013). Due to its high water use or consumptive use (CU) requirement, dry season production has been challenging and limited. This problem in part has been due to the lack of information on the water use requirement of the crop and as well as on the dissemination of the recent irrigation technologies that can support increased production of the vegetable during the dry season. Production in commercial quantity is usually limited to the rainy season (April to September) and waterleaf becomes scarce and expensive during the rest of the year due to high water requirement of the crop. The low yield and revenue generated from waterleaf farming by farmers in Nigeria can be attributed to poor/inadequate irrigation water management.

Waterleaf is a vegetable that needs water in order to produce high yield. Hence, for high yield of waterleaf crop all year round, it is important to determine the amount of water required by the crop to grow and yield well as well as and time of water application to the crop. For high yield, nutritive and economic value of waterleaf crop to be achieved, the effect of irrigation scheduling and water use requirement of waterleaf crop is important to be determined. The consumptive use of water by waterleaf crop may be determined through the use of a lysimeter.

The main objective of the work is to determine the best irrigation schedule on the basis of the percentage of water application to produce maximum crop yield at lowest cost. The specific objectives are: (i) To determine the evapotranspiration of waterleaf crop using a lysimeter (i.e. the water requirement of waterleaf crop). (ii) To apply water at different volume of the crop water requirement (T_1 at 100%, T_2 at 80%, T_3 at 60%, and T_4 at 40%) at the same irrigation frequency / irrigation period, and (iii) To determine the best irrigation scheduling of waterleaf crop based on the treatments (i.e. to determine which one among the four different treatments gives the best growth pattern (or yield of the waterleaf crop). The findings from this study would serve as a data bank and would be accessible to all especially, the researchers, farmers and field workers involved in irrigation activities and research.

2.0). Materials and method

The study was carried out at Agricultural Technology Glass House in Imo State Polytechnic Umuagwo, Ohaji. Imo State Polytechnic is located on longitude of 6.9437, latitude of 5.3071 while the altitude is 252m. Imo State Polytechnic is about 26 kilometers from Owerri, capital of Imo State on the Port Harcourt-Owerri Road. The lysimeter as designed by Egbuikwem and Obiechefu (2017) was used for this irrigation scheduling studies. The lysimeter is cylindrical in shape and water was applied by using sprinkling cans at the top. An outlet at the bottom ensured good drainage. The lysimeter has a rigid wire-mesh foundation supporting the soil and weighing system for data acquisition for analysis. (Sayler, *et al*, 1985).

Soil was collected from Imo State Polytechnic farm and mixed with poultry droppings before putting into the lysimeter. The soil was allowed to settle for one week prior to placing the final topsoil, wetting and planting the waterleaf. About 12.928kg of soil was used to fill each lysimeter and 8 stands of waterleaf crops obtained from the market with leaves and stems were planted in each of the lysimeter.

The particle size analysis of the soil used was carried out in order to determine the textural classification of the soil. The initial moisture content of the soil was carried out to know the amount of water contained in the soil before the start of irrigation and amount of water needed for subsequent application to the waterleaf crop in order to maintain the appropriate water percentage for the treatments.

In this study, four different application volume of water was applied. The treatments are:- T1, T2, T3 and T4. T1 is 100% of water that was required to bring soil to saturation. while T2 is 80% of water. For T3, 60% of water was applied and for T4, 40% o; water was applied. Treatment T1 (100% water application) served as a control to all the treatments under natural precipitation and no further or subsequent application of water was applied after the initial irrigation. (i.e. a non-application of irrigation water) in order to determine the difference among the treatments.

After planting had occurred, soil samples were collected from each of the lysimeter (T_2, T_3 & T_4) to determine the moisture content of the soil so as to know the amount of water that will be required to replenish the lysimeters and bring the moisture content up to its initial water percentage (i.e. T_2 at 80%, T_3 at 60% and T_4 at 40%) while T_1 served as a control to all the treatments. No further water was replenished for T1. The rate of growth of the crop was monitored at different time intervals and irrigation schedule.

Soil samples for moisture content measurement were collected after every 10 days after planting from the treatments (lysimeters) for moisture content determination and necessary replenishment. Soil samples for moisture content were collected for other subsequent applications of water after each irrigation interval as well.

During the scheduling period when plants were small, the crop water need was less than the mid-season stage. The management strategy adopted was to prevent over application of water to the crop as well as minimize yield loss due to water shortage.

Climatic data were obtained from the weather stations at Sam Mbakwe airport, Imo state and Anambra Imo-River Basin Development Authority (AIRBDA), Owerri, Imo State, Nigeria, for Blaney-Criddle (BC) and Blaney-Morin Nigeria (BMN) evapotranspiration calculations to compare with ET data from the lysimeters.

The parameters such as volume of the lysimeter, area of lysimeter stand, mass of soil, evapotranspiration (using Blaney-Morin Nigeria and Blaney-Criddle) were calculated. The water use requirements were calculated using the data from the lysimeter. The ET data obtained from the lysimeter were compared with those calculated using empirical models of Blaney-Morin Nigeria and Blaney-Criddle. Growth patterns of the crops were also measured / monitored during the whole period of the experiments.

4.0). Results

The photos of the waterleaf crop growth from early stage, to the medium stage and to maturity stage including views of all the four different treatment was presented in photos 1 to 4.

From the photos, the growth and response of the crop to irrigation can be observed. After planting, it was observed that it took the crop over 15 days to establish and start growing well. After 30 days, the crop was well established.

Plate 1: Photo at early stage of the crop growth.

Plate 2: Photo at Mid stage of crop growth

Plate 3: Photo at Maturity stage of crop growth

Plate 4: Photo at late stage of growth after maturity

Table 1: Moisture content of soil samples for the different treatments

Date	Lysimeter Treatments (kg)	Weight of container (kg)	Weight of wet soil and container (kg)	Weight of dry soil and container (kg)	Weight of wet soil only (kg)	Weight of dry soil only (kg)	Weight of moisture content (kg)	Moisture content (%) M.C x 100
06-07-18	T1	0.0322	0.13	0.0988	0.0978	0.0666	0.0312	46.84685
	T2	0.0334	0.13	0.1002	0.0966	0.0668	0.0298	44.61078
	T3	0.0338	0.13	0.101	0.0962	0.0672	0.029	43.15476
	T4	0.0326	0.1318	0.0998	0.0992	0.0672	0.032	47.61905
	Average	0.033	0.130	0.100	0.097	0.067	0.031	45.558
18-07-18	T2	0.0341	0.1366	0.118	0.1025	0.0839	0.0186	22.16925
	T3	0.0339	0.1366	0.1157	0.1027	0.0818	0.0209	25.55012
	T4	0.0342	0.1368	0.1145	0.1026	0.0803	0.0223	27.77086
	Average	0.0341	0.1366	0.1161	0.103	0.082	0.021	25.163
29-07-18	T2	0.0326	0.1344	0.1143	0.1018	0.0817	0.0201	24.6022
	T3	0.0328	0.134	0.1156	0.1012	0.0828	0.0184	22.22222
	T4	0.0334	0.1347	0.1135	0.1013	0.0801	0.0212	26.46692
	Average	0.0329	0.1344	0.1145	0.101	0.082	0.020	24.430
09-08-18	T2	0.0321	0.1333	0.1149	0.1012	0.0828	0.0184	22.22222
	T3	0.0339	0.1341	0.1133	0.1002	0.0794	0.0208	26.19647
	T4	0.0338	0.134	0.1177	0.1002	0.0839	0.0163	19.42789

	Average	0.0333	0.1338	0.1153	0.101	0.082	0.019	22.616
20-08-18	T2	0.0321	0.1337	0.1138	0.1016	0.0817	0.0199	24.35741
	T3	0.0339	0.1349	0.1178	0.101	0.0839	0.0171	20.38141
	T4	0.0338	0.135	0.1167	0.1012	0.0829	0.0183	22.07479
	Average	0.0333	0.1345	0.1161	0.101	0.083	0.018	22.271
31-08-18	T2	0.0341	0.1377	0.1199	0.1036	0.0858	0.0178	20.74592
	T3	0.0339	0.1386	0.1196	0.1047	0.0857	0.019	22.17036
	T4	0.0342	0.1386	0.1204	0.1044	0.0862	0.0182	21.11369
	Average	0.0341	0.1383	0.12	0.104	0.086	0.018	21.343

Table 1 shows the amount moisture contained in the soil before the start of irrigation and also subsequent moisture remained in the soil before reapplication of irrigation water to the waterleaf crop. From the table it will be seen that the subsequent percentage moisture content replenishment was about 22%. The plants appeared to be requiring the same percentage moisture content replenishment even though different volumes wer applied. The implications of this is that crops were probably having the same consumptive use or water requirement.

No wonder the crops at 40% replenishment were doing as well as the 80% replenishment.

Table 2: Calculated Evapotranspiration of each irrigation interval of all the Treatments.

Date	ET from Lysimeter T2 mm/day	ET from Lysimeter T3 mm/day	ET from Lysimeter T4 mm/day	ET from BMN	ET from BC
18/07/18	5.12	4.98	5.06	5.61	4.23
29/07/18	5.91	6.12	5.10	5.39	4.85
09/08/18	4.98	5.76	5.01	5.54	4.69
20/08/18	5.67	5.12	4.92	4.10	3.95
31/08/18	6.10	5.45	5.40	5.29	4.66
Average	5.56	5.49	5.10	5.19	4.48

Table 2 shows the calculated evapotranspiration that occurred in the days of irrigation interval from all the lysimeters as compared with calculated values from BMN and BC. There were differences between the measured values from the lysimeter compared to the values from the models of BMN and BC. A z-test statistical analysis of the differences at 5% level of significance showed that there was no significant difference between the results obtained. This observation was also made by Egbuikwem and Obiechefu (2017).

4.1. Discussion

The result obtained showed the average evapotranspiration of waterleaf crop for the months under study as 5.36, 5.03, 5.43 mm/day for the lysimeters T2, T3, T4 respectively, while the calculated values for the empirical models of Blaney-Morin Nigeria (BMN) for T_2, T_3, and T_4 were 4.95 mm/day, 4.45 mm/day, 4.58mm/day and 4.72 mm/day respectively, and for Blaney-Criddle (BC) for T_2, T_3, and T_4 were 5.44 mm/day, 5.95 mm/day, 6.17mm/day and 5.39 mm/day respectively. From the statistical analysis conducted, it was found that there was no significant difference between the ET calculated from the lysimeter with the BMN and BC. The growth pattern as a result of the % water application showed that waterleaf crop from even the 40% application did as well as the 80% application. From this study it is recommended that farmers who apply water at 40% can also obtain as good as maximum yield as the application at 80%. This will minimize cost of irrigation water application and maximize waterleaf crop production.

The results showed gradual increase in ET_C from the early stage and decreases in the later stage of the waterleaf growth. This implies that as the crop grows it needs more water to grow thereby uses more water for its growth. The early stage of waterleaf crop coefficient is estimated at between 1 and 0.8 and at the later stages of waterleaf crop coefficient decreases to 0.7. Looking the photos and the growth stages, it will be observed that the waterleaf crop for T4 (40% replenishment of water) did very well. For T1 (control), due to non-application of irrigation water subsequently, the crop could not produce any yield while T2, T3 and T4 of different percentage of water, the waterleaf crop were doing well irrespective of the different water percentages. The water was applied 10 days interval and the crop produce well.

Therefore, water use efficiency of waterleaf crop can be estimated using lysimeter which gives direct evapotranspiration of waterleaf crop.

5.0). Conclusion and recommendation

From this study, the evapotranspiration of water leaf crop was determined using a lysimeter. The values obtained compared favourably well with the values calculated from climatic data models. The statistical analysis (z-test) conducted on the means of the different methods at 5% level of significance showed that there is no significant different between the measured lysimeter ETc data and each of the ET model of (BMN and BC). The growth pattern as a result of the % water application showed that waterleaf crop from even the 40% application did as well as the 80% application. From this study it is recommended that farmers who apply water at 40% can also obtain maximum yield as good as the application at 80%. This will minimize cost of irrigation water application and maximize waterleaf crop production.

Acknowledgement
We wish to acknowledge the supports provided by the Rector and Management of Imo State Polytechnic, Umuagwo for support to this research.

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The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

Some Engineering Properties of Pomegranate Fruit Relevant to Postharvest Handling and Processing

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ABSTRACT

The thermophysical properties of two pomegranate fruit cultivars (Wonderful and Acco) and their epicarp, mesocarp and arils were experimentally determined. A calibrated transient heating probe was used for the measurement of the specific heat capacity, thermal conductivity, and thermal diffusivity over a temperature range of 7 to 45 °C. The thermophysical properties did not vary significantly between the two cultivars. The density of whole 'Wonderful' and 'Acco' fruit was 986.99 ± 23.82 and 1041.23 ± 18.93 kg m-3, respectively. The epicarp of both cultivars had significantly lower density compared to the mesocarp and arils. The values of thermal conductivity and diffusivity of the two pomegranate cultivars increased with increase in tissue temperature. In both cultivars, the aril part was observed to have the highest values of thermal conductivity and specific heat capacity. For 'Acco' at 7 °C, the thermal conductivity values of the arils was 0.419 ± 0.047 W m-1 K-1, compared to 0.352 ± 0.040 W m-1 K-1 of the mesocarp, and 0.389 ± 0.030 W m-1 K-1 for the epicarp. These data are useful towards understanding the temperature distribution inside a single fruit, as well as the design and optimising packaging for handling of pomegranate fruit in the cold-chain.

Keywords: *Punica granatum*, heat exchange, temperature effect, transport phenomena, effective thermal properties.

1. INTRODUCTION

There has been continuous growth in the demand of Pomegranate fruit due to increasing consumer awareness regarding its health benefits (Rahmani et al., 2017). Following this, studies to maintain quality during harvesting, packaging, transport and storage of pomegranates are increasing (Opara et al., 2009; Mukama et al., 2017). The fruit are prone to weight loss and shrinkage, decay, blemishes appearance on skin (especially scalds), impaired sensory attributes and taste (Elyatem & Kader, 1984).

Adequate implementation, monitoring, and management of the cold chain is essential to maintain postharvest quality of pomegranate fruit. The recommended temperature and relative humidity conditions for pomegranate handling can vary from 5 to 8 °C and 90 to 95% relative humidity (RH), respectively, depending on cultivar, postharvest treatment and production area (Kader, 2006; Arendse et al., 2014).

Thermophysical properties characterize the rate and degree of heat exchange between produce and its surrounding. Thus, this data is a prerequisite for predicting heating and cooling rates and are used to estimate heating or cooling loads of thermal processes. Hence, knowledge of the thermophysical properties of food material is vital for the design and implementation of handling, processing, and preservation processes (Carson et al., 2016). The most important thermal properties that influence process and system design are the specific heat, thermal conductivity, and thermal diffusivity (Mohsenin, 1980).

Most fruit are heterogeneous solid systems with parts that are physically different and thus may have different thermal properties. Knowledge of the thermophysical properties of the different parts of a fruit are crucial for the detailed investigation of the spatiotemporal temperature distribution inside the fruit. Thermophysical data of pomegranate fruit or its parts is lacking. Hence, the main objective of this study was to obtain the thermophysical properties of the whole and tissue parts of pomegranate fruit. This work thus focused on experimental measurement of the thermal and biophysical properties of two different commercially important pomegranate fruit cultivars (‘Wonderful’ and ‘Acco’) at different temperatures.

2. STUDY DESCRIPTION

2.1 Fruit

A sample of ten fruit of each pomegranate cultivar was randomly selected for each of the tests. To measure the thermal properties of the different fruit parts, fruit were hand peeled and carefully separated into the epicarp, mesocarp, and arils.

2.2 Measurement of physical properties

2.2.1 Moisture content

Whole fruit moisture content was determined by drying dismantled fruit (arils separated from mesocarp; mesocarp and epicarp cut into small pieces onto an aluminium foil) at 105 °C in an oven until a constant weight reading was reached (Al-Said et al., 2009). The moisture content of the fruit parts (epicarp, mesocarp, and arils) was measured using a digital moisture meter (Kern & Sohn GmbH, Model DBS60-3, Balingen, Germany). The mean and the standard deviation of the values were determined from ten replications.

2.2.2 Density determination

The weight of randomly selected 10 sample fruit of the two cultivars were determined using a digital weighing scale (Mettler Toledo, Model ML 3002E, Switzerland, with 0.0001 g accuracy) and the corresponding volumes of fruit were measured using the water displacement method to calculate the density of each fruit.

2.3 Thermal properties measurement

Thermal conductivity, resistivity, diffusivity, and volumetric specific heat of the whole fruit and the fruit parts (epicarp, mesocarp, and arils) were determined using dual needle of the KD2 Pro multimeter (Decagon Devices, Inc., USA). The KD2 Pro multimeter uses the transient line-heat source method and inbuilt algorithms to give direct readings of the thermal properties following temperature measurements made during a heating and a cooling interval.

2.4 Statistical analysis

Analysis of variance (ANOVA) was carried out using STATISTICA 13 (StatSoft, Inc. Oklahoma, USA). Means were separated using Duncan's multiple range tests (factors: temperature, cultivar and fruit part). The results are presented as mean values (± standard deviation) and means with $p < 0.05$ were considered significant.

3. RESULTS AND DISCUSIONS

3.1 Fruit density

The density and moisture content of whole pomegranate fruit and its fruit parts are given in Table 1. For whole fruit, 'Acco' was denser (1041.23 ± 18.93 kg m^{-3}) than 'Wonderful' (986.99±23.82 kg m^{-3}). This suggests a more compact morphology of 'Acco' compared to 'Wonderful'. Al-Maiman and Ahmad (2002) reported density of 1380 ± 200 kg m^{-3} for a fully ripe 'Taifi' pomegranate grown in Saudi Arabia.
The epicarp had significantly lower density compared to the mesocarp and arils for both pomegranate cultivars. This could be due to the relatively low moisture content of the pomegranate peel compared to the mesocarp and arils in both cultivars (Table 1). No previous research has examined the density and moisture content of the fruit parts (epicarp and mesocarp) to compare.

Table 2 Density and moisture content of the intact (whole) and the different parts of pomegranates fruit (‘Wonderful’ and ‘Acco’)

Cultivar	Fruit part	Density (kg m^{-3})	Moisture content (%)
Wonderful	Whole	986.99 ± 23.82[a]	76.52 ± 0.63[a]
	Epicarp	922.54 ± 76.09[b]	64.00 ± 4.05[b]
	Mesocarp	950.37 ± 31.15[a]	76.87 ± 3.40[a]
	Arils	992.23 ± 63.28[a]	76.88 ± 1.72[a]
Acco	Whole	1041.23 ± 18.93[a]	74.05 ± 1.94[a]
	Epicarp	915.40 ± 56.25[b]	57.14 ± 1.32[b]
	Mesocarp	1025.85 ± 38.00[a]	70.45 ± 2.54[a]
	Arils	1063.33 ± 64.09[a]	76.20 ± 0.62[a]

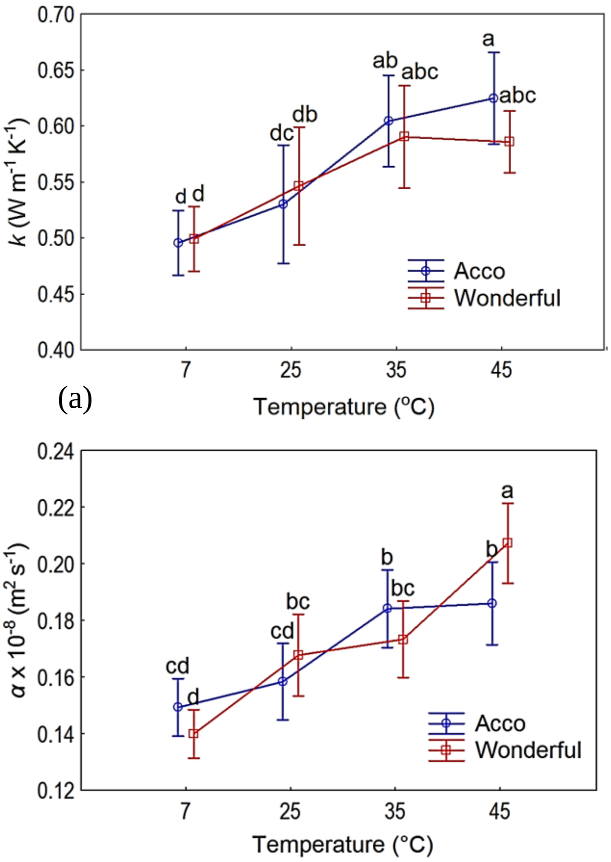
Values are means ± standard deviation, values with different letters in one column infer to significant difference ($p < 0.05$).

3.2 Thermal properties

Whole fruit thermal conductivity of ‘Acco’ and ‘Wonderful’ pomegranates at 7 °C were 0.499 ± 0.200 and 0.496 ± 0.024 W m^{-1} K^{-1}, respectively. There was no significant difference between the thermal conductivities of the two cultivars in the temperature range tested (Fig. 1). For both cultivars, thermal conductivity increased with temperature, with a sharp increase from 7 to 35 °C. On average, the thermal conductivity values of the epicarp, mesocarp, and arils were 0.431 ± 0.042, 0.395 ± 0.055 and 0.497 ± 0.087 W m^{-1} K^{-1}, respectively. The aril part of the fruit generally had higher thermal conductivity values compared to the epicarp and mesocarp, and this could be due to the comparatively higher moisture content of the arils (Table 1).

The specific heat capacity of ‘Acco’ varied from 2964.763 ± 369.755 to 3371.013 ± 379.359 J kg^{-1} K^{-1} while that of ‘Wonderful’ varied from 3846.037 ± 302.941 to 3198.614 ± 394.128 J kg^{-1} K^{-1}, for temperature ranging from 7 to 45 °C. There was no observed trend with temperature in the range tested. Cultivar too had no significant effect on the specific heat capacity.

The thermal diffusivity values of the fruit and fruit parts increased with increase in tissue temperature (Fig. 1). The lowest thermal diffusivity value (1.369 ± 0.165 m^2 s^{-1}) was observed at the lowest temperature (7 °C). Contrary to our findings, Zabalaga et al. (2016) reported a lower level of dependency of thermal diffusivity with temperature for banana slices (thermal diffusivity ranges between 1.97×10^{-7} and 1.26×10^{-7} m^2 s^{-1} between 40 and 60 °C).



(b)

Fig. 1 Changes of (a) thermal conductivity (k) and (b) thermal diffusivity (α) of pomegranate fruit (‘Acco’ and ‘Wonderful’) with temperature. Vertical bars denote standard deviation of mean. Different letters indicate significance difference ($p < 0.05$).

4. CONCLUSION

Based on the present investigation, it can be concluded that thermal properties did not differ between the two studied cultivars. Additionally, there was heterogeneity in thermophysical properties of the studied pomegranate fruit parts; for example, the aril part of the fruit had higher thermal conductivity and specific heat values. The thermal properties also generally increased with increase in temperature. The experimental data obtained in this study can be used to design and improve the performance of postharvest handling and processing of pomegranate fruit

5. ACKNOWLEDGEMENTS

This work is based upon research supported by the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation. The project was supported through contract research with Agri-Edge Ltd funded by the Department of Trade and Industry (dti) through the Technology and Human Resources for Industry Programme (THRIP). We acknowledge the award of postgraduate scholarship to Mr M Mukama by DAAD (In-Region Scholarship

Programme) and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for support.

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