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TABLE OF CONTENTS

COMPRESSION CHARACTERISTICS OF BAOBAB, OKRA, GINGER, AND MURUCHI POWDERS

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ABSTRACT

Powdery products of food origin have the potential to be used as ingredients and or raw materials in food industries. But powdery foods are usually compressed intentionally during densification process or unintentionally during handling and processing. Thus, this study sought to determine the compression behaviour of baobab leaf, okra fruit, ginger root, and muruchi powders with tapping and under normal low pressure < 2500 N/m^2. Compression models were also used to simulate experimental data in order to compare their performances and estimate compression parameters. All samples were subjected to tapping and normal pressure tests. Muruchi powder was compressed after 1250 taps followed by baobab and ginger powders at 1000 taps and then okra powder at 750 taps. Ginger powder had the highest volume reduction ratio (0.265) by tapping followed by muruchi powder (0.236), baobab powder (0.230) and okra powder (0.149). Ginger powder had the highest compressibility (31.6%) under normal pressure followed by baobab (16%), muruchi (15.5%), and okra (12.8%) powders. The compression models used showed good simulation of the experimental data, where Walker's model had the highest coefficient of determination (0.993-0.9998) followed by Jones' (0.9943 to 0.9997) and Barbosa-Canovas'(0.9953 to 0.9989) models. These results are very useful for solving obstacles in handling, processing and packaging of bulk powdery food materials.
KEYWORDS: *compression behaviour, baobab leaf powder, okra fruit powder, ginger powder, muruchi powder, compression models*

1. INTRODUCTION

Compression of powder refers to the increase of powder's density due to reduction of its volume by mechanical means such as vibration, impact and static load. In food powder industries food powders are usually compressed during industrial operations. Some of these operations are either intentional as in tableting and agglomerating or unintentional during handling, transportation and storage (Barbosa-Canovas *et al*., 2005). Therefore, compression behaviour of food powders is an important phenomenon in food powder industries. Compressibility is a parameter that is used to describe the compression behaviour by quantifying the degree of compression of a powder under a specified mechanical stress. This parameter is an important input during process design in a food powder industry and the design of compaction/agglomeration equipment.

Several mathematical models have been developed and used by authors to estimate the compressibility of powders using experimental results. Sone (1969) developed a model that expressed the relationship between volume reduction ratio and number of taps. This model contains a parameter that estimates the compressibility of powder during tapping. The compressibility of chopped switchgrass, wheat straw and corn stover were investigated using Sone's model by Chevanan *et al*. (2010) and reported significant effect of biomass type on compressibility, and increase in compressibility with increase of particle length. The compressibility under the influence of static load has been estimated by researchers using several mathematical models. Emami and Tabil (2008), Skonecki *et al*. (2014), and Molenda *et al*. (2002) investigated the compression characteristics of chickpea flour and components, wheat meal and corn and soybean meal respectively. The compression characteristics of several food powdered materials have been investigated experimentally and using several compression models. However, no work has been reported on the compression characteristic of powders of ginger, baobab leaf, okra fruit and muruchi by tapping and under normal low pressure of less 5000 N/m^2. These products have become or are now becoming important industrial raw materials and ingredients in Nigeria. Thus, the objectives of this research work were to: investigate the compression behaviour with tapping and under normal light load for baobab (*Adansonia digitata* L.) leaf, okra fruit (*Abelmoschus esculentus* L.), ginger *(Zingiber officinale*), muruchi (young shoot of *Borassus aethiopum*) powders.

2. MATERIALS AND METHODS

2.1 Sample Preparation

About 10 kg each of dried ginger, dried baobab leaf, and dried okra fruit were procured from Maiduguri Monday market and 30 kg of fresh muruchi was procured from Hong Local Government Area of Adamawa State, Nigeria. After sorting out foreign and unwanted materials, samples were placed in thin layer at ambient condition for a week before grinding. For fresh muruchi after sorting out damaged ones, the remaining samples were de-fibred using knife, chopped into slices and then dried under ambient conditions for two weeks. Locally fabricated hammer mill with 2 mm screen size was used to grind the dried samples. The initial (market) moisture content of each of the materials procured was not determined however, their moisture contents after drying and grinding were determined. Three samples of 10 g each from the ground ginger, dry baobab leaf, dry okra fruits were collected and their moisture contents were determined using oven dried method (Barbosa-Canovas *et al*. 2005). The average moisture content of baobab leaves, okra fruits, ginger, and muruchi powders were calculated to be 10.7%, 11.4%, 10.3% and 9.98% (wb).

2.2 Experimental Tests and Design

Loose bulk density was measured using the USP (2012) standard method. This involved passing 100 g through a sieve of 2 mm into a dry graduated 250 ± 2 ml cylinder placed 2 cm below the sieve and carefully levelling the powder without tapping or compressing (Plate 1). The unsettled apparent volume, V_o was read to the nearest graduated unit. The tapping test was carried out by securing the filled cylinder in the holder of a tapping apparatus capable of dropping from a height of 10 mm. The tapped volumes, V_n, after 10, 250, 500, 750, 1000 and 1250 taps on the same sample were recorded.

Plate 1: Tapping apparatus

The compression test at normal pressure between 1000 and 5000 N/m^2 for each sample of the powders was performed using a compression cell fabricated at the Mechanical Engineering Workshop, University of Maiduguri. The compression cell consisted of a cylindrical die with 47 mm internal diameter and 500 mm height and a plunger with 45 mm diameter flat-end plate. A sample of 100 g was filled in the die and was allowed to be compressed with the plunger to predefined loads using a Texture press. The force-deformation data were recorded after a sample was subjected to uniaxial compression loads of 1, 2, 3, 4, 5 and 6 N.

Completely randomized design was used in all tests as the experimental design. Samples of each powder were randomly assigned to the sequence of test runs during each experiment. Each test on ground ginger, dry baobab leaf, dry okra fruits was replicated three times.

2.3 Data Analysis and Simulation

The compression behaviour of each powder with tapping was simulated using model developed by Sone (1969) (equation 1):

$$\frac{n}{\gamma_n} = \frac{1}{a \times b} + \frac{n}{a} \tag{1}$$

where, n is the number of taps, γ_n is volume reduction ratio, a and b are constants representing infinite compressibility by tapping and degree of difficulty by tapping parameters respectively. The compression characteristics with normal loads were investigated using models developed by Walker (1923), Jones (1960) and Barbosa-Canovas and co (1987) expressed as equations 2, 3, and 4 respectively:

$$\frac{\mathrm{V}}{\mathrm{V}_o} = \mathrm{m}_1 \times \ln P + \mathrm{c}_1 \tag{2}$$

$$\ln \rho_b = \mathrm{m}_2 \times \ln P + c_2 \tag{3}$$

$$\frac{\rho(\sigma) - \rho_o}{\rho_o} = \mathrm{m}_3 \times \log\sigma + \mathrm{c}_3 \tag{4}$$

where P is applied pressure (kN/m^2), V_o and V are zero and compressed volumes in cm^3, ρ_b is bulk density in kg/m^3, ρ_σ bulk density at applied pressure in kg/m^3, ρ_o initial bulk density in kg/m^3, σ is normal stress (kN/m^2), m_1, m_2, and m_3 constant parameters related to compressibility, c_1, c_2, and c_3 are constants.

Simple descriptive statistical analysis was used to report averages and standard deviations of experimental data. Data obtained were subjected to ANOVA to determine if there were significant differences among the different powder samples. Microsoft Excel software was used to plot graphs and carryout the statistical analysis.

3. RESULTS AND DISCUSSION

3.1 Compression Characteristics during Tapping

Figure 1 presents the relationship between volume reduction ratio and the number of taps for baobab, okra, ginger and muruchi powders. Okra, baobab, ginger, and muruchi powders reached maximum volume reduction ratio at 750, 1000, 1000, and 1250 taps respectively. The highest volume reduction ratio was observed for ginger followed by muruchi, baobab and okra powder. Maximum volume reduction ratios of 0.23, 0.149, 0.265 and 0.236 were observed for baobab, okra, ginger and muruchi powders respectively. Chevanan et al. (2010) reported values of volume reduction ratio for finely chopped switchgrass, wheat straw, and corn that are similar to okra.

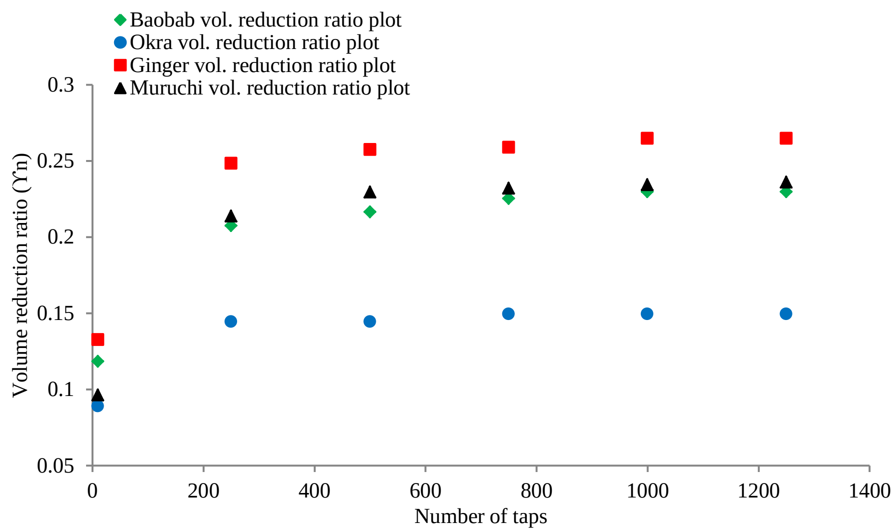

Figure 1: the plots of volume reduction ratio against number of taps for baobab, okra, ginger and muruchi powders

The experimental data and Sone's simulation plots of the linear relationship between n and n/γ_n for baobab, okra, ginger and muruchi powders are presented in Figure 2. An indication of very good Sone's simulation was observed due to the very high coefficient of determination values, R^2 that ranged between 0.9996 and 0.9999 for the powders. Infinite compressibility, a, was highest for ginger followed by muruchi, baobab, and okra powders (Table 1). The parameter for degree of difficulty of tapping, b, was the highest for baobab followed by muruchi, ginger and okra. Values of b for all the powders indicate that okra powder compressed easily by tapping followed by ginger, muruchi and baobab powders. It is worth noting here that experimental results of tapping indicated that baobab powder showed moderate difficulty of compression among the powders while Sone's model predicted highest degree of difficulty.

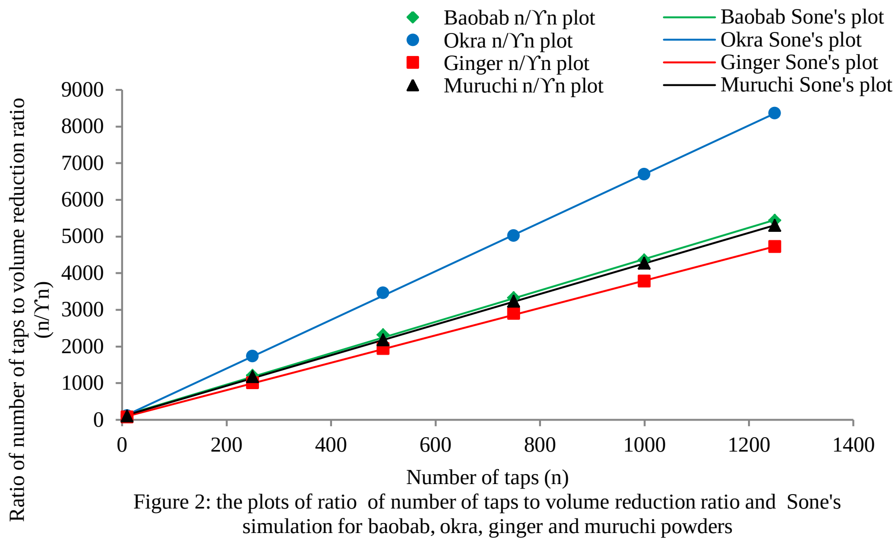

Figure 2: the plots of ratio of number of taps to volume reduction ratio and Sone's simulation for baobab, okra, ginger and muruchi powders

Table 1. Parameters of Sone's, Walker's, Jones' and Barbosa-Canovas *et al*. models for compression of baobab, okra, ginger and muruchi powders

	Models							
	Sone parameters		Walker parameters		Jones parameters		Barbosa and co parameters	
Powder	a	b	c_1	m_1	c_2	m_2	c_3	m_3
Baobab	0.2336	24.5	1.35	-0.0612	5.60	0.0682	-0.4441	0.1754
Okra	0.1508	11.2	1.34	-0.0567	5.85	0.0615	-0.2480	0.1936
Ginger	0.2678	16.8	1.12	-0.0529	5.63	0.0724	-0.3565	0.2286
Muruch	0.2396	22.2	1.27	-0.0513	5.91	0.0576	-0.1877	0.1872

3.2 Compression Characteristics during Normal Pressing

The relationship between compressibility and applied normal pressure is presented in Figure 3. The highest compressibility was observed for ginger while okra had the lowest compressibility. It can be observed that the maximum compressibility attained at 6 N for baobab, okra, ginger, and muruchi powders were 16%, 12.8%, 31.6% and 15.5% respectively. Thus, ginger had the highest compressibility followed by baobab, muruchi, and okra powder.

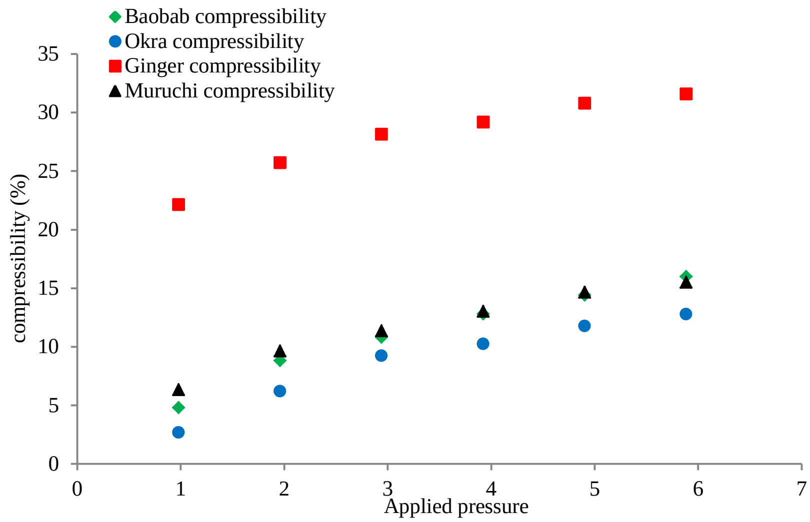

Figure 3: the plots of compressibility against applied pressure for baobab, okra, ginger, and muruchi powders

Walker's model was fitted into the pressure-volume data of baobab, okra, ginger and muruchi powders obtained during compression test (Figure 4). High R^2 values were obtained when Walker's model was fitted to the pressure-volume data. The R^2 for baobab, okra, ginger, and muruchi powders were 0.993, 0.9993, 0.9998, and 0.9997 respectively. The slope parameter, m_1 in Walker's model is proportional to density in the powder (Walker 1923). The densities of the powders increased in the following order muruchi, ginger, okra, and baobab (Table 1).

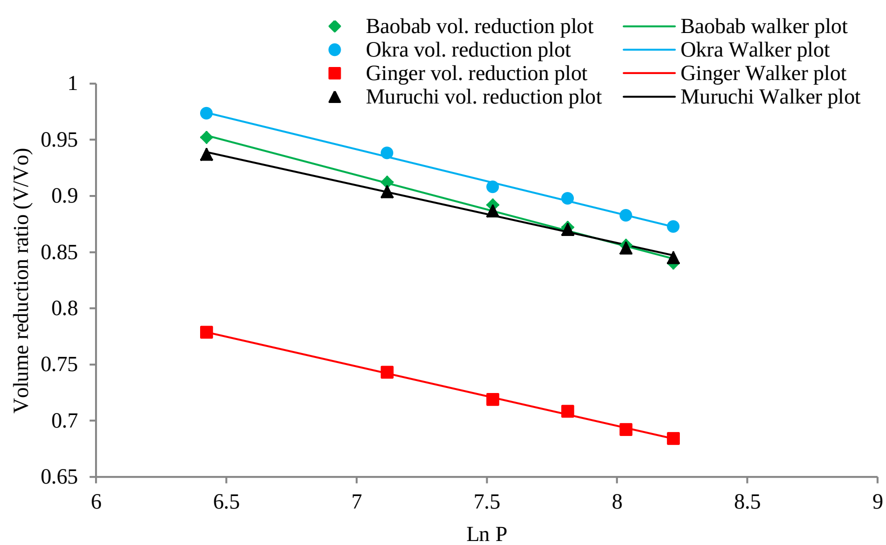

Figure 4: the plots of volume reduction ratio and Walker's simulation for baobab, okra, ginger and muruchi powders

Figures 5 and 6 present the plots of pressure data against the corresponding values of density calculated during compressibility test of baobab, okra, ginger and muruchi powders and the simulated plots of Jones, and Barbosa-Canovas *et al.* models respectively. High R^2 values for Jones' (0.9943 to 0.9997) and Barbosa-Canovas *et al.* (0.9953 to 0.9989) models indicate good fit. The slope parameter of Jones' model, m_2 provide valuable information about the onset of plastic deformation at low pressure therefore indicating that the material is more compressible. Ginger had the highest compressibility, followed by baobab, okra and muruchi respectively (Table 1). Barbosa-Canovas *et al.* model predicted compressibility, m_3 in the following decreasing order ginger, okra, muruchi, and baobab. It can be observed from the simulation results that the compressibility parameters estimated by Jones model had similar trend to the experimental data while both Jones and Barbosa-Canovas *et al.* predicted highest compressibility.

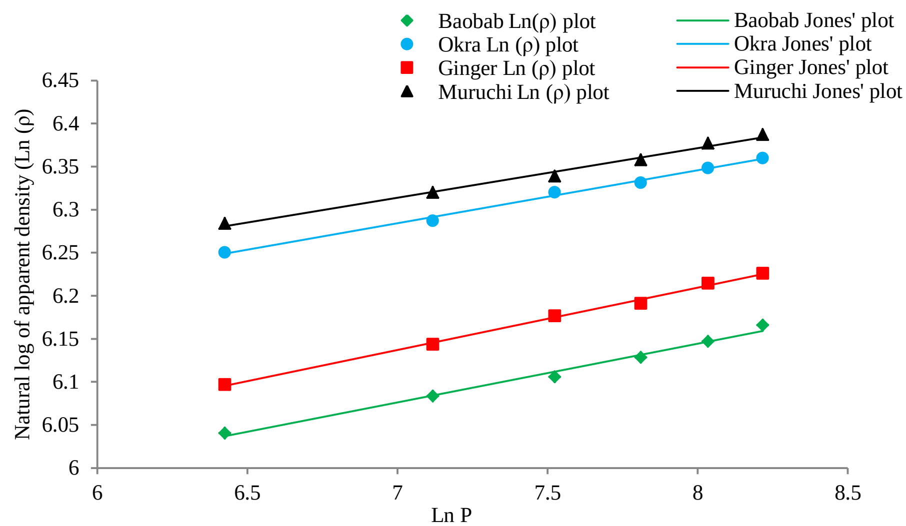

Figure 5: the plots of natural log of apparent density at applied lpressure and Jones' simulation for baobab, okra, ginger and muruchi powders

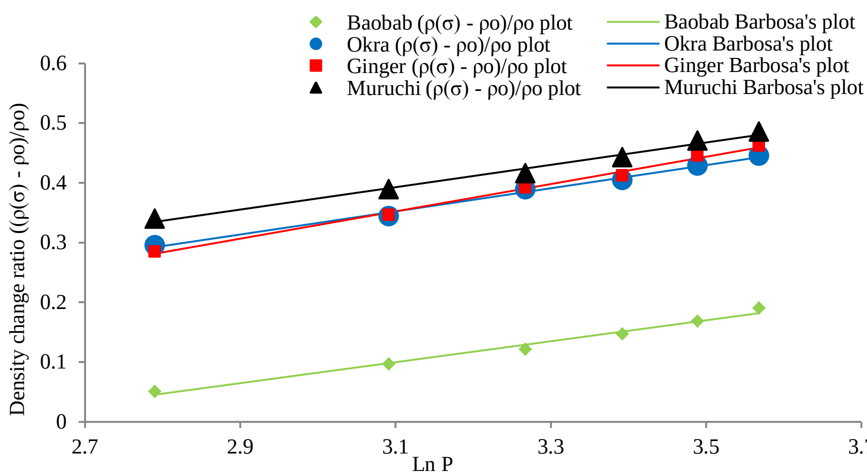

Figure 6: the plots of density change ratio and Barbosa and Co simulation for baobab, okra, ginger and muruchi powders

4. CONCLUSION

Muruchi powder was the most difficult to compress by tapping followed by baobab and ginger, and then okra which is easily compressed. Ginger had the maximum volume reduction ratio by tapping followed by muruchi, baobab, and okra. Ginger had the highest compressibility under normal pressure followed by baobab, muruchi, and okra powder. The compression models used showed good simulation of the experimental data, where Walker's model had the highest coefficient of determination followed by Jones' and Barbosa-Canovas' models.

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EFFECTS OF OPERATING SPEED AND SCREEN DIAMETERS ON THE EFFICIENCY OF A HAMMER MILL.

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Abstract

A hammer mill was developed for pulverizing dried yam. The machine was evaluated using screens of different sizes (1.5mm and 5.0mm) and different operating speeds (650 rpm and 1300rpm) to ascertain effects of these parameters on the machine output efficiency, capacity and fineness of the end-products. Four replicate samples were prepared namely: A – [5.0mm ø screen, 650rpm speed], B – [1.5mm ø screen, 650rpm speed], C – [1.5mm ø screen, 1300rpm speed] and D – [5.0mm ø screen, 1300rpm speed] respectively. The end-products were subjected to sieve analysis; the following inferences were drawn: (i) D is most time efficient with operational time of 8.10sec for 10Kg of dried yam, followed by C (8.60sec), A (9.15sec) and B (9.40sec) respectively for same mass of test material; this shows that higher operational speed and screen size enhanced the milling time.(ii) The output efficiency (%) are in the order: C (81.50%), B (79.40%), D (77.10%) and A (73.39%) respectively; best output efficiency was achieved at higher speed cum small screen hole diameter.(iii) Also that the operational speed and screen hole diameter affects the machine output capacity, as shown:D (74.07 Kg/hr), C (69.77 Kg/hr), A (65.57 Kg/hr), and B (63.83Kg/hr) in decreasing order respectively and fineness modulus: A (0.88), D (0.84), B (0.75) and C (0.62) in increasing order respectively. Therefore, a suitable operational speed and screen size was ascertained and recommended for the optimum efficiency of the hammer mill.

Key words*: Hammer mills, Screen, Pulverizing, Efficiency and Sieve analysis.*

1.0. INTRODUCTION

Nigeria is the world's largest yam producer, contributing approximately two thirds of the global production with about 2,837,000 hectares land area under yam cultivation (FAO, 2013). Yam is an important staple food crop in Nigeria, produced both for household consumption and as a cash crop.It is an important source of carbohydrate for many people of the sub-Sahara region, especially in the yam zone of West Africa (Akissoe et al., 2003). Yam contributes more than 200 dietary calories per capita daily for more than 150 million people in West Africa and serves as an important source of income to the people (Babaleye, 2003). It is not rich in vitamin A and C, as sweet potatoes, but tends to be higher in protein and minerals like phosphorous and potassium than any other root crops (Degras, 1993).

According to AMCOST (2006), pre- and postharvest food crop loss among African countries is estimated at about 40%, which is higher than the global average. Onebunne (2006), reported that due to its perishable nature, lack of good processing equipment and methods and poor storage facilities, high percentage of yam (about 30%) produced is wasted annually in Nigeria. Various efforts have been made to add value to this pernicious crop in order to retain, sustain and maintain its quality and quantity. Part of this effort is the storage of yam in pit, building structures, platform and barn (Igbeka, 1985). Yam can be stored in these various structures for 4 to 6 months in fresh weight (Hounhouingan, 2006).

Fresh yam can be dried as lump or sliced; this extends the shelf life to between 11-14 months under proper storage. This makes yam less susceptible to pest and rodent attacks; makes it readily available in the market during off- season and helps to reduce post- harvest losses (Hounhouingan, 2006). Dried yam can further be processed into flour which stores longer under proper storage and is used in making special local delicacy called "Amala" (an elastic food paste) enjoyed in the Western part of Nigeria and some parts of West Africa.

The process line for yam after harvest is highlighted below,

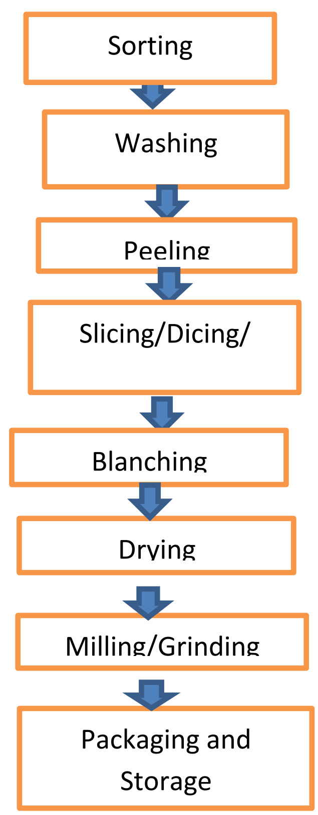


Figure 1: Block diagram for processing yam to flour.

Processing of dried yam into flour is a series of size reduction processes. The general term, size reduction, includes the mechanical processes of cutting, shearing, crushing, grinding, and milling feed grains. These processes expose more surface area for digestion without causing any noticeable change in the chemical properties of the material. At the same time, size reduction facilitates uniform mixing. And although uniformity in size and shape of the reduced particles is usually desired, it is seldom attained (Rudnitski et al, 2012).

Traditionally, size reduction is done using mortar and pestle; the end product gotten is sifted with sieve and the process repeated over again till the chaff residue is minimal. After the introduction of the burr mill, the manually pulverized dried yam is milled into fine powder with the help of the burr mill.

Presently, the manual pulverization with the mortar and pestle is no more practiced, with the invention of hammer mill, which is used in pulverizing dried yam mechanically before the process is completed with the use of burr mill. In other words, a typical dried yam milling shop is equipped with a hammer mill and a burr mill with a diesel engine in between them for power supply to each of the machine one after the other (*personal findings*). These mechanical means of pulverizing dried yam saves times and energy and better end product is gotten than the old traditional means.

Various hammer mills have been developed for different purposes ranging from post harvest processing to stone grinding for civil construction works. Various hammer mills have been developed for different purposes ranging from post harvest processing to stone grinding for civil construction works. Nasir (2005) developed a multi-purpose hammer miller for cereals and dried cassava tubers and evaluated the performance based on operational time using cereals and dried cassava flakes. Ngabea et al (2015) fabricated a magnetic sieve crusher to remove metal objects from the test materials. Xuan et al (2012) developed a hammer mill with separate sieving device and evaluated the machine based on the sieve performance.

Efforts to improve milling process would be further boosted through this research by establishing a suitable operational speed and screen size for optimum output result of end-product. The hammer mill used for this research was designed and fabricated for pulverizing dried yam.

2.0. MATERIALS AND METHODS

2.1. MACHINE DESCRIPTION

The hammer mill used for this research was designed and fabricated for pulverizing dried yam with a modification in the mechanism by incorporating sets of rollers with the hammers and an interchangeable screen.

The hopper is made up of 2.5mm mild steel plate. It has a composite shape and a cover for safety of the operator and to prevent the dried yam from falling during operation. A mild steel solid shaft of 35mm diameter supported by pillow bearings was used. A V-belt (type B) was used on a single groove cast iron pulley to transmit the power from the electric prime mover.

The sieves were made of 5.0mm thick mild steel with two screen sizes (1.5 and 5.0 mm) constructed for the testing. Angle iron bars of 50 x 50mm were used for the frame supports to give the need rigidity to shock and vibration.

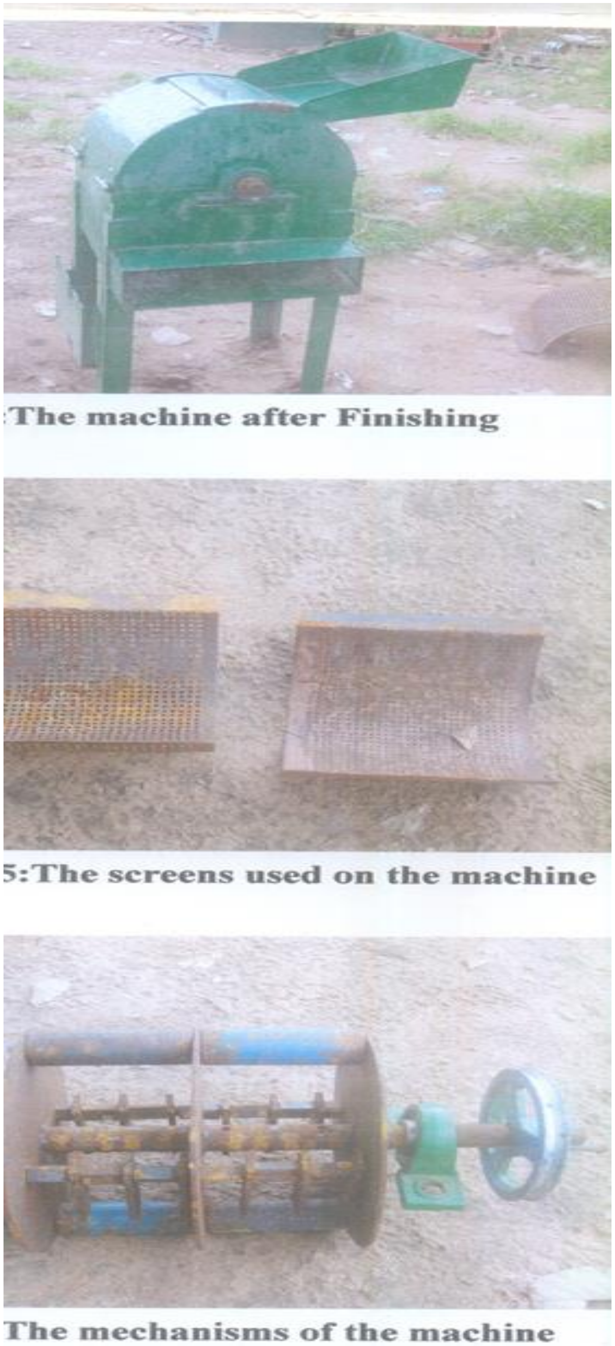


Figure 2: Pictorial views showing the machine, sieves and the mechanism arranged from top to down respectively.

2.2. Materials

Dried yam lumps (White yam “D. rotundata”) were sourced from Ijeru market, in Ogbomoso South Local Government Area of Oyo state for the performance evaluation. It was subjected to further drying; a moisture content of 8.68% dry base was achieved. A weighing scale of accuracy ±0.01kg was used for weighing each portion of the test material, a tachometer to determine the operating speed of the machine when loaded, collecting bowls for collecting the crushed sample, a stopwatch to record the time of operation at each instance and polythene bags for storing the end product for safe keep.

2.3. Methodology

Two screens of diameters 1.5 mm and 5.0mm Screens of size 1.5 and 5.0 mm were made to have large difference in screen size. A Chinese Steelman 5.0 hp prime mover with 1430 rpm with adjustable speed regulator was used to vary the operating speed. From literatures, Nasir, 2005 and Ngabea et al, 2015 affirmed the average speed for operating hammer mill as 700 and 850 rpm respectively. Therefore, a speed slightly below (i.e. 650 rpm) was chosen as the base operating speed; the speed was doubled (1300 rpm) to examine its effects on the output efficiency of the machine.

10 Kg of the dried yam lump was weighed out in four portions on the weighing scale at a moisture content of 8.68% dry basis.

The two speeds (650 and 1300 rpm) were run on the machine with the screen interchanged one after the other and the operating time recorded. The crushed dried yam at each instance was tagged as follow: A – (5.0 mm screen diameter with 650 rpm speed), B – (1.5 mm screen diameter with 650 rpm speed), C – (1.5 mm screen diameter with 1300 rpm speed) and D – (5.0 mm screen diameter with 1300 rpm speed).

The end-products gotten were taken for particle size analysis to determine the degree of fineness and uniformity index of the four replicates. The procedure as explained by California Test 202 (2011) was followed: 200g of the grinded replicates were weighed out and shaken through 5 set of Tyler sieves for 5 minutes by means of tapping sieve shaker. The mesh numbers of the 5 sieves are 40, 60, 80, 100 and 150 microns from top to base respectively. The sieves are designated 1 – 5 starting from the smallest to the biggest (i.e. from 150 to 40), while the pan is designated as 0. The following were thereafter determined,

(i) The percentage of material retained on each sieve by:

$$\%\, retained\ in\ sieve = \frac{W_{sieve}}{W_{total}} \times 100 \tag{1}$$

Where, W_{sieve} is the weight of aggregate in the sieve, W_{total} is the total weight of the aggregate.

(ii) $$\%\, cumulative\ retained = R_{S1} + R_{S2} + \cdots + R_{S5} \tag{2}$$

Where, R_s- % retained on each sieve from largest to smallest.

(iii) The percentage of material passing each sieve:

$$\%\, cumulative\ passing = 100 - \%\, cumulative\ retained \tag{3}$$

(iv) The machine output efficiency was determined by:

$$machine\ efficiency = \frac{mass\ output}{mass\ input} \times 100 \tag{4}$$

(v) $$material\ loss = \frac{(M_b - M_a)}{M_b} \tag{5}$$

Where, M_a- Mass after grinding, M_b- Mass before grinding.

(vi) $$machine\ capacity = \frac{mass\ of\ input\ material}{milling\ time} \times 60 minutes \tag{6}$$

(vii) $$\Sigma FM = \frac{\Sigma\ \%\, retained}{100} \tag{7}$$

Where, ΣFM- Fineness modulus.

3.0. RESULTS AND DISCUSSION

1. The effect of operating speed and screen size on particle size:

High operating speed with small screen size gave the best result in terms of fineness (Figure 3). The percentage of material retained is lowest for sample C followed by B, D and A respectively. This conforms to the findings of Anderson, 2003 and Yancey, et al, 2014 which affirmed that the optimal grinder configuration for maximal process throughput and efficiency of hammer mill is strongly dependent on tip speed of the rotor, screen diameter, feedstock type and properties, such as moisture content. Hence, in selecting the proper grinder process parameters, speed and screen size are important factors.

2. The effect of operating speed and screen size on operation time:

The time for milling same quantity of dried yam increased in the order: D, C, A and B respectively (table 1); showing that at larger screen size and higher speed, the operation is more time efficient. This is in line with El Shal et al (2010) which reported that aside moisture content, factors like screen size, speed rating, etc. also affect the residence time of feed in hammer mill operation.

3. The effect of operating speed and screen size on machine throughput:

The machine throughput (table 1) is highest for D, followed by C, A, and B respectively in decreasing order. This connotes that the higher the operating speed and screen size, the higher the output capacity because of lower residency time in the machine (Yancey, et al, 2014).

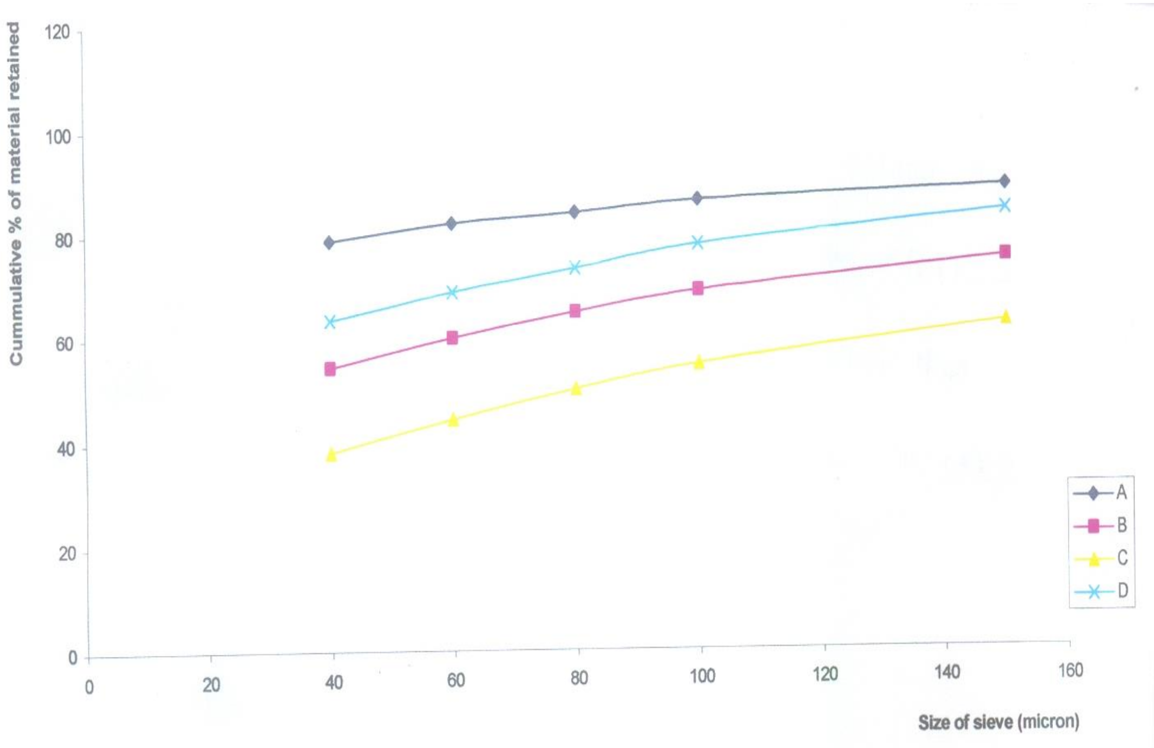
4. The effect of operating speed and screen size on machine efficiency:

Based on the ratio of residue retained on the sieve during sieve analysis to fine particles, the machine was most efficient at instance C followed by B, D and A in the decreasing order (table 1). This conforms to Yancey, et al, (2014), which reported that the smaller the size of the screen the finer the grains generated from the grinding machine.

Table1: Parameters from machine testing.

Sample	Mass of material input (Kg)	Milling Time (Min.)	Machine Capacity(Kg/hr)	Material Output(Kg)	Material Loss(Kg)	Machine Efficiency (%)
A	10.0	9.15	65.57	7.34	2.66	73.40
B	10.0	9.40	63.83	7.94	2.06	79.40
C	10.0	8.60	69.77	8.15	1.85	81.50
D	10.0	8.10	74.07	7.71	2.29	77.10
Average	**10.0**	**8.81**	**68.31**	**7.79**	**2.21**	**77.85**

Figure 3: Graph of the sieve analysis of the samples of crushed dried yam showing the fineness in increasing order from top to down.



4.0. CONCLUSIONS

Hammer mill, as a processing equipment, is more efficient if operated at the appropriate optimal conditions. The machine throughput, efficiency, fineness of end-product and timeliness of operation are essential to the overall performance of the machine. This research has been able to establish that higher operational speed (1300 rpm) and smaller screen size (1.5mm) is best among other operational instances used giving a throughput of 69.77 Kg/hr, working efficiency of 81.50% in terms of fineness of end-product and operational time of 8 minutes 60 seconds for 10 Kg of dried yam lump at 8.68% moisture content.

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EVALUATION OF DOMESTIC WATER SUPPLY SYSTEM: CASE STUDY OF BOSSO COMMUNITY, MINNA, NIGER STATE, NIGERIA

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ABSTRACT

Water supply system plays a vital role in preserving and providing a desirable life to the public. The reliability of sources of water supply is an essential component to every development. In this study, a detailed analysis of the major factors behind people's choice for a particular source of water in Bosso Community was investigated. To achieve this, an investigative research approach method was employed by randomly distributing one hundred and fifty (150) structured questionnaires within Bosso community. The result showed that, 14% of the households in Bosso community obtain their drinking water from Tap water, 8% from the wells dug in their respective homes, 10% from boreholes, 58% from packaged water and 10% from water vendors whose exact source of water is unknown. It was observed that majority of the residential areas in Bosso community do not depend on the tap water supply rather they depend on dugged wells and bore holes. It was therefore concluded that large water storage facility and pump stations should be provided at major areas of the town to service the residents with treated water.

Keywords: *Water supply, reticulation, public-private partnership, Bosso*

1. INTRODUCTION

Since independence of Nigeria from her colonial masters, several administrations have made water supply to growing population its primary target, thus many water supply schemes have been and are still being commissioned to satisfy political promises and aspirations without resources maintenance consideration (Onuoha *et al*., 2012).

Water distribution system plays a vital role in preserving and providing a desirable life quality to the public, of which the reliability of supply is a major component. Reliability analysis of a water distribution system is concerned with its ability to deliver water to individual consumers in the required quantity and under a satisfactory pressure (Musa and Fumen, 2013).

Domestic water supply is water used for all useful domestic purposes including consumption, bathing and food preparation. The need for domestic water supplies for basic health protection exceeds the minimum requirement for consumption (drinking and cooking). Additional volumes are required for maintaining food and personal hygiene through hand and food washing, bathing and laundry. Without water, people's health and livelihoods can be severely affected; the education of children (particularly girls) suffers as the daily tasks of survival take precedence overall other concerns (Onuoha *et al*., 2012). It is recognized all over the world that water is a vital resource for the existence of man and also a commanding factor with respect to the development of human civilization.

The importance of good quality and quantity of water for use by man cannot be over emphasized as there are still a lot of cases of diarrhoea in sub-Saharan Africa. Water, the most essential commodity in human life is becoming very scarce due to human activities. The availability of potable and safe water is a problem in developing countries of Africa especially Nigeria (Agbabiaka *et al*., 2014). Nigeria in the recent time is experiencing an increasing change in her population coupled with increased urbanization and living standards (Owoeye and Adedeji, 2013). Thus the increasing needs of water for domestic and other uses, places an increasing demand on our water resources. Water as a vital resource is not in short supply in Nigeria particularly in Minna but regulating its availability and ensuring even distribution is in fact a serious challenge. However, the quantity of potable water availability to the inhabitants of this community has received cries of inadequacies (Adepoju and Omonona, 2009). The rapid urbanization process in Bosso has taken its toll on overcrowded dwellings, high rate of pollution, inadequate household facilities, and carefree attitude of people toward poor environmental conditions which have been the precondition for deteriorating environment.

Water is a movable natural resource that can be administered in various methods pertaining to specific socio-economic activities. This involves ground water drilling, rainwater harvesting, hauling, stockpiling and redirecting. These are typical features of water that makes it unique as compared to other innate reserves. This being the case, any kind of water management that hampers the natural course will result in an adverse effect upon the natural environment and put human health at risk.

The purpose of domestic water delivery systems is to transport potable water from a water treatment facility to residential consumers, for use as drinking, cooking, sanitary conditions, and other domestic purposes (Hickey, 2008). Water supply also is essential for business and industry to operate in a municipal environment (Alayande, 2005). Of no less importance is the need to supply water to properly located fire hydrants with maximum pressure for an effective level of fire protection.

The objectives of this work is to study and evaluate the installed municipal water supply delivery system by identifying the physical components of the specified water distribution and supply system in Bosso community, Niger State; to assess the water delivery system capability and ascertain whether the system is meeting the water supply demand and to proffer possible solutions to the domestic water supply problems encountered in Bosso community.

2.0 METHODOLOGY OF RESEARCH

2.1. The Study Area

Bosso is one of the twenty-five local government areas in Niger State, with its headquarters in Maikunkele with a land mass of 1,592 km^2 and a population of 147,359 (NPC, 2006), with Latitude 9° 39' 11" N and Longitude 6° 30' 57" E. Bosso like every other community in the north central area of Nigeria is divided into two seasons of wet and dry period within a year with an annual rainfall of 578 mm and a mean temperature of 34 ^{0}C (Musa *et al*., 2011).

2.2. Data Collection

This study was conducted using the Investigative Research Approach method, which deals with the distribution of questionnaires, personal interview and field observations. These were done using structured questionnaires to households in Bosso community in addition to field observation, focus group discussions, and informal interviews. Secondary information were also collected from the internet, Census and survey reports, news reports, journals as well as other published and unpublished documents. Table 1 presents the distribution pattern of the questionnaires to the Government Reserved Area (GRA), Bosso Village, Tudun Fulani, Dusten Kura Gwari and Dusten Kura Hausa, respectively.

Table 1: Distribution pattern of questionnaires

Area	No of Questionnaires	% of Total Questionnaires
GRA	40	26.67
Bosso Village	40	26.67
Tudun Fulani	30	20.00
Dusten Kura Gwari	20	13.33
Dusten Kura Hausa	20	13.33

The questionnaires contained both close and open-ended questions. The close-ended questions were meant to capture direct answers from the respondents, while the open-ended questions were also meant to allow the respondents to express their views as they wish. This was also meant to arrive at relevant information that could not be obtained by the close-ended questions. The entire field data collection covered 150 households of Bosso which also implies that 1 % of the total population in the community was covered. During the administration of the questionnaires, field observation was carried out to fully understand what people go through when they clamor for water. The questionnaire was structured to obtain both primary and secondary data which was to be completed by the selected households within the study area.

The Statistical Package for the Social Scientists (SPSS) and MS Excel 2010 were employed to analyze statistically the obtained information from the questionnaires.

3.0. RESULTS AND DISCUSSION

3.1 Major Source of Household Drinking Water

A total of 150 questionnaires were administered and only 147 (98%) were returned.The source of water in the study area depends upon the regularity and the adequacy of supply of tap water, well water, borehole, other sources of water. Figure 1 shows that 14% of the households in Bosso community obtain their drinking water from the tap water, 8% from the wells dug in their respective homes, 10% from their boreholes, 58% from packaged water and 10% from water vendors. This is similar to the work carried out on public perception of potable water supply in Abeokuta South west, Nigeria by Odjegba *et al*. (2015).

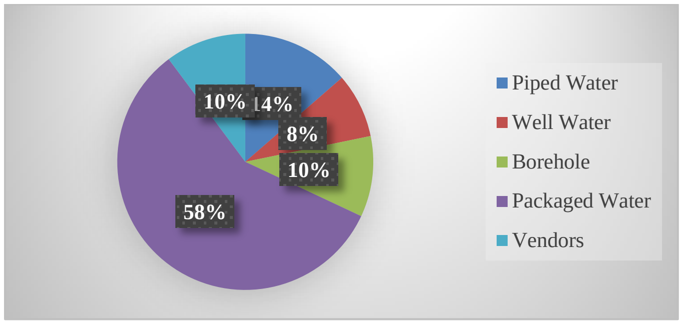

Fig. 1: Major Source of Household Drinking Water.

Despite the efforts of all the three levels of government, the effect of clean potable water and its constant availability is yet to be felt in the Bosso community. This community is known to house one of the campus of a higher institution, thus the rate of provision of water through the water Board has in the recent time not being able to meet the growing demand of the public because of the population explosion in the area. The study showed that 46% of the residents had reticulated water system and other sources of water (borehole and open wells) connected to their various residents which provide them the much needed water for their domestic use and improving the sanitary condition of the community. This is similar to the work of Odjegba *et al*., (2015) which looked at public perception of potable water supply in Abeokuta South west, Nigeria and that of Ndiyo *et al*., (2013) who reviewed the domestic water supply and basic sanitation gaps in local government areas in Cross River State, Nigeria in relation to Millennium Development Goals (MDG) investments. The percentage of those that were not connected to the Water Board network was 54%. This percentage state that they depend mainly on wells and boreholes from neighboring houses for their daily provision which only meets some of the basic needs which is similar to the study carried out by Ajadi (2010). The 46 % confirmed that they obtain a higher quantity of treated water from the public source of water supply other than the private water supply system of wells and boreholes. The study showed that the water supply is not sufficient to meet the water demand over the projected future due to inefficiency of the piped water supply system and the inadequacy of alternative private sources of potable water and also the increasing population.

3.2. Condition of Tap Water Supply

The survey results indicated that only about 7% of the respondents have satisfactory condition of tap water supply; about 37% of the respondents have poor conditions of water supply, while the remaining 66% do not have tap water running in their houses. Figure 2 shows the response of the residents of Bosso community with respect to the condition of the reticulating system. Thirty three percent (33%) of the respondents being served through the reticulated systems observed that their taps produce particles which they have to either allow to settle down or sieve before use. The particles observed were dirty brown in color which is an indication of rusting in the pipes servicing the various residents. 67 % of those served with reticulated systems stated that such particles are found in the water they collect. On further interview, the residents whereby particles were found in their water stated that most of the pipes were laid in the mid 70s, thus the rusting could be linked to the age of the pipes. They also stated that the Water Board bill them certain amounts which they are willing to pay more provided there will be an improved service delivery to their various homes.

This is similar to the situation reported by Ayanshola, *et al*., (2013) who evaluated the willingness of the public to pay for reliable and sustainable household water use in Ilorin, Nigeria.

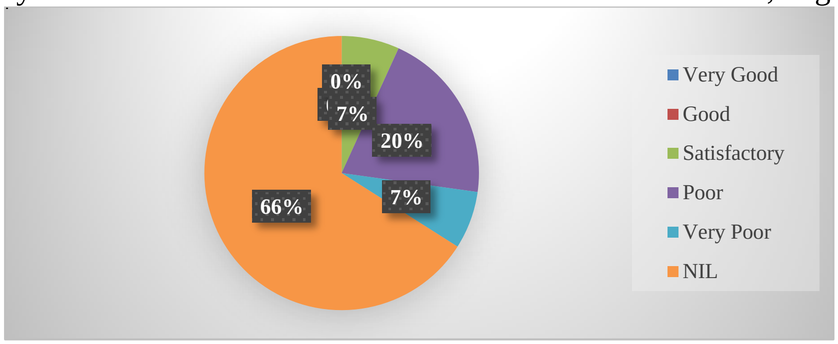

Fig. 2: Condition of reticulatry system for Water Supply in Bosso Community

Due to inefficiency of the other alternative sources of water, the purchase of water from water vendors have become rampant in Bosso community. When asked during the survey, the respondents stated that a jerry can of water is sold for about N20 – N25 during the rainy season, and N30 - N40 during the dry season. A tanker of 5000 liters of water is purchased for between N7,500 and N10,000 depending on the distance. A bag of sachet water is sold for N120 and a pack of bottled water costs N500 within the community. Ariyo and Jerome (2004) in their studies reported similar figures.

3.3. Water Collection and Storage

Water from the public water supply system and from the alternative sources are collected and stored to service the needs of various homes over a period of time. Figure 3 shows that 8% of the respondents store water in Jerry cans, 20% of the respondents store in open and covered buckets, 31% of the respondents store water in basins and the remaining 41% of the respondents store water in tanks or reservoirs privately purchased or constructed. This they stated will provide water for domestic use for a minimum of two days and maximum of four days before the next supply. This is similar to the works of Ubani *et al*., (2013) and Gerlach and Franceys (2006).

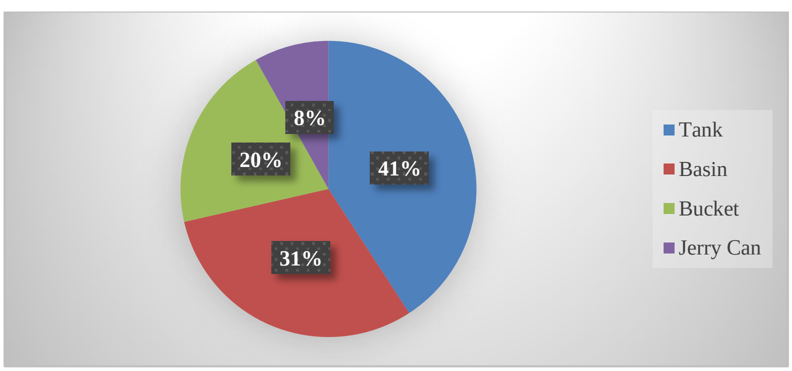

Fig. 3: Storage mediums for water by residents of Bosso Community.

4. Conclusions

Provision of water supply and management poses a serious challenge to most cities in Nigeria. The increasing pressure on government in relation to challenges emanating from the water sector has made the private sector participation inevitable just as it has brought improved performance to some few developing nations where it has been practiced. Evaluation of water supply and distribution system in Bosso community was studied to measure the ability of meeting the consumers demand. It was discovered that majority of the residential areas in Bosso community do not depend on tap water supply rather they depend on water vendors, dugged wells and bore holes. This has resulted in the drilling and digging of boreholes and open wells in most residential homes. These methods of underground water extraction possess many environmental hazards such as landslides. Due to the topographical nature of Bosso and its environment, a large water storage facility and pump stations should be provided at major areas of the town to service the residents with treated water. This will reduce the rate of drilling and digging of boreholes and wells, respectively and will further enhance prompt supply of water at every other day to the residents of the town.

One of the policy trusts of National Water supply and Sanitation (NPWSS), 2000 and the MDG's goals are to provide; adequate and potable water supply to the urban and rural population by the year 2015. To achieve the national and state water supply policy objectives major institutional reforms must be carried out in our water sector. This requires the dramatic scaling up of efforts, both in terms of the extent of action required and the speed with which these actions must be undertaken by the various arms of government and the public. The NPWSS policy and World Bank programmes have identified commercialization and private sector participation as some of the options in solving these problems. Public-Private-Patternership (PPP) option for water supply offers one of the ways out of the urban water problems in our city and meeting the 2015 MDGs. Once it is promoted and appropriate division of roles for the identified partners is decided, improvement will be recorded without further increase in investment by government.

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OPTIMIZATION OF BIODIESEL PRODUCTION FROM LOOFAH OIL USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Biodiesel derived from the trans-esterification of inedible oils with simple alcohol in the presence of catalyst is now attracting great attention as a renewable fuel for diesel engines. Response Surface Methodology (RSM) based on D-Optimal was used to optimize biodiesel production process from loofah oil. Oil was extracted from loofah seeds using mechanical extraction method. Biodiesel (ethyl ester) was produced from raw loofah oil using potassium hydroxide (KOH) and ethanol as alcohol. The effect of variables including reaction time, reaction temperature, amount of ethanol and amount of catalyst on the biodiesel yield was examined and optimized by RSM. The optimum reaction time, temperature, amount of alcohol and amount of catalyst were found to be 75 minutes, 70 ^{o}C, 20ml, and 0.81g respectively, resulting in optimum loofah biodiesel yield of 88%. The RSM indicates an optimum ridge in yield by increasing amount of catalyst but with decreasing amount of alcohol.

***Keywords**: Biodiesel, Trans-esterification, Response Surface Methodology, Optimization, Inedible oil.*

1.0 INTRODUCTION

Biodiesel is a substitute for diesel fuel made wholly or partly from an organic product, especially processed vegetable oils such as soybean oil and peanut oil (Encarta Dictionaries, 2009). Consumption of fossil fuels has increased to a greater extent and the use of these energy resources is seen as having major environmental impact. Energy diversification is seen as an insurance policy against geopolitical risks and government insecurity about fossil fuel costs and fuel scarcity (Refaat *et al.,* 2007). Biodiesel derived from vegetable oil or animal fats by trans-esterification with alcohol like methanol and ethanol is recommended for use as a substitute for petrol-diesel mainly because biodiesel is an oxygenated, renewable, biodegradable and environmentally friendly biofuel with similar flow and combustion properties and also low emission profile (Siti, 2009).

Researches into production and optimization of biodiesel is encouraged due to rising demand for energy globally and major crude oil importers expressing concerns in the prices and sustainability of supplies couple with the fact that biodiesel has excellent lubricating properties (Alamu *et al*., 2007). The future of biodiesel lies in the world's ability to produce renewable feedstocks such as vegetable oils and fats to keep the cost of biodiesel competitive with petroleum, without supplanting land necessary for food production, or destroying natural ecosystems in the process (Meher *et al*., 2006). The use of under-utilized inedible oil seeds such as loofah seeds is suitable for the production of biodiesel thereby eliminating food-fuel competition.

Since the efficiency of ester synthesis depends on the applied reaction conditions, it is of great importance to investigate their influence on the esters yield in order to determine the optimal. The classic way of investigation by varying one process variable while others are held constant is time-consuming and expensive. Instead, the statistical methods, known as design of experiments, are frequently used as a power tool for the process optimization in the past decade such as the Response Surface Methodology (RSM) combined with the central composite rotatable design (Da Silva *et al*., 2006), factorial design (Da Silva *et al*., 2009) or Box–Behnken factorial design (Liao and Chung, 2009). Although biodiesel has been successfully produced from loofah oil (Ajiwe *et al*., 2005), there is scarcity of literature on the optimization of biodiesel production from loofah oil. Hence, this work focused on the use of RSM for optimizing biodiesel production from loofah oil which would describe the relationships between variables and obtain minimum and maximum yields.

2.0 MATERIALS AND METHODS

2.1 Collection of Seeds

The loofah fruits were harvested from bushes and uncompleted buildings within Ogbomoso, Oyo State, Nigeria. The exterior brownish part was peeled, and the interior spongy fruit was dissected into four parts using a knife, for easy removal of the seeds. The seeds were parboiled in a cooler filled with hot water (heated to 100 ^{o}C) to soften the shell for easy deshelling of the seeds. The seeds were eventually sundried so as to remove the moisture absorbed during parboiling in cooler.

2.2 Mechanical Extraction of Loofah Oil

The oilseeds were ground to fine particle sizes and roasted in the oven preset to a temperature of 100 ^{o}C for about 30 minutes. After roasting, the samples were wrapped in cheese cloth and introduced into the pressing cylinder of a laboratory press. The oil expressed was collected into a funnel beneath the cylinder and then drained into a container for storage.

2.3 The Transesterification Reactor

The main design consideration for the trans-esterification process is that the transesterification reactor should be closed to the atmosphere with no fumes escaping. Esters are very volatile and most of it may escape to the atmosphere as vapour if open reactors are used. Therefore, close reactors were used for this work. Also, the reactor must be made of materials that can resist corrosion of the chemicals used for trans-esterification. For example, the potassium ethoxide formed by adding potassium hydroxide to ethanol. Therefore, glass and metal batch, stirred reactors were used for this work.

2.4 Production of Biodiesel Fuel

Loofah ethyl ester was produced by base catalyzed trans-esterification. The biodiesel production process was carried out using the transesterification reaction mechanism reported by Ogunkunle *et al*. (2017). Potassium hydroxide was used as the alkali and ethanol as alcohol. The corresponding yield for each run was recorded and the experiment was carried out for 25 runs as analyzed by the computer program.

Three operations were performed in the production of the biodiesel fuel. These are:

i. Transesterification: The process of transesterification to produce ethyl esters was a two-step process carried out by Abowei *et al.* (2013). The advantage of the two-step process is the ease with which each of the trans-esterification process can be monitored. Different yields of biodiesel were obtained under different reaction variables. The variables are reaction time, temperature, amount of alcohol and amount of KOH.
ii. Phase separation: When the transesterification reaction was completed, the reaction products were separated into two layers by allowing the product mixture to settle overnight under ambient condition. After separation, the ester product formed the upper layer and by-product glycerol formed the lower layer. The residual catalyst and the un-reacted excess alcohol were distributed between the two phases.
iii. Washing and heating: After separation of the phases, the dissolved catalyst and alcohol were washed from the ester with distilled water. The ethyl ester obtained was then heated at 120 ^oC for 30 minutes to remove all moisture residues present in it. The ester product was then stored in sample bottles.

2.5 Determination of the Yield of Esters

The yield of the ethyl esters, Y, produced was calculated using Equation 1:

$$Y = \frac{V_e}{V_r} \times 100\% \qquad \ldots \qquad \ldots\ldots (1)$$

Where:

Y= Yield of the ethyl esters, %

V_e= Volume ethyl esters produced, milliliters.

V_r = Volume of raw oil used, milliliters.

2.6 Optimization of the Transesterification Reaction

Optimization of the production process of biodiesel from the loofah oil was carried out experimentally as randomized by Response Surface Method. Design Expert software 6.0.8 Version was used for regression and graphical analysis of the data obtained. Analysing the experimental yield data supplied into the Design Expert, the predicted optimum values from the 25 experimental runs were found to be 25 The optimal yield conditions for biodiesel production from the transesterification of loofah oil were obtained from the optimization of the yield responses for the experimental reaction data. The experimental reaction conditions were set in range and the yield response was set on maximum level in order to obtain an ideal optimized reaction conditions for biodiesel production. The optimal solution predicted for biodiesel yield are favourable optimum levels based on economic considerations (reduced temperature and reaction time and moderate alcohol amount and catalyst amount) according to Oniya *et al*. (2016). Table 1 shows the 2^k factorial values for the experimental design.

Table 1: 2^k factorial values for the experimental design

Variables	Units	Low	High
Reaction time	Minutes	60	90
Temperature	Degree Centigrade	40	70
Amount of Alcohol	Milliliters	15	30
Amount of KOH	Grams	0.81	1.11

3.0 RESULTS AND DISCUSSION

The results of the 25 randomized experimental runs and the percentage biodiesel yield are presented in Table 2. From Table 2, the optimum yield was obtained at run 13 under the following conditions of variables: reaction time of 75 minutes, temperature of 70^oC, amount of alcohol of 20 ml and amount of KOH of 0.81g. While the lowest yield was obtained at run 7 and 8 under the following conditions: reaction time of 60 minutes, temperature of 55^oC, amount of alcohol of 20 ml and amount of KOH of 0.81g for run 7 and 0.91g for run 8. This result was also similar to the values obtained by Yusuf and Sirajo (2009).

It can also be seen from Table 2 that the ester yield increases with decreasing amount of catalyst and increasing temperature but progressively decreases at lower level of temperature. This can be explained by the formation of by-products, possibly due to triglycerides saponification process, a side reaction which is favoured at high temperature. This side reaction produces potassium soaps and thus, decreases the yield of biodiesel. The varying biodiesel yield values presented in Table 2 are indications that loofah oil transesterification reaction parameters considerably affected the biodiesel yield. The Model F-value of 7.06 obtained for biodiesel yield implies the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case reaction time, temperature, amount of alcohol, amount of KOH and the interactive effects are significant model terms.

Standard deviation of 4.37, mean of 72.40, C.V. of 6.04, R^2 of 0.9082, adj R^2 of 0.7796, pred R^2 of -1.0171 and adeq precision of 9.910 were obtained for biodiesel yield. A negative "Pred R-Squared" implies that the overall mean is a better predictor of your response than the current model. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. In this case, a ratio of 9.910 indicates an adequate signal. This model can be used to navigate the design space. Guan and Yao (2008) reported that an R^2 should be at least 0.80 for the good fit of a model. In this case, the R^2 value of 0.9082 indicated that the sample variation of 90.82% for the biodiesel production is attributed to the independent factors (temperature, time, and alcohol to oil molar ratio) and only 9.18% of the total variations are not explained by the model.

The interaction term for reaction time and temperature indicates these two factors did not affect percentage yield independently. Thus, the effect of one factor on percentage yield depends on the specific level of the other factor. This interaction can be observed in the fitted response surface plot shown in Figure 1. There is significant interaction (95% CI) between the response surface of percentage yield vs. time and amount of alcohol as observed in Figure 2. There is reduction in percentage yield at initial time and amount of alcohol. According to Oniya *et al.* (2016), biodiesel yield is always low for low reaction time because there is not yet a phase formation between the reactants at low reaction time. Also, Ogunkunle *et al.* (2017) reported that higher molar ratio resulted into higher production of biodiesel. Higher volume of would allow complete transesterification of the seed oil and favour the forward reaction. Lower volume of alcohol can only allow partial transesterification of the oil, hence the lower yield of biodiesel obtained.

Also, the significant interaction term for amount of KOH and amount of alcohol indicates these two factors did not affect percentage yield independently. Thus, the effect of one factor on percentage yield depends on the specific level of the other factor. The fitted response surface plot for the interaction can be observed in Figure 3.

The effect of the amount of catalyst was also very significant upon biodiesel production the transesterification process. The relationship between percentage yield and amount of KOH with time in Figure 4 was curvilinear with a positive linear coefficient. This suggests that percentage yield was inhibited at high catalyst concentration. And this result is consistent with previous research carried out by Hem (2008).

Table 2: Result of yield of biodiesel produced from optimization of transesterification reaction of loofah oil

Run	Amount of oil (ml)	Reaction time (mins)	Reaction temperature (^oC)	Amount of Alcohol (ml)	Amount of KOH (g)	Yield (%)
1	70.0	70.0	70.0	30.0	0.96	80
2	70.0	70.0	70.0	22.5	1.11	74
3	70.0	75.0	40.0	20.0	0.91	68
4	70.0	70.0	70.0	15.0	0.81	82
5	70.0	90.0	60.0	20.0	0.91	69
6	70.0	70.0	40.0	20.0	0.96	68
7	70.0	60.0	55.0	20.0	0.81	54
8	70.0	60.0	55.0	20.0	0.91	54
9	70.0	75.0	70.0	15.0	0.81	83
10	70.0	60.0	70.0	20.0	0.81	76
11	70.0	70.0	40.0	20.0	0.81	68
12	70.0	70.0	70.0	30.0	0.91	78
13	70.0	75.0	70.0	20.0	0.81	88
14	70.0	75.0	70.0	15.0	0.91	82
15	70.0	75.0	70.0	22.5	0.81	74
16	70.0	70.0	40.0	22.5	0.81	68
17	70.0	80.0	70.0	15.0	0.81	82
18	70.0	75.0	40.0	22.5	0.96	68
19	70.0	70.0	70.0	30.0	0.81	83
20	70.0	70.0	55.0	22.5	0.96	74
21	70.0	60.0	55.0	20.0	1.11	55
22	70.00	70.0	40.0	15.0	1.11	68
23	70.00	70.0	70.0	30.0	0.91	80
24	70.00	60.0	60.0	15.0	1.11	66
25	70.00	75.0	40.0	20.0	0.81	68

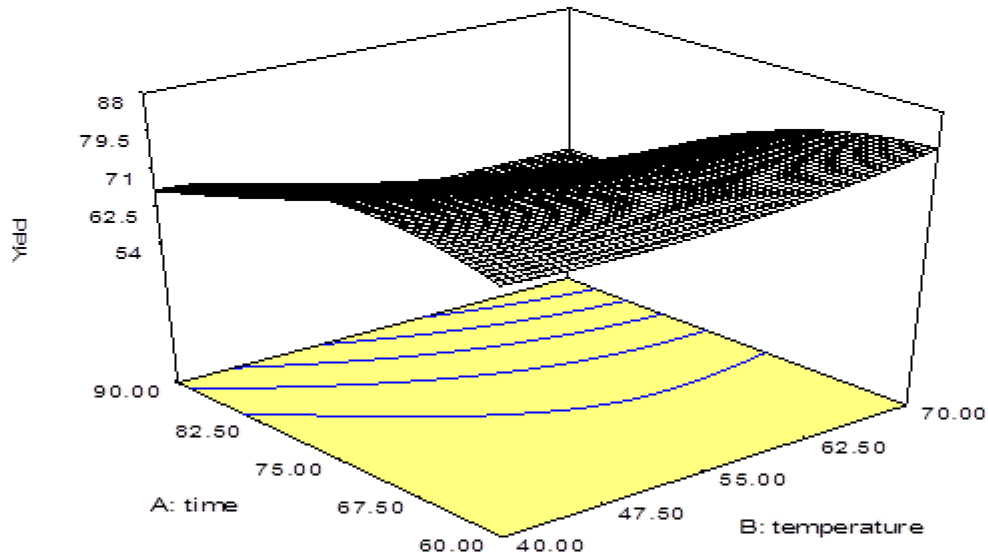

Figure 1: Response surface plot showing the effect of reaction time and temperature on percentage yield

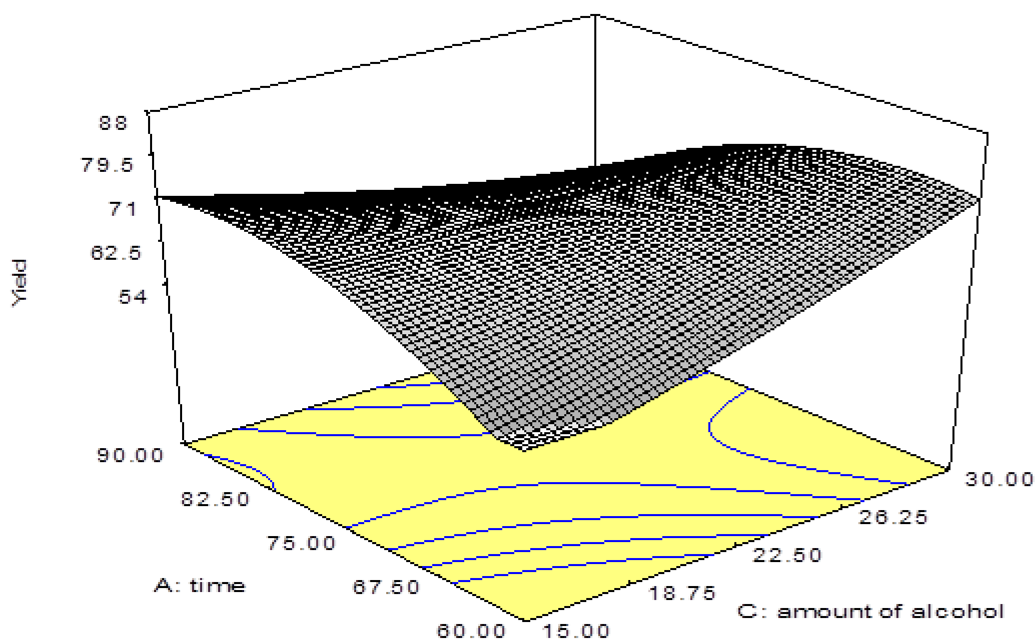

Figure 2: Response surface plot showing the effect of time and amount of alcohol on percentage yield

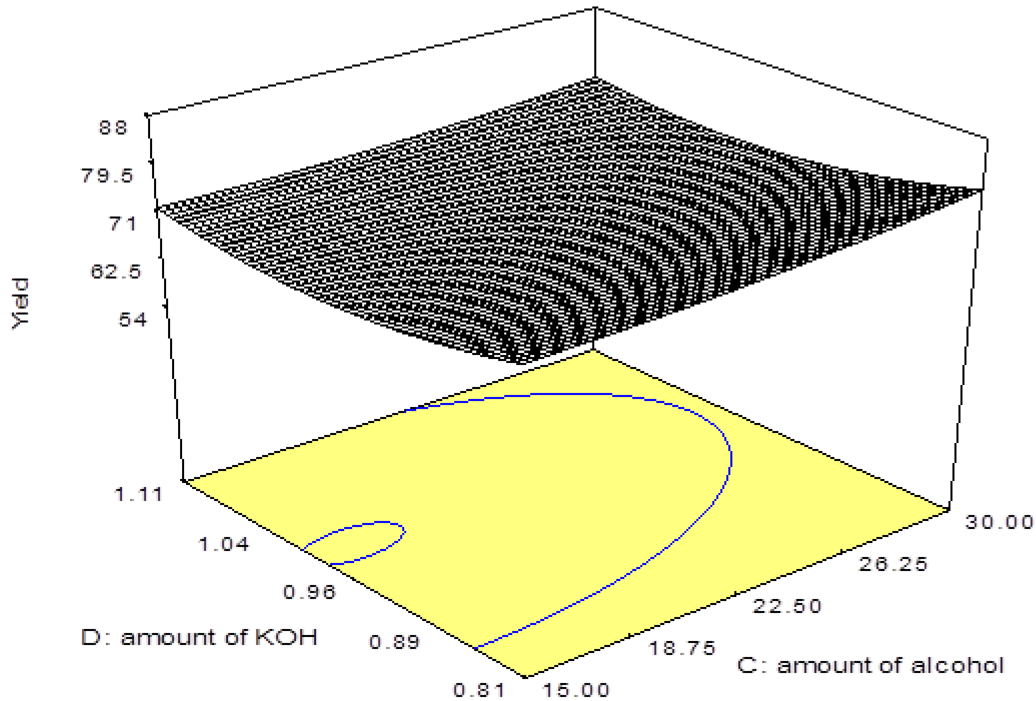

Figure 3: Response surface plot showing the effect of amount of KOH and amount of alcohol on percentage yield

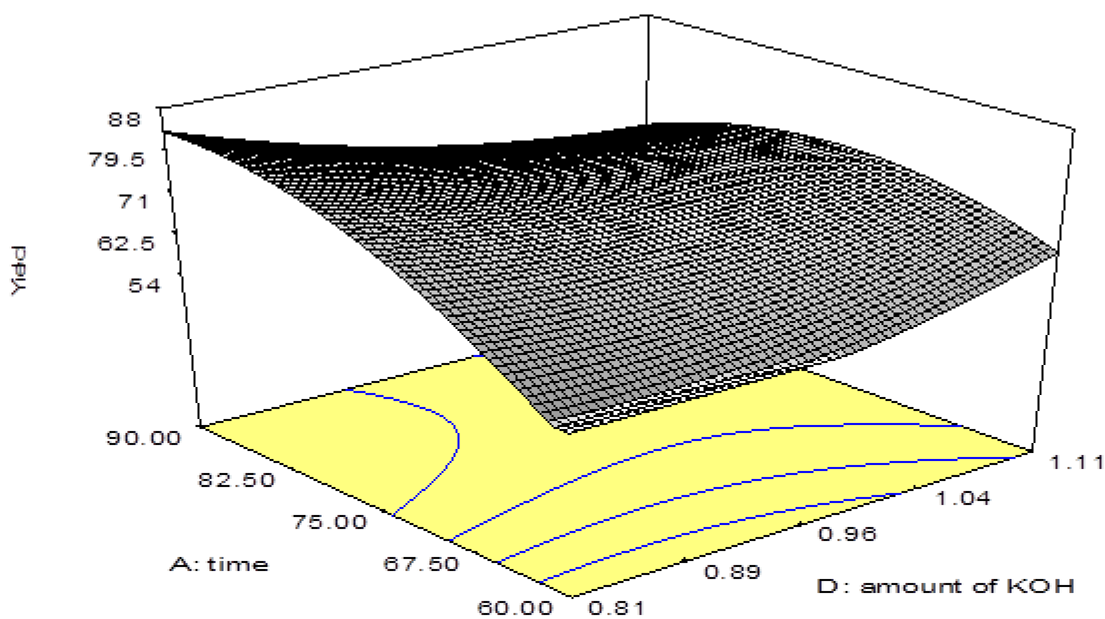

Figure 4: Response surface plot showing the effect of time and amount of KOH on percentage yield

The design summary for the optimization of biodiesel production from loofah oil is shown in Table 3. The final empirical model in terms of coded factors (reaction parameters) for the biodiesel yield is given in Equation 1. The model shows that reaction parameters are significant on biodiesel production from loofah oil. A, B, C and D represent time, temperature, amount of alcohol and amount of KOH, respectively. The expected yield can thus be predicted using the model with the inclusive of quadratic and interactive terms of the reaction parameters.

Table 3: Design Summary for the Optimization of Biodiesel Production from Loofah Oil

Study Type	Response Surface			Experiments	25		
Initial Design	D-optimal			Blocks	No Blocks		
Design Model	Quadratic						
Response	Name	Units	Obs	Minimum	Maximum	Trans	Model
Y1	Yield	%	25	54.00	88.00	None	Quadratic
Factor	Name	Units		Low Actual	High Actual	Low Coded	High Coded
A	Time	minutes		60.00	90.00	-1.000	1.000
B	Temperature	^{o}C		40.00	70.00	-1.000	1.000
C	Amount of alcohol	ml		15.00	30.00	-1.000	1.000
D	Amount of KOH	Grams		0.81	1.11	-1.000	1.000

Final Equation in Terms of Coded Factors:

Biodiesel Yield = $70.23 + 0.074*A + 1.37*B + 1.92*C - 1.75*D - 8.33*A^2 + 2.80*B^2 + 1.11*C^2 + 1.11*C^2 - 4.00*D^2 - 6.69*A*B - 10.77*A*C - 7.85*A*D - 4.38*B*D - 0.40*C*D$ … (2)

Where A, B, C and D were the coded values of the independent variables i.e. time, temperature, amount of alcohol and amount of KOH.

3.1 Optimization of the Transesterification of Loofah Oil Reaction Variables

Optimum reaction conditions for maximizing biodiesel yield were determined by statistically analyzing the experimental data. The reaction variables (time, temperature, amount of alcohol and amount of catalyst) were set in range reaction time in order to provide an ideal case for optimized biodiesel yield from loofah oil transesterification using ethanol and KOH as alcohol and catalyst respectively. Based upon the requirements of the reaction parameters, biodiesel yield was set on maximum level. The predicted optimum values of reaction time, temperature, amount of alcohol, and amount of catalyst were found to be 62.54 minutes, 69.05 ^{o}C, 23.48 ml and 1.00 g respectively, to achieve 89.98% maximum loofah biodiesel yield; while desirability was 1.00 for the experiment. This optimal solution chosen for biodiesel yield are favourable predicted optimum levels based on economic considerations (reduced reaction time, temperature and moderate amount of alcohol and catalyst which corresponds to reduced operating costs of the transesterification process for biodiesel yields) and not necessarily the highest biodiesel yield value.

The biodiesel yield in the optimized conditions was 89.98% while the highest biodiesel yield from experimental work was 88%. The results clearly indicated the effectiveness of process variables optimization in biodiesel production using RSM. Ogunkunle *et al*. (2016) used a 2k factorial Box-Behnken design (BBD) to maximize biodiesel production from milk bush seed oil and obtained optimized reaction variables of 10.18:1 of alcohol to oil, 1.89 hours of time and a 63.67oC temperature. Under these conditions, a methyl ester (biodiesel) yield of 81.45% was predicted. Further validation experiments conducted at the predicted optimal conditions yielded an average of 90.72% of biodiesel. This is in reasonable agreement with the optimized experimental conditions.

4.0 Conclusion

The response surface analysis was performed to assess the effect of reaction time, reaction temperature, amount of alcohol and amount of catalyst on the percentage yield and for biodiesel produced from loofah oil. The response surface indicates an optimum ridge in yield by increasing amount of catalyst but with decreasing amount of alcohol was near the experimental maximum, a significant reduction in yield was noted possibly due to potential reaction reversal. Temperature of 70 ^{o}C, reaction time of 75mins, amount of alcohol of 20ml (5.0:1 molar ratio of alcohol to oil) and amount of KOH of 0.81g (1.2% weight of oil) for transesterification reaction gave the optimum yield. It is recommended that optimization of transesterification reaction for the production of biodiesel should be extended to other inedible oils seeds so that attention will be shifted from edible oils to inedible oil seeds for the large scale production of biodiesel.

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FRICTIONAL PROPERTIES OF THE ROOTS OF THREE CASSAVA CULTIVARS

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ABSTRACT

Frictional properties of cassava are needed in the design and development of machines for postharvest operations of cassava roots. Most postharvest processing operations of cassava tubers are still being done manually. Efforts at mechanizing these operations have recorded modest success due largely to scarce publications on the engineering properties of cassava, frictional properties of cassava inclusive. This study was conducted to determine the coefficients of friction, internal friction and rolling resistance of two improved cassava cultivars; TMS 30572, and TME 419 and TME 7 (locally called Oko iyawo) at five moisture levels of 40 - 60% (wet basis) at 5% interval. The coefficients of friction and rolling resistance were determined on stainless steel, galvanized sheet and wood surfaces. The data were analyzed using ANOVA on SPSS 15. Mean coefficient of friction ranged from 0.20 - 0.28, 0.43 - 0.55 and 0.61 - 0.78 respectively on stainless steel, galvanized sheet and wood surfaces with positive linear relationship with moisture increase. A reverse trend was observed for coefficient of internal friction which ranged from 0.40 – 0.69 while the coefficient rolling resistance of the periderm, cortex and flesh of the tubers ranged from 0.14 - 0.15, 0.20 - 0.26 and 0.25 - 0.30; 0.10 - 0.13, 0.16 - 0.19 and 0.20 - 0.26, and 0.08 - 0.09; 0.12 - 0.1 and 0.15 - 0.19 on stainless, galvanized and wood respectively. Moisture content significantly influenced the coefficients of friction and internal friction while skin coverings of the roots significantly influenced the coefficient of rolling resistance of the roots. The study provided useful data essential for the design and development of effective cassava processing and handling machines.

***Keywords**: Coefficient of friction; coefficient of internal friction; coefficient rolling resistance; cortex; periderm.*

1. INTRODUCTION

Cassava is a tuberous root crop grown majorly in the tropical regions of the world such as Southern America, Sub-Sahara Africa, and Asia. Its drought tolerance and ability to thrive in marginal soils has been widely acknowledged (El-Sharkawy, 2006; Kolawole and Agbetoye, 2007; Uthman, 2011; Julianti *et al.*, 2011), and this endears it to most farmers. It is known globally as a cheap source of calorie in human diet and animal feeds especially in Africa where it accounts for 60% of root crops consumption. Currently, it is fast becoming a foreign exchange earner due to its new status as a major industrial raw material for the production of wide varieties of flour-based and starch-based products such as *Lafun* (fermented flour), *gari* (flakes), High Quality Cassava Flour (HQCF), alcohol for fuel, glue, starch etc. (Agbetoye, 2003; Kolawole *et al.*, 2010). Today, about 60% of cassava is used for industrial purposes while 40% is consumed by the households (Olusegun and Ajiboye, 2010). In Nigeria, a Federal Government directive on 10% cassava flour utilization in wheat-based baking flour has triggered a serious hike in demand for cassava.

Processing tubers into stable forms such as chips offer an alternative to storage (Raji, and Igbeka, 1994), from which other products can be produced. Also, the chips as an intermediate product can be used in the production of animal feeds, cassava flour and starch and starch-based products. Presently, large quantities of cassava chips are being ordered from Nigeria to Asian countries for industrial uses (Agbetoye, 2005). This increase in demand for cassava tubers and its products implies increased cassava production, processing and handling operations which consequently makes the mechanization of these processes imperative in order to remove the negative attributes of the traditional processing methods currently in use. Thus, cassava processing is very essential in order to reduce its perishability since it deteriorates within few days after harvest (Ngeve, 1995; Akintunde *et al.*, 2005). Mechanization of cassava processing operations will no doubt play a pivotal role in removing the drudgery associated with the traditional processing techniques and promote large scale production. Mechanization implies the design and development of efficient and cost effective machines and equipment for cassava postharvest processing and handling operations, the success of which solely depends on thorough understanding of the engineering properties of the roots such as the frictional properties among others. The importance of the frictional properties of fruits and vegetables against machine parts has been underscored as one of the main causes of mechanical injuries during handling (Singh *et al.*, 2004). Irtwange and Igbeka (2002) also emphasized the importance of the knowledge of the frictional properties of materials in the adequate design of theoretical performance of machines and mechanisms. Review of literature showed that sufficient data have been published on frictional properties of grains, fruits and seeds as a function of moisture content (Visvanathan *et al*., 1996; Suthar and Das, 1998; Simonyan *et al.*, 2008). However, this was found to be scanty for cassava roots. For instance, the published study on the frictional properties of cassava by Ejovo *et al.* (1988) was conducted with scanty number of samples (3 samples), one cassava variety of unspecified genotype and without considerations for the effects of moisture contents of the roots on the frictional properties being studied. Therefore, it is essential to study the frictional properties as a function of different factors such as moisture content and variety since cassava features are dependent on genotype (variety) and environmental conditions (Alves, 2002), hence, the aim of this study was to determine the coefficients of friction, internal friction and rolling resistance of three cassava varieties at five different moisture contents.

2. MATERIALS AND METHODS

The cassava cultivars used for the study were TMS 30572, TME 419 and TME 7 (*Oko iyawo*). *Oko iyawo* is a local cultivar popular among cassava farmers in the south western part of Nigeria while the first two were improved varieties, the stems of which were obtained from the International Institute for Tropical Agriculture (I.I.T.A), Ibadan, Nigeria.

2.1 Preparation of Samples

The samples used for the experiments were prepared from freshly harvested 12 months old roots obtained from Ladoke Akintola University of Technology, Ogbomoso Teaching and Research farm which was established purposely for this study. The tubers used for the determination of the coefficients of friction and internal friction were cleaned and carefully peeled and cut manually, into sizes of (30 x 20 x 10) mm using very sharp stainless steel knives (Chijindu *et al.*, 2008; Palaniswami *et al.*, 2008; Tunde-Akintunde and Afon, 2009). The initial moisture content of the samples was first determined with the use of an OHAUS MB 35 Halogen moisture analyzer. Thereafter, the samples were placed in a DHG 9101.1SA (UK) oven which had already attained a temperature of 50^oC for conditioning to the desired moisture content. They were brought out in batches after attaining the desired moisture contents of 40, 45, 50, 55, and 60% (wb) and placed in a dessicator for about an hour for moisture equilibration before being used for experimentation. The coefficient of rolling resistance was determined using 60 mm long roots cut out from the straight portions of the roots with the periderm, cortex and flesh of the tubers against stainless steel, galvanized sheet and wood surfaces.

2.2 Determination of Coefficient of Friction

The coefficient of friction of the chips was determined using the inclined plane with adjustable top. Cassava chips of size 30 x 20 x 10 mm (Chijindu *et al.*, 2008; Palaniswami *et al.*, 2008; Tunde-Akintunde and Afon, 2009) was placed on the table and tilted until sliding occurred. The angle at which this occurs was noted and recorded. The tangent of this angle gave the coefficient of friction of the chip. This experiment was replicated five times each on stainless steel, galvanized sheet and wood surfaces (in turns) and the values averaged.

2.3 Determination of Coefficient of Internal Friction of Cassava

The coefficient of internal friction of roots was determined using chip samples of size (30 x 20 x 10) mm. A big wooden frame of size (120 x 80 x 10) mm and a smaller guide block of size (90 x 60 x 10) mm were used in addition to a frictionless pulley, a chord and a scale pan. The big wooden frame and the guide block were filled with chip samples. The guide block was placed atop the bigger frame. A light chord attached to the smaller frame was passed over the frictionless pulley. The other end of the chord bored the scale pan. Weights were then added to the scale pan until sliding of the guide block (filled with cassava chips) occurred over the big frame (also filled with cassava chips). The weight (M_1) causing the sliding was noted and recorded. The guide block was then emptied and placed back on the bigger frame and the scale pan loaded until the empty guide block just started to move over the contents of the big frame. The weight (M_2) causing sliding of the empty frame was also noted. The coefficient of internal friction was then calculated at the above mention moisture contents using equation 1.

$$\mu = \frac{M_1 - M_2}{W} \quad (1)$$

Where,

$M_1 - M_2$ = Weight required to slide the sample material (g)

W = Weight due to the sample material in the cell = vol. of cell (cm^3) x bulk density of the samples (g/cm^3).

μ = Coefficient of internal friction

Five replicates of each experiment were produced at each moisture level.

2.4 Determination of Coefficient of Rolling Resistance

Root samples of length 60mm were carefully cut off from whole cassava roots and placed on an inclined plane with adjustable angle of inclination (tilting top). Care was taken to ensure that the samples were cut from the straight portions of the roots. The top of the table was then tilted with the specimen until the tuber just started rolling down the inclined plane. The angle at which this occurs was measured and recorded. This was done using the periderm, the cortex, and the tuber flesh in turns against stainless steel, galvanized sheet and wood surfaces. The coefficient of rolling resistance was then calculated using equation (2).

$$\mu = R \tan \theta \qquad (2)$$

Where,

R = Average radius of the tuber

θ = Angle of inclination at which tuber just started rolling down the plane

Each experiment was replicated five times for each variety of cassava.

Statistical analysis was carried out to study the effects of moisture content on the engineering properties of the cassava cultivars studied using SPSS 15 software. Analyses of Variance of the mean values of the engineering properties studied were carried out to determine the level of significance of the differences in the measured parameters

3. RESULTS AND DISCUSSION

3.1 Coefficient of Friction

The mean coefficient of friction (COF) of TMS 30572, TME 419 and *Oko-iyawo* cultivars used in this study are presented in Table 1. The coefficient of friction of the samples ranged from 0.20 to 0.28; 0.42 to 0.55 and 0.61 to 0.78 on stainless steel, galvanized sheet and surfaces respectively for the three cassava cultivars at different moisture content levels (MC)

Table 1: Mean Coefficient of Friction of different Cassava Cultivars

SURFACE	MC	TMS 30572	TME 419	*OKO IYAWO*
	40	0.20	0.21	0.21
Stainless	**45**	0.21	0.22	0.22
Steel	**50**	0.23	0.24	0.23
	55	0.26	0.26	0.24
	60	0.27	0.28	0.28
	40	0.44	0.43	0.43
Galvanized	**45**	0.45	0.45	0.47
Sheet	**50**	0.46	0.49	0.49
	55	0.52	0.52	0.53
	60	0.53	0.53	0.55
	40	0.61	0.61	0.61
Wood	**45**	0.67	0.63	0.62
	50	0.69	0.69	0.67
	55	0.74	0.73	0.75
	60	0.76	0.75	0.78

Generally, the coefficient of friction of the roots increased with increase in MC moisture content on all the three surfaces (Figures 1- 3). This may be due to the fact that the moisture made the starchy surface of the samples to become stickier thereby increasing the force of adhesion between the surface of the samples and that of the stainless steel as the moisture content of the samples was increased. Expectedly, the coefficient of friction of the samples was lowest, within the moisture content studied, on the stainless steel surface and highest on wood due to the difference in the degree of roughness of the three surfaces used in the study, stainless steel surface being smoother than the other two surfaces. Table 1 also shows that the TME 419 cassava variety shares the same coefficient of friction with TME 7 (*Oko iyawo*) at low moisture contents (40 – 45%) while it exhibited the same trend with TMS 30572 at high moisture content (55 – 60%) on stainless steel. A closer look at the values of the coefficient of friction of the three cassava varieties shows that they are very close, which suggest that the value of COF for one of them can be used for the other.

However, the values of COF obtained for the root flesh in this study are slightly higher especially on galvanized sheet and wood when compared with the results (0.364 and 0.404) reported by Ejovo *et al.* (1988) for mild steel and wood. This may be due to the difference in the ages of the cassava roots used in the two studies. The result obtained in this study for the coefficient of friction of cassava on stainless steel surface were, however, slightly within the range of value (0.213) reported by Ejovo *et al.*1988 for coefficient of friction of cassava flesh on aluminum.

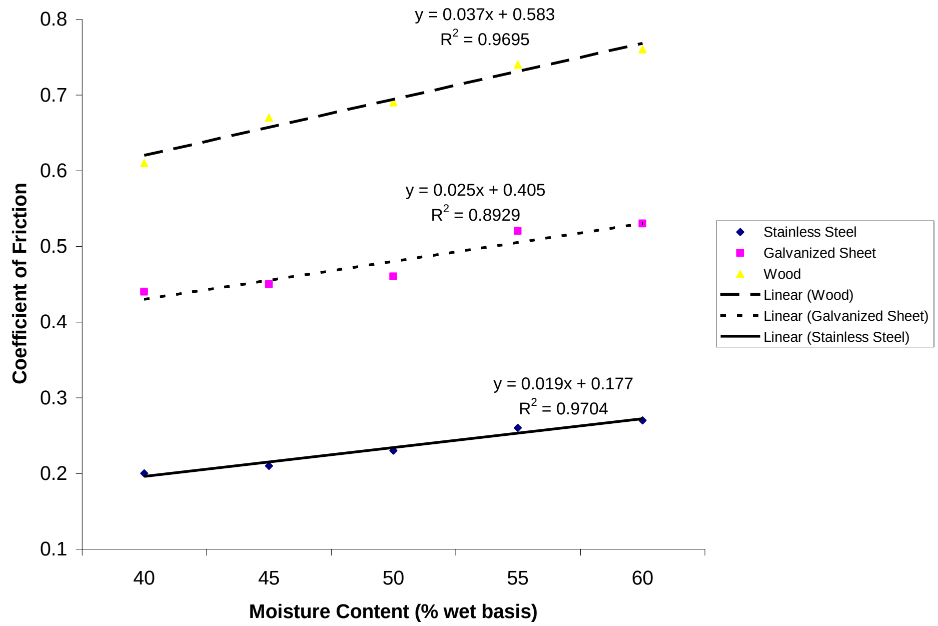

Figure 1: Coefficient of Friction of TMS 30572 Cassava Cultivar

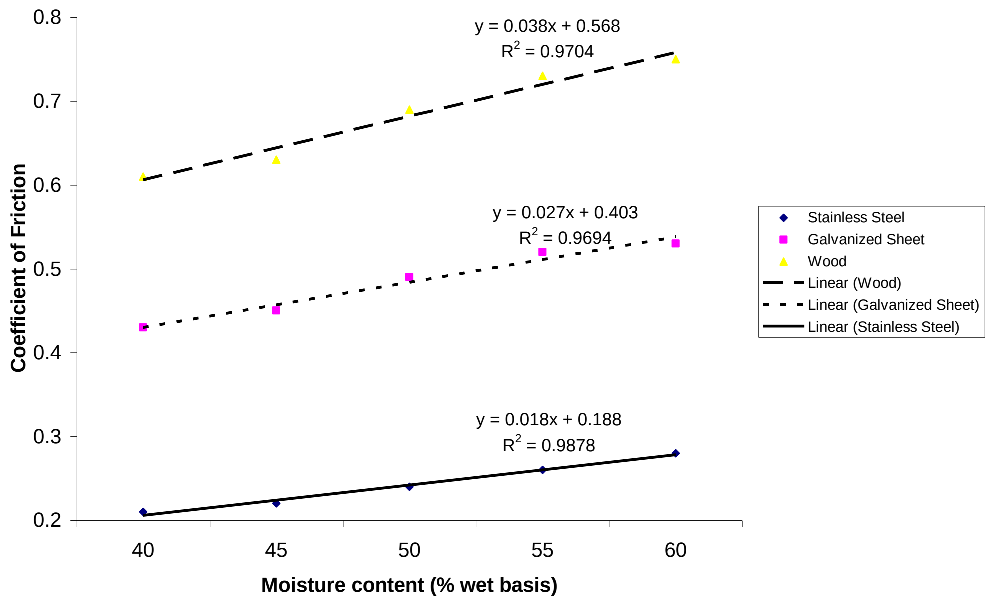

Figure 2 : Coefficient of Friction of TME 419 Cassava Cultivar

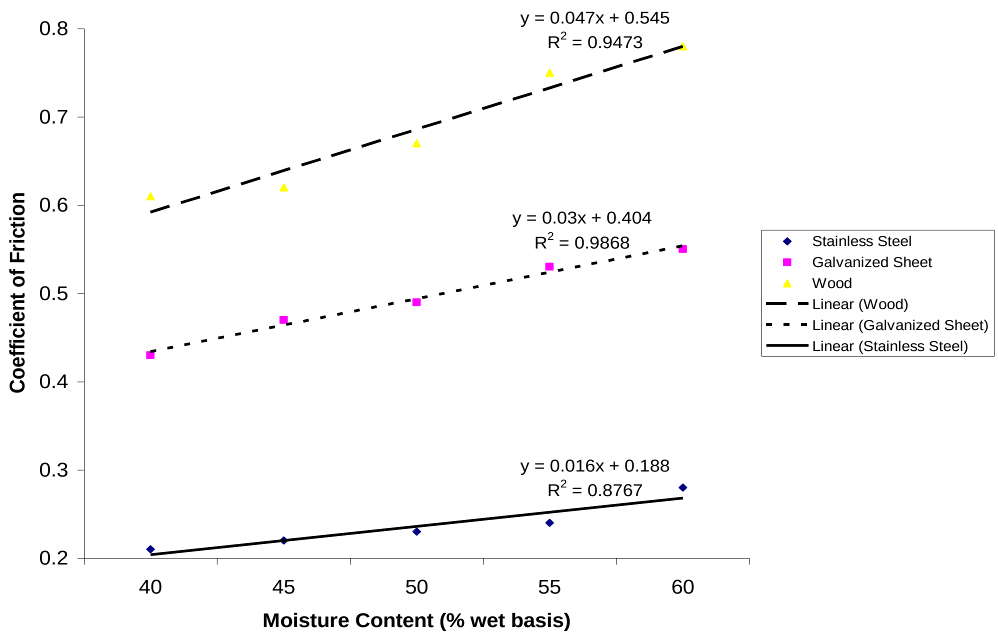

Figure 3: Coefficient of Friction of TME 7 Cassava Cultivar

The coefficient of friction of the cassava samples on galvanized sheet were also very close, with that of TME 7 being the highest within the moisture content studied and those of the improved cassava varieties being almost the same. Also, at moisture contents between 40 and 50% (wet basis) samples of the local cassava variety generally had the least COF while the two improved varieties had the highest (Table 1). A reverse trend was however observed when the moisture content was raised beyond 50% with samples of TME 419 exhibiting the least COF on wood. Results of the ANOVA showed that the influence of moisture content of the samples on their coefficients of friction on the three structural surfaces was very significant ($P < 0.05$) except that of TME 419 on wood.

3.2 Coefficient of Internal Friction

Results of the coefficient of internal friction (CIF) of the cassava samples are presented in Table 2. It ranged from 0.44 to 0.57; 0.58 to 0.69 and 0.40 to 0.58 for samples of TMS 30572, TME 419 and *Oko iyawo* varieties respectively at different Moisture content levels (MC).

Table 2: Mean Coefficient of Internal Friction of different Cassava cultivars

MC	TMS 30572	TME 419	*Oko Iyawo*
40	0.57	0.69	0.58
45	0.56	0.68	0.57
50	0.56	0.63	0.54
55	0.46	0.60	0.41
60	0.44	0.58	0.40

It was observed that the CIF reduced with increase in moisture content of the samples (Figure 4) with TME 419 exhibiting the highest CIF within the moisture content studied while

TMS 30572 and TME 7 had the least at moisture contents below and above 50% respectively. A linear negative relationship exists between the CIF and moisture content as shown in Figure 4, with the R^2 values of the CIF graphs ranging between 0.9657 and 0.8266. The negative linear relationship may be due to strong influence of the ability of moisture to reduce the friction between two surfaces over and above the influence of the cohesive force between the surfaces of the cassava samples, hence, as the moisture content increased the friction between the surfaces of the cassava samples decreased. Result of analysis of variance showed that the influence of moisture content was significant on the coefficient of internal friction of samples of all the three cassava varieties studied.

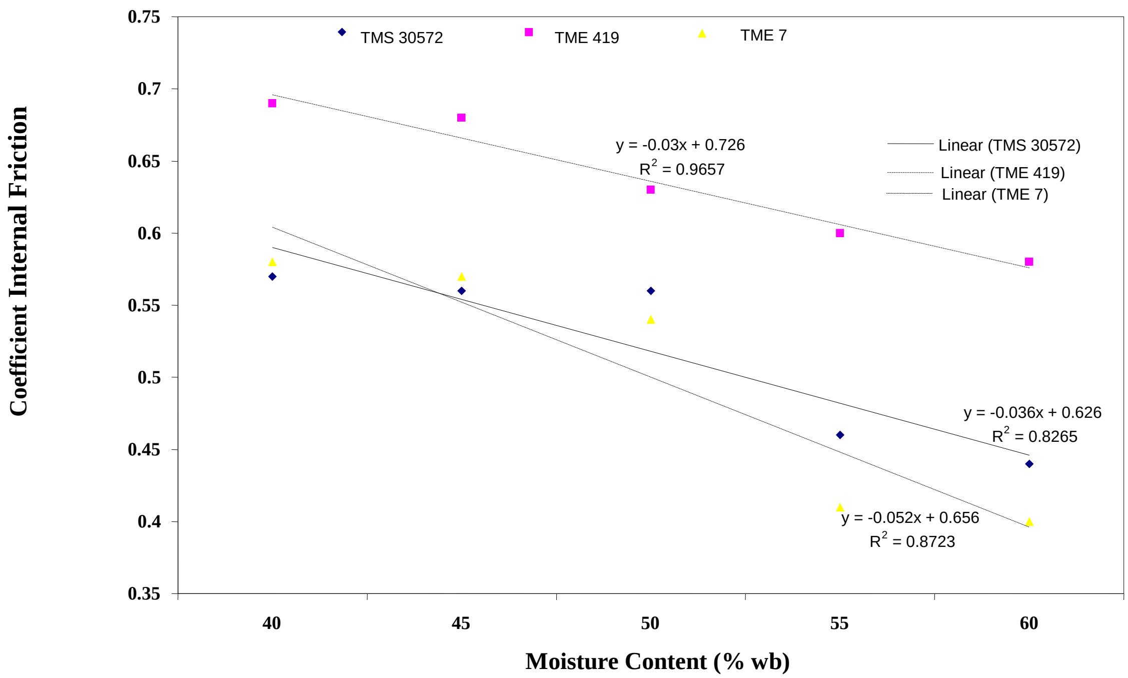

Fig 4: Coefficient of Internal Friction of Cassava

3.3 Coefficient of Rolling Resistance

Mean coefficient of rolling resistance (CRR) of the three cassava cultivars using the periderm, cortex, and flesh of the tuber against stainless steel, galvanized sheet and wood surfaces are presented in Table 3. As expected, the coefficient of rolling resistance of the cassava roots was generally lower on stainless steel and highest on wood. Also, the periderm gave the highest coefficient of rolling resistance on all the surfaces while the tuber flesh gave the least.

Table 3: Average Coefficient of Rolling Resistance of different Cassava Cultivars on Different Surfaces

	TMS 30572			TME 419			*OKO IYAWO*		
Covering	Stainless	Galvanized	Wood	Stainless	Galvanized	Wood	Stainless	Galvanized	Wood
Periderm	0.14	0.22	0.25	0.14	0.20	0.25	0.15	0.26	0.30
Cortex	0.10	0.16	0.20	0.12	0.18	0.20	0.13	0.19	0.26
Flesh	0.08	0.12	0.15	0.09	0.13	0.17	0.08	0.14	0.19

This is due to the fact that the periderm of the roots was the least smooth compared to the cortex and flesh. The roots of TME 7 cultivar exhibited the highest coefficient of rolling resistance on all the surfaces irrespective of the root covering (periderm, cortex or wood) used. The influence of tuber skin coverings was significant on the coefficient of rolling resistance of the roots irrespective of the surface used.

4. CONCLUSIONS

The values of coefficient of friction of cassava were generally higher than those of the coefficient of rolling resistance on the three surfaces used for the study. Coefficient of friction of the three cassava cultivars on stainless steel surface were very close within the moisture content and age studied thereby suggesting that the values of one variety may be used for the other but it increased with increase in moisture content. TME 419 had the highest Coefficient of internal friction and exhibited negative relationship with moisture content like the two other cultivars. The coefficient of rolling resistance of the roots of TME 7 was generally higher than those of the roots of the improved varieties. Moisture content significantly influenced the coefficients of friction and internal friction of all the cassava cultivar while root coverings influenced the coefficient of rolling resistance. The study provided useful data essential for the design and development of effective cassava processing and handling machines.

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DESIGN AND DEVELOPMENT OF A HYBRID SOLAR-ELECTRIC DRYER FOR SLICED VEGETABLE CROPS

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Abstract

A hybrid cabinet dryer was designed and developed to reduce vegetable waste and improve their storage conditions. The dryer consists of three main units: drying chamber, heating unit and control unit. Design calculations were made based on some basic engineering assumptions, considerations and principles of heat and mass transfer. The dryer has a batch capacity of 25kg of fresh sliced vegetables per day. A no-load test was conducted to evaluate the thermal profile of the dryer, which involved running the dryer at five different air velocities (0.1, 0.5, 1.0, 1.5, and 2.0m/s) in order to determine the required time to reach the preset optimum drying temperatures (50, 55, 60, 65, 70^{o}C) for the selected sliced vegetable crops (okra, tomato, and pepper). Results obtained indicate that an average minimum dryer heat-up time of 5.2 minutes was required by the hybrid dryer at a temperature and air velocity of 70^{o}C and 2m/s respectively. Drying temperature and air velocity were observed to have significant influence on the dryer heat-up time and dryer tray temperatures. The performance of the dryer was attributed to the heat contribution of the solar collector which is affected by the hourly solar radiation and ambient air relative humidity as well as the heat contribution of the electric heater, making the dryer a hybrid. The hybrid energy regression equation model was developed in terms of drying time. These results were obtained for no-load condition of the designed dryer. Good prospects for future applications as well as recommendations were stated.

Keywords: *drying, vegetables, hybrid dryer, solar heat, electric heat.*

1.0 Introduction

Farmers in Nigeria have been producing large quantities of fresh agricultural output with high moisture contents which are lost annually due to decomposition by micro-organisms (Nwakuba, 2011). This results in reduction of the net agricultural output and subsequent reduction in the gross domestic product (GDP) of the nation. This is a serious concern for an agricultural country like Nigeria where approximately 91% of the rural dwellers are dependent on subsistent farming for their livelihood. Several factors contribute to this postharvest losses and some of the technological factors include faulty harvesting and handling practices, poor packing and transport systems, lack of storage facilities and poor processing techniques (Nwajinka and Onuegbu, 2014) including drying.

Drying is a major method of preserving agricultural food products especially in developing countries like Nigeria (Nwakuba *et al.,* 2016). It involves the removal of moisture present in agricultural products like vegetables to a certain limit at which all metabolic activities are hindered (Mujumdar, 2000; Montero, 2005; Montero *et al.,* 2010; Okoroigwe *et al.,* 2013; Idah *et al.,* 2014). The basic essence of drying is to reduce the amount of moisture contained in the product to a level that prevents deterioration after harvest (Mujumdar, 2000; Antwi, 2007; Okoroigwe *et al.,* 2013; Nwajinka and Onuegbu, 2014). Longer shelf-life, product diversity and substantial volume reduction are the reasons for the popularity of dried agricultural produce, including improvements in product quality, preservation of nutritive values, reduction in costs of packaging, storing, transportation and process applications (Antwi, 2007; Idah *et al.,* 2014). Such improvements could lead to an increase in the current acceptance of dehydrated foods in the market (EL-Mesery and Mwithiga, 2012).The most common method of dehydration is by open-air sun drying but this often results in food contamination, insect and bacteria infestation, nutritional deterioration, heat stress, loss of flavour, colour, taste, case-hardening, due to wetting by rain squalls (Ratti and Mujumdar, 1997; Ehiem *et al.,* 2009; Nwajinka and Onuegbu, 2014). In order to protect the products from these mentioned disadvantages and also to accelerate the time for drying, moisture reduction and hence wastage through bacterial action, different types of solar dryers have been developed. Nwajinka and Onuegbu (2014) observed that shortages of oil and natural gas, and increase in the cost and depletion of fossil fuels have stimulated efforts in the development of solar energy as a practical power source. This power source was harnessed for heating, cooling, drying, irrigation pumping, and numerous other thermal processes in food industries (Oje and Osunde, 1995; Itodo *et al.*, 2002; Madhlopa *et al.*, 2002).

Vegetables are seasonal crops characterized by their rich vitamins, high moisture (usually above 70% wet basis) and low fats contents especially at harvest. This makes its drying a highly energy intensive operation; and for this reason, large amount of energy is needed to bring down the high moisture content to a safe storage level (usually 5 – 15%) at a temperature range of 35 – 65^{o}C (Mu'azu *et al.*, 2012; Idah *et al.,* 2014). In Nigeria alone, up to 50% of fruit vegetable harvested get spoilt annually (Musa-Makama, 2006) causing seasonal shortage and fluctuations in supply and prices. Vegetables can be successfully preserved through drying by reducing their moisture content. Drying of vegetables however, is facilitated by slicing and spreading out the product to increase their surface area to hot convective air; using a reliable heat source; increasing the airflow around the product; insulating the areas that are not exposed to the same heat source to avoid heat loss; avoiding direct heating since it affects the quality and appearance of the product; and protecting the dried products against contamination, reabsorption of moisture from the environment and harmful effects of sunlight such as undermining of sensory qualities of vegetables, increased ambient air temperature etc. The process of indirect heating is achieved by heating of air in a separate solar collector and circulating same through the drying racks where it picks moisture from the crop. Owing to intermittent solar radiation throughout the day, continuous drying of agricultural products can be accomplished through a combination of solar and non-solar heating sources in a mixed mode system with biomass or electricity (Prasad and Vijay, 2005; Prasad et al., 2006). This informs the design of a hybrid dryer.

Many dryers have been developed and used to dry vegetable crops in order to improve their storage conditions using different sources of energy such as electricity, solar, liquefied petroleum gas, biomass *etc.* or a combination of solar energy and other forms of energy. The most common dryers for vegetables are continuous tunnel dryers, vacuum dryers, microwave, heat pump and solar dryers (Huber and Menners, 1996; Nwakuba et al., 2016). This wide range is as a result of different physical forms of the vegetables to be dried, desired rate of drying and quality constraints of the dried products.

In the development of solar hybrid dryers in Nigeria, Komolafe and Osunde (2005) evaluated the performance of a hybrid convective solar dryer for drying vegetables. Similarly, Oparaku *et al.* (2003) evaluated a solar cabinet dryer with auxiliary heater. Some researchers like Minka (1986), Mulhlbauer *et al.* (1996) and Berinyuy (2000) have outlined some of the major technical bottlenecks confronting the development of this dryer technology in Nigeria, which include poor design and construction of the dryers, lack of data on the effects of the various design parameters on the behaviour of the dryers, little or no mathematical modeling and poor choice of materials for construction. This has necessitated a search for suitable and efficient dryers based on local technology rather than importing dryers not suited for Nigerian conditions. Based on this, it is necessary to design and develop a hybrid vegetable dryer operating either on electricity, fossil fuel or wood/ charcoal biomass in conjunction with solar flux using local weather parameters in order to enhance the drying potential of the dryer, given the moisture-laden nature of most vegetables such as tomato, okra, onion, pepper, carrot, eggplant, *etc.* by reducing the relative humidity so as to dry the crops more efficiently. This work has the specific objective of designing and developing a hybrid crop dryer using solar heat and electricity to produce hot air for sliced vegetable drying.

2.0 Materials and Methods

2.1 Design assumptions and considerations

The following assumptions were made in order to obtain the macroscopic scale governing equations for the dryer design:

i. Air density is constant = 1.2922kg/m^3 and its velocity distribution in the dryer is uniform.
ii. Drying is considered in thin layers for the sample crops.
iii. All the crops samples are considered homogenous, which are characterized by its superficial temperature taken to be constant across the thin layers.
iv. Shrinkages of the product samples during drying process is neglected and the products can be estimated to a thin layer of water.
v. The phenomenon of water condensation on the inner walls of the drying chamber is neglected and so is the radiative transfer phenomenon inside and outside the drying chamber.
vi. Hot air is provided by two sources; the solar module and the electric heating unit, and the drying chamber is assumed to be water proof and heat losses minimal except through the air vent/chimney.
vii. Daily maximum period of drying is taken as 8 hours (i.e. between 9:00am to 5:00pm) daily, assuming no rainfall, when the solar radiation flux is optimal.

The design considers an active hybrid convective crop dryer with integral and distributed modes with outlet. It emphasizes the drying air temperature and control, air velocity, energy requirement for drying and other drying parameters such as drying rate, drying time, and drying efficiency. The following considerations were made:

i. Initial and desired final moisture contents and allowable drying temperature for the selected crop samples (okra, tomato, and pepper) are 88.7%, 10 - 15%wb, 65^{o}C; 96%wb, 5%wb, 60^{o}C; and 87%, 10%, 55^{o}Crespectively(Tiwari, 2012), as well as the specific heat capacities of the crops, which are1.85, 3.68, and 1.97kJkg^{-o}C respectively (Eke, 2014; Ekpunobi et al., 2014).

ii. Crop sample slice thicknesses of 10, 15, 20, 25, and 30mm at different drying air temperatures of 50, 55, 60, 65 and 70^{o}C, and airflow rates of 0.1, 0.5, 1.0, 1.5, and 2.0m/s would be used.

iii. The average ambient environmental conditions of Federal University of Technology (F.U.T.), Owerri between April and November is 29.6^{o}C and 77.7% for temperature and humidity respectively; total amount of solar flux available is1.02kWm^{-2} and the solar tilt angle, $\beta = 15.4^{o}$.

iv. Amount of moisture to be removed from a batch of crop sample and the amount of heat generated from each heat source for optimum drying of a given batch quantity should be about 83.1%, 94.8%, and 88.5% of any given mass of okra, tomato and pepper respectively.

v. The energy required for the drying operation should be generated from a clean naturally renewable source (such as the sun), and supplemented with a clean source of heat like electricity for further drying during inclement weather.

vi. The heat units should be sizeable enough to be able to generate the required enthalpy for drying each crop sample.

vii. The solar collector should be oriented with respect to the local latitude of Federal University of Technology (F.U.T.), Owerri, Nigeria (5.4^{o}N).

viii. The entire system is mounted on a roller rectangular base angle-iron frame for easy movement.

ix. Considerations are also made on the availability, quality, and cost of the prospective construction materials.

x. The hybrid crops dryer should be designed based on the initial and final desired moisture content of tomato, given its most moisture-laden nature when compared to the other two samples (okra and pepper).

2.2 Basic design calculations

(a) Batch capacity

There is a choice of batch capacity since the dryer is a prototype and drying is done in racks. The rack dimensions are taken based on the chamber size (400mm x 400mm x 500mm). The batch capacity varies based on the available drying space and quantity of crop produced by a farmer. An average Nigerian subsistent farmer dries between 2kg and 15kg of sliced okra and tomatoes per batch per day with open-air sun drying (Eke, 2003). Using this as a basis to develop the batch capacity of the hybrid dryer, a maximum of 25kg, 30mm thick sliced crop (sample with an average diameter of 3.5cm) arranged in single layers on drying racks is chosen.

(b) Drying chamber volume and tray size

The volume of the drying chamber V_C is expressed as equation (1):

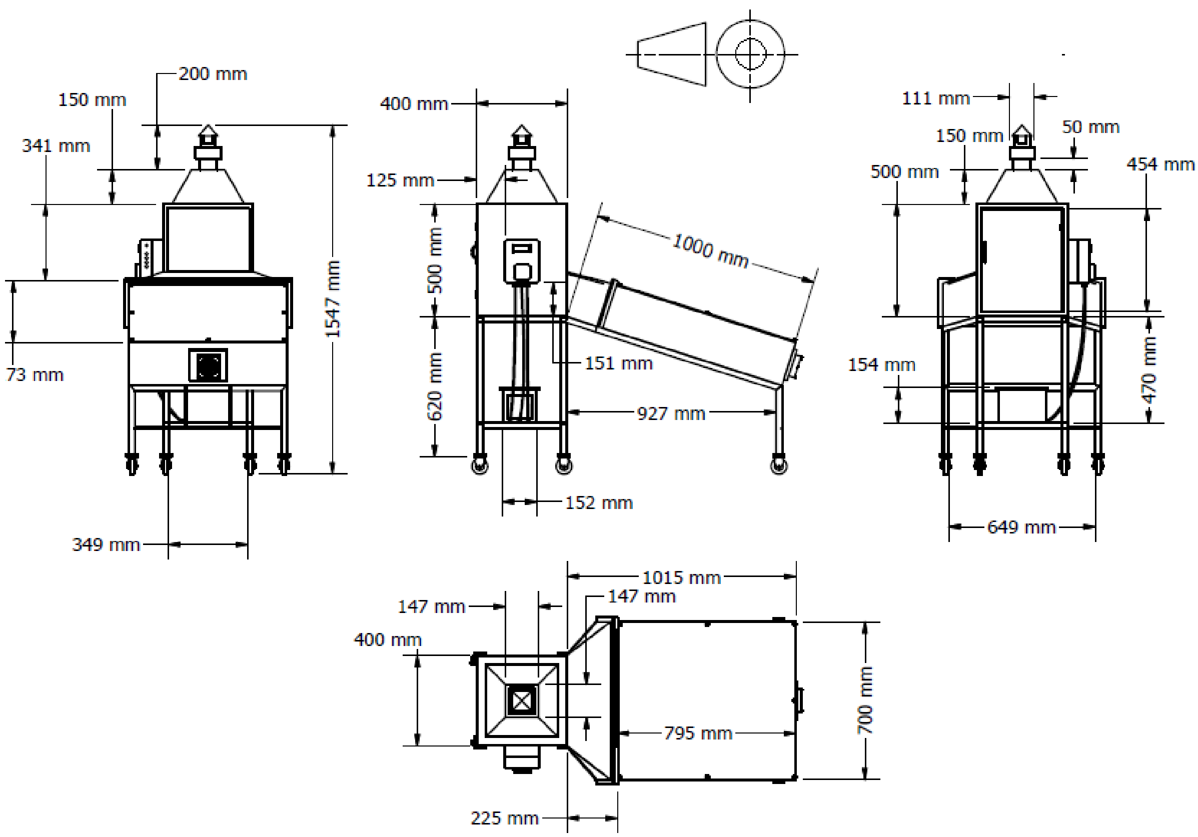
$$\mathbf{V_C = L.W.H} \qquad \mathbf{1}$$

Where: L = length of chamber (cm); W = width (cm); H = height (cm).

Since the average diameter of fresh sliced tomato with circular cross-section (most moisture-laden crop sample) is 3.5cm and drying is done in thin layers, a maximum of 125 sliced samples can be dried per batch per tray. Thus, tray length, L_T is given as:

$$L_T = \frac{125}{3.5} = 35.7\text{cm}$$

Hence, two square trays were selected with dimensions, 39cm x 39cm. one is placed 15cm from the base of the drying chamber while the other is 15cm from the chimney hood. Hence the, drying chamber dimension becomes: 40cm x 40cm x 50cm as shown in Figure 1.



(c) Amount of moisture to be removed (M_R)

The amount of moisture to be removed from the sliced sample, M_R is estimated from equation (2) as:

$$\mathbf{M_R = M_i \frac{(Q_1 - Q_2)}{1 - Q_2}} \qquad \text{(Ehiem } et\ al.\text{, 2009)} \qquad \mathbf{2}$$

Where: M_i = initial mass of wet sliced sample to be dried (25kg); Q_1 = initial moisture content of sample crop (% wet basis); Q_2 = desired final moisture content (%wb).

Using equation (2), the following quantities of moisture would be removed from a batch of 25kg of sliced samples for optimum storage:

Therefore, the amount of moisture to be removed (M_R) from okra, tomato and pepper becomes: M_{Rokra} = 21.86kg, $M_{Rtomato}$ =23.95kg, and $M_{Rpepper}$ = 21.39kg given their Q_1 and Q_2 as 88.7%, 15%; 95%, 5%; and 87%, 10% respectively (Tiwari, 2012).

(d) Quantity of air required for drying (Q_a) per batch

The quantity of air needed for moisture absorption in a given batch is estimated as in equation (3):

$$\mathbf{Q_a} = \frac{\mathbf{M_R} H_L}{\mathbf{C_a \rho_a (T_{f-} T_i)}} \quad \text{(Ehiem et al., 2009; Nwajinka and Onuegbu, 2014)} \qquad 3$$

Where: M_R = Amount of moisture to be removed (kg); H_L = latent heat of vaporization (2499.94kJ/kg); C_a = specific heat capacity of crop sample (kJ/kg^{o}c); ρ_a = density of drying air (1.2922kg/m^3); T_i and T_f = 29.6 and 65 = initial and final temperatures of the drying air before passing through the drying bed respectively (^{o}C).

The latent heat of vaporization at 65^{o}C for the highest drying temperature is given by Eke (2014) as equation (4):

$$\mathbf{H_L = 2,502,535.259 - 2,385.76424\ (T_d - 273.16)} \qquad 4$$

Where: T_d = drying air temperature = 65^{o}C; H_L = 2499.94kJ/kg; C_a for tomato = 3.68kJ/kg^{o}C; $M_{Rtomato}$ = 23.95kg.Therefore, Qa = 355.68m^3 of air.

Note: This hybrid crop dryer is designed based on the optimum drying temperature of fresh tomato (65^{o}C) - the most moisture-laden sample.

Assuming a maximum drying time of 24 hours per batch of sliced tomato sample of maximum diameter = 3.5cm, the drying rate which is the loss of moisture from the wet sample per unit time can be estimated according to Amer (1999), Nwakuba (2011), Usman and Idakwo (2011) as equation (5):

$$\boldsymbol{DR = \frac{W}{A}\left(-\frac{dx}{d\theta}\right)} \qquad 5$$

Where: DR = drying rate kg/hr.); W = weight dry sample (kg); A = surface area of sample exposed (cm^2); $-\frac{dx}{d\theta}$ = difference of humidity with regard to time. It is the differential quotient operating in constant drying condition when air conditions (temperature, humidity and velocity) are constant along time.

(e) Amount of energy required to heat drying air (H_D)

The amount of energy required to heat this volume of air to the chosen drying temperature in order to remove any given amount of water in the crop samples is given by Ehiem et al. (2009) as equation (6):

$$\mathbf{H_D = (M.H_K) + (H_L.M_R)} \qquad 6$$

Where H_K is given in equation (7).

$$\mathbf{H_K = C_T(T_2 - T_1)} \qquad \mathbf{7}$$

Where: M = Batch size (dryer capacity) = 25kg; H_L = Latent heat of vaporization at 65^0C = 2499.94kJ/kg; M_R = amount of moisture removed = 23.95kg; C_T = specific heat capacity of tomato = 3.68kJ/Kg^{o}C; $T_2 - T_1$ = (65 – 29.6); and H_K = 130.27kJ.

Therefore, theoretical amount of energy required for the drying process,

H_D = 63,131.06kJ = 17.54kW.

(f) Heat generated from electric heater (Q_E)

The maximum quantity of heat produced by the resistance wire per hour is given by equation (8) as:

$$Q_E = IVT \qquad \text{(Gustafon et al., 2004)} \qquad \mathbf{8}$$

Where: I = current (Amps); V = applied voltage (220Volts); T = time (hrs.); Power rating of the heater, P = 2000W.

From (8), I = 4.6Amps, Q_{Emax} = 1.012kW-hr ≡ 3.64MJ = 224.7kW.

(g) Solar collector tilt angle

For maximum solar energy received by the flat plate collector, the inclination angle of the collector to the horizontal was determined using equation (9).

$$\boldsymbol{\beta = 10 + \text{lat}\,\emptyset} \qquad \text{(Gbaha et al., 2007; Nwajinka and Onuegbu, 2014)} \qquad \mathbf{9}$$

Where: β = angle of tilt of the solar collector, degrees
$\emptyset$ = Latitude of collector location, the latitude of F.U.T, Owerri where the dryer was designed is 5.4^{o}N.

Therefore, β = 10 + 5.4 = 15.4^o

(h) Solar Collector Area (A_c)

The area of the solar collector is calculated using the expression given in equation (10):

$$\boldsymbol{A_c = \frac{Q}{F_R T_{\infty\emptyset} I_H}} \qquad \text{(Komolafe and Osunde, 2005)} \qquad \mathbf{10}$$

Where: F_R = Collector heat removal factor = 0.7; I_H = average solar radiation incident on the collector = 1.02kW/m^2 (Kate, 2011); Q = collector useful heat(kW); $T_{\infty\emptyset}$ = effective transmittance-absorbance of glass = 0.79.

But the collector useful heat gain, Q required to dry a given batch of sliced crop samples is calculated using the expression given in equation (11):

$$Q = [C_P W_P (T_C - T_a) + L_V . M_R] \quad 11$$

Where: Cp = Crop specific heat capacity (3.68KJ/Kg^{o}c); Wp= initial weight of sample before drying (25kg); Lv= latent heat of evaporation (2499.94kJ/kg).

Therefore, Q = 63, 130.36kJ ≡ 17.54kW.

Substituting for Q into equation (11) above, Area of the solar collector, Ac= 0.7m^2 ≡ (100 x 70) cm^2.

With a minimum drying time of 15hrs from 8am to 10pm (using the electrical heat) for sliced tomato in the hybrid dryer (Abano et al., 2013; Eke, 2003), the mass flow rate of air through the solar collector to the drying bed is calculated thus as in equation (12):

$$M_a = \frac{I_H A_C \eta_C}{C_{pa} \Delta T} \quad 12$$

Where: C_{pa}= specific heat capacity of air (1.0kJ/kgK); ∆T = temperature difference: (65 – 29.6) ^{o}C; η_c = efficiency of the hybrid system computed as 78.5%.

The mass flow rate M_a = 1.58kg/sec.

(j) Thermal efficiency of heat source, η_{th}

Thermal efficiency is the ratio of the heat used to effect drying to the total heat supplied by the heat source. It is expressed as equation (13):

$$\eta_{th} = \frac{\text{Heat actually used}}{\text{Total heat supplied}} \text{ X } 100 \quad 13$$

For electrical heater and solar collector, this efficiency is given in equations (14) and (15) (Eke, 2014):

$$\eta_{eh} = \frac{H_D}{224.7\text{kW}} \text{ X } 100 \quad 14$$

$$\eta_{sc} = \frac{M_R L_V}{A_C T_t I_H T_r} X\ 100 \quad 15$$

Where: A_C = Area of solar collector (m^2); T_r = transmissivity of glass (0.79); T_t = theoretical drying time (15hrs.).

The specific energy consumption SEC is computed as given in equation (16):

$$\text{SEC} = \frac{\text{Total hybrid energy}}{\text{Mass of water removed during drying}} \quad 16$$

(k) Dryer insulation thickness, T_d

To maximize the energy of the solar collector unit, the base of the collector box was insulated with fibre glass (40mm thickness) while the heating and drying chambers were insulated with refractory material (kaolin – 25.4mm thickness) in order to minimize heat loss. The minimum thickness of insulation was determined by the expression given by (Papade and Boda, 2014) as equation (17):

$$\mathbf{T_d = \frac{kA_C}{F_R M_a C_{pa}}} \qquad \mathbf{17}$$

Where: K = thermal conductivity of insulation of fibre glass and kaolin (0.04W/m^{o}C and 0.023 – 2.9W/m^{o}C respectively); M_a = mass flow rate of air (kg/s); other parameters are earlier defined.

(l) Fan selection

The fan serves the purpose of transferring heated air from the heating unit to the dryer cabinet as well as expelling the exhaust air from the drying chamber to improve the drying rate. The selection was based on the characteristics of centrifugal fan performance curve based on the recommendation of Henderson and Perry (1976) reported in Ehiem *et al.* (2009) as equation (18):

Fan power, $h\mathbf{p_2} = \mathbf{hp_1}\,(\frac{\mathbf{N_2}}{\mathbf{N_1}})^{\mathbf{3}}$ **18**

Where: N_1 and N_2 = rpm of electric motor and fan respectively, and their relationship given in equation (19).

And, $\mathbf{N_2 = N_1 \left[\frac{q_1{}^{1/2}}{H_1{}^{3/4}}\right]\left[\frac{H_2{}^{3/4}}{q_2{}^{1/2}}\right]}$ Ehiem et al. (2009) **19**

Where: q = volumetric flow rate of air (m^3/hr); H = static pressure (Pa). From fan chart in Henderson and Perry (1976), N_i = motor speed =1000rpm, q_1 = 225.99m^3/hr, q_2 = 195.54 m^3/hr. (calculated volumetric air flow rate), H_1 = 1.41, H_2 = 1.09 (tabulated); Then, fan speed, N_2 = 886.5rpm; hp_1 = 2.28 (from chart); hp_2 = 1.74. This means that an electric motor horsepower of 2hp can be used.

However, Okafor, O. (personal communication, February 5, 2016) recommended that a DC, 12V fan of 3 – 7Watts capacity can be used in a crop dryer for thin layer drying. Therefore, two 4W, 12V DC fans were selected for use in the inlet and exhaust points of the hybrid dryer.

2.3 Description of the hybrid sliced vegetable crop dryer

The hybrid vegetable dryer consists of two major integral components (see Figure 2) namely: the air heater unit (solar collector) and the dying chamber having two layers of drying racks made of wire mesh on which the sliced crops are placed for drying. Other components of the dryer system include: solar panel (80W, 12V), DC battery (75Amps, 12V), control unit, liquid crystal display (LCD), inverter system, inlet and exhaust fans, plain glass (4mm thick), temperature and relative humidity sensors (LM-35 transducers), weighing balances, weight sensors, heating element, frame support, and rollers.

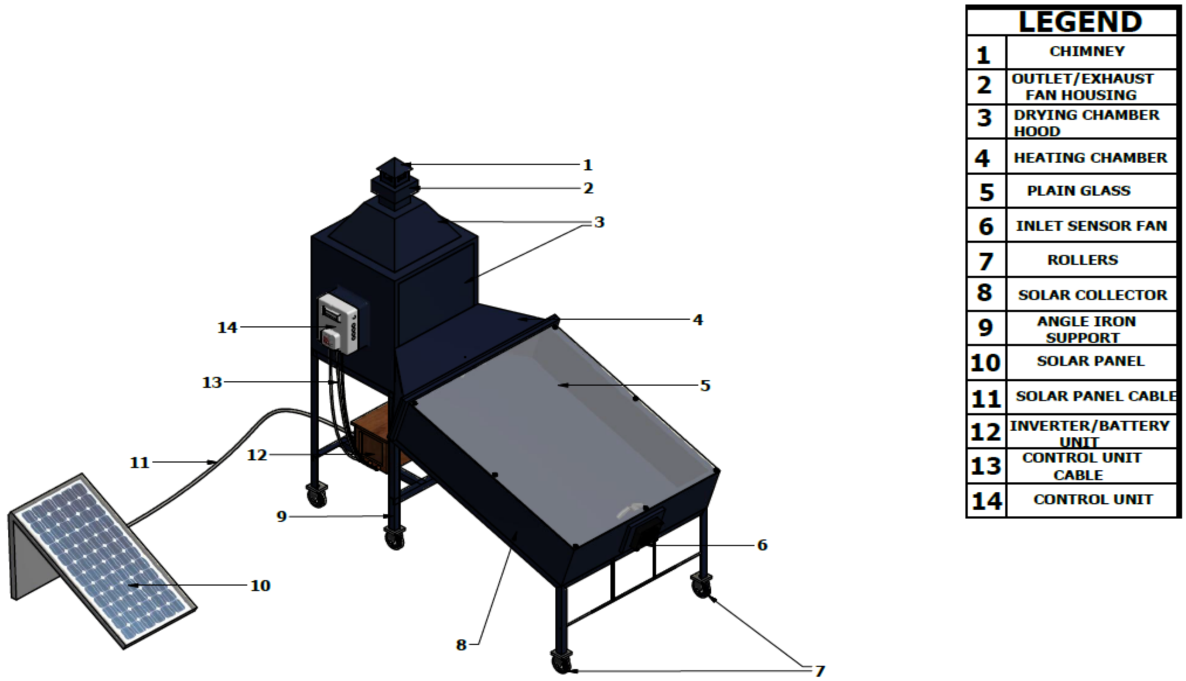


Figure 2: Isometric view of the hybrid sliced vegetable crop dryer.

The heart of the dryer comprises an Arduino microprocessor which controls the overall operation of the system and automates tasks such as temperature and humidity control, sample weight loss, and electrical energy consumption (from AC and DC sources). The system also contains a main heating element powered by alternating current (AC) from the Public Power Supply or an electricity generating set. Transducers (for recording both temperature and relative humidity) are placed at five strategic points on the hybrid dryer namely: chimney, two drying racks, solar collector, and inlet fan, where measurements are taken automatically by the microprocessor unit and displayed on the LCD as shown in Figure 3 (Legend S/N 1).

Different drying temperatures and air speeds can be selected by the use of keypad panel for input and LCD for displaying the current state of the system. In the drying chamber, the drying racks are suspended rigidly by a weighing balance that records the sample weight loss through the use of a weight sensor attached to it. A 1000W resistance wire supplies electrical heat to the drying chamber at preset temperature. The control unit and its accessories as well as other instrumentations are powered by a -75Amp accumulator, which is simultaneously charged by an-80W solar panel; whilst the resistance wire is powered by a public power supply or an electric generator. The energy consumption from the accumulator and AC are measured and recorded by the control unit. When the control unit is connected to the computer, a specialized software called SCADA (Supervisory Control and Data Acquisition) is used to log the readings at 30 minutes interval and the results, stored in a database for immediate or future analyses. This SCADA software is connected to the Arduino microprocessor via a USB cable. The SCADA also conducts analysis using models and performs a regression analysis to the same effect. The results of this analysis (graphs, figures, notes, etc.) are stored in the micro-computer for future reference and documentation purposes, thus the system is fully automated. Through the use of a universal serial board (USB) cable, stored data are transferred to a computer for further analysis.

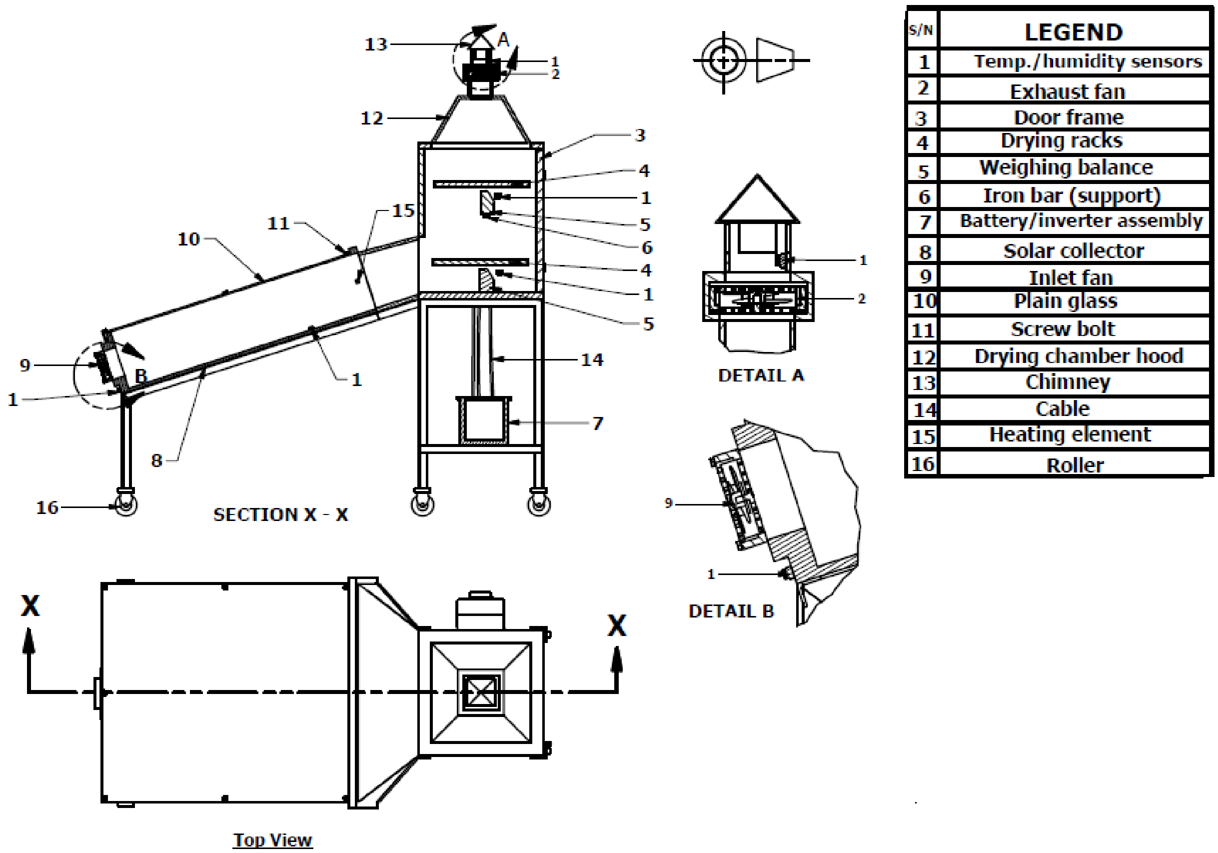


Figure3: Sectional view of the hybrid dryer.

2.4 *Experimental procedure*

The preliminary experiment (no-load test) was conducted at the Federal University of Technology, Owerri (F.U.T.O), Nigeria located at longitude 7.03^{o}N and latitude 5.48^{o}E between 22ndMay and 14th of June 2016, in order to evaluate the thermal profile of the hybrid dryer heat sources. The dryer was positioned in the open, a far distance from the shadows of trees and buildings, and the solar collector faced towards the North-South axis for maximum solar flux collection. The test which lasted between 9am and 4pm was conducted by first selecting the fan speed using the 4 x 4 matrix keypad of the control unit to initiate the required air velocity. Solar radiation was trapped by the solar collector and the heat forced in with use of a suction fan. The incident solar flux on the solar collector was measured with a pyranometer (Apogee MP-200) at 30 minutes interval. The electrical heating unit was switched on to operate at five different preset air temperatures of 50, 55, 60, 65 and 70^{o}C at five varying air velocities (0.1, 0.5, 1.0, 1.5, 2.0m/s). The time taken for the dryer to be heated up to each preset temperature was recorded for each air velocity. When the optimum temperature was attained, the Arduino microprocessor automatically switches off the heating element, and turns it on again when the drying chamber temperature falls one degree below the preset temperature. The dryer was operated in three replications on no-load for a total of 15 days (between 8am to 4pm), and the average results of the drying chamber temperature, relative humidity, time as well as ambient air temperature and relative humidity were measured and recorded by the transducer sensors placed at five different points on the dryer (i.e. outside the solar collector, inside of the solar collector box, by the sides of each of the drying racks, and in the chimney). These readings were transferred and displayed on the LCD of the control unit. The incident solar flux on the solar collector was measured with a pyranometer (Apogee MP-200) at 30 minutes interval.

3. Results and Discussion

The temperature profile of the hybrid dryer was obtained under no-load condition by measuring the temperature inside the drying chamber and the hourly ambient air between 9am and 4pm (local time). The technical performance of the hybrid system of the dryer is as presented in Table 1. Tray 1 receives the highest convective heat due to its closeness to the heat source than tray 2. This is as a result of the increased difference in the quantity of heat produced by the hybrid heat source as evidenced in the Table 1. The hybrid dryer chamber temperature is always higher than the ambient temperature - an indication of greater prospects of the hybrid system. This, therefore signifies that the hybrid dryer system is functional.

Table 1: Technical performance of the hybrid dryer

Local time (mins.)	Avg. ambient condition		Avg. drying chamber condition (hybrid heat)			
	Temp (^oC)	Rh (%)	Tray 1 temp (^oC)	Rh (%)	Tray 2 temp (^oC)	Rh (%)
0	26.2	86.6	34.9	71.0	34.8	71.6
30	27.1	81.4	45.8	68.3	39.8	70.0
60	28.6	77.6	68.9	59.4	62.6	59.8
90	29.7	73.8	71.7	33.4	68.9	52.4
120	30.4	71.7	74.9	31.5	69.5	47.8
150	34.9	69.1	79.6	30.6	73.7	35.2
180	36.5	68.8	85.7	25.4	79.9	31.9
210	39.6	67.6	88.5	23.2	81.3	28.1

The time taken by the hybrid dryer to be heated up to the different preset temperatures at different air velocities were recorded as shown in Figure 4. At constant temperature and varying air velocities, the hybrid system shows a consistently lowered dryer heat-up time. However, drying temperature and air velocity have important roles to play on the total dryer heat-up time as well as the dryer energy consumption. More energy (in form of convective heat) is transferred to the drying chamber as the temperature and air velocity increase for each of the heat sources. For each parameter regime in Figure 4, the hybrid dryer heat-up was found to be reduced with increased air velocity, hence less energy requirement for the dryer heat-up. The hybrid dryer heat-up time decreases as drying air temperature decreases with constant air velocity. At low air velocity (0.1m/s) and temperature (50^{o}C), the dryer heat-up time was observed to be 54.6 minutes. Whilst for a higher air velocity (2m/s) and temperature (70^{o}C), the dryer heat-up time was significantly reduced by 85%. This implies that higher air velocity at constant temperature increases the heat-up time, which would considerably reduce the drying rate.

At higher fan speed, more volume of dry air is forced into the drying chamber and less heat-up time is achieved which results in increase in the energy requirement of the dryer. Generally, a maximum and minimum average dryer heat-up times of 8.5 and 2.5 minutes respectively were taken by the hybrid system at each treatment combination. This significant time lag accounts for economy in terms of time savings, higher rate of moisture transport, and less dryer energy consumption, which are good prospects of hybrid crop dryers. This implies that at higher temperatures, drying time decreases due to increasing thermal gradient inside the drying chamber and consequently increasing the drying rate. Drying time also decreases with increasing air velocity due to decreased vapour pressure with increasing air velocity; thus, the product moisture would encounter less resistance on its way out and exits at a higher rate. These observations were similar to the results reported by Idah et al. (2014); Motevali et al. (2011); Nwajinka and Onuegbu (2014), and Nwakuba et al. (2016).

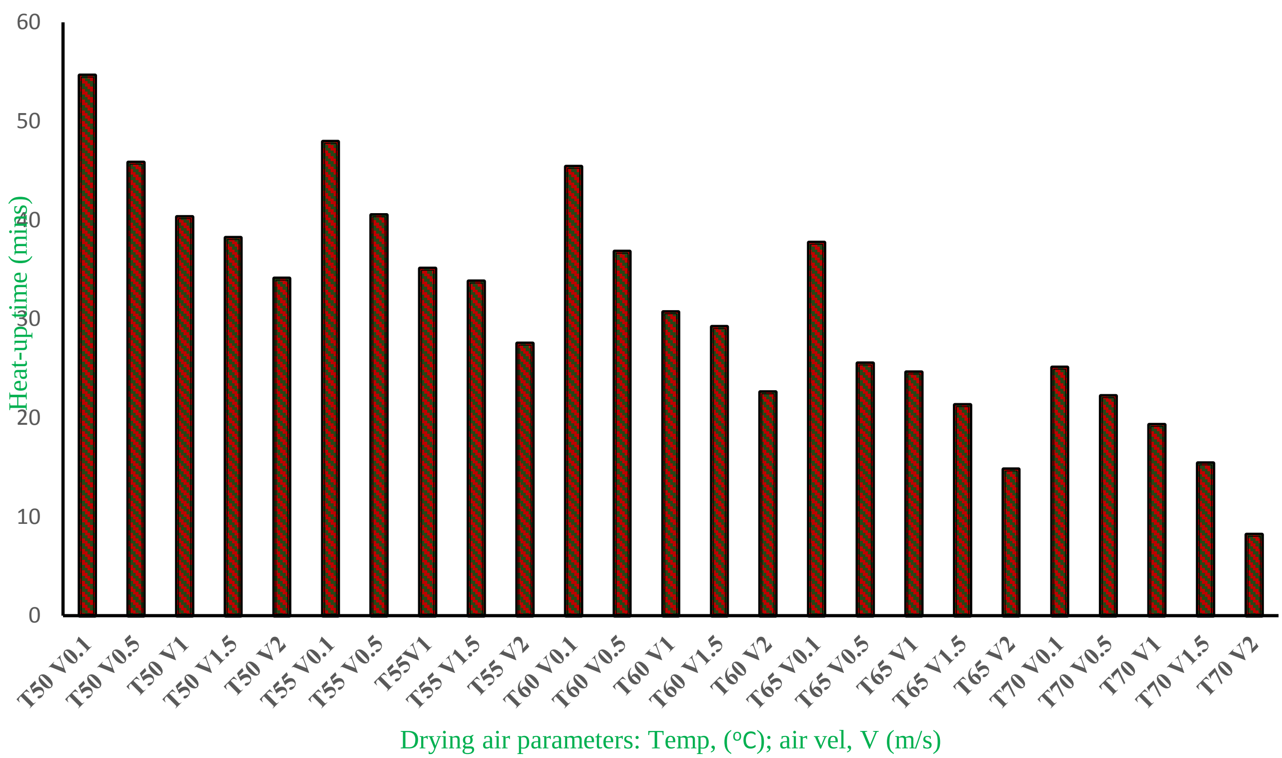


Figure 4: Effect of drying parameters on hybrid dryer heat-up

The amount of energy developed by the dryer heating units under no-load condition has been observed to be dependent on time as presented in Figure 5. As time increases, more energy is developed to heat-up the drying chamber to the desired (preset) temperature level for drying. The hybrid system sums the energy from solar and electricity units and thus develops higher energy in a lesser time (as earlier described in Figure 4). As the drying time increases, more energy is developed by the hybrid unit due to increase in the solar collector heat contribution as a result of increased solar flux in the afternoon. However, about 375 to 400kWhr of energy was developed at 9:00am, whilst 1774 to 1906kW was developed by the hybrid unit between 14:00 to 15:00 local time. These amounts of energy according to Abdulla *et al.* (2011), Motevali *et al.* (2011) and Afolabi *et al.* (2014) are adequate for both initial surface evaporation and moisture migration of sliced moisture-laden crops respectively. The hybrid energy is presented in Equation (20).

$$\boldsymbol{E_h = -30.894T^2 + 989.55T - 6037.5} \qquad \mathbf{(R^2 = 0.9932)} \qquad \mathbf{20}$$

Where: E_h = hybrid energy (kWh), T = drying time (minutes).

This energy model is described by a polynomial function of the 2nd order with R^2-value of 0.993. The energy consumption increases polynomially with drying time. This behavior is majorly due to variation in hourly solar heat trapped by the solar component of the hybrid system. The peak hybrid energy of about 1946kWhr was observed at 4pm and begins to decrease with time (as the sun goes down), while the minimum energy of 372kWhr was developed at 9am. This trend, together with the high R^2-value show very close correlation with dryer energy parameters (such as voltage, current, solar intensity, and time) with respect to the drying time.

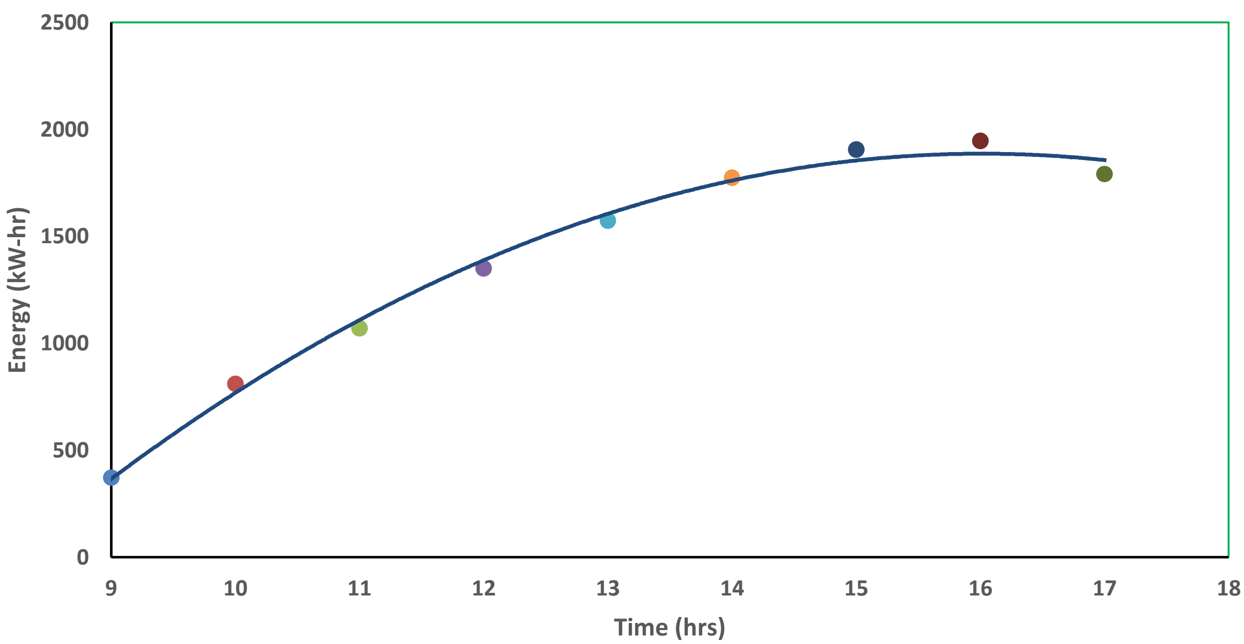


Figure 5: Effect of drying time on dryer energy consumption.

4. Conclusion

A hybrid solar-electric sliced crop dryer has been successfully designed and developed for drying sliced vegetable crops. The dryer was designed for a maximum temperature of 70^{o}C (given the optimum drying temperatures of the crops to be handled) with a maximum batch size of 25kg of fresh sliced vegetables. Results of no-load tests obtained show that the dryer demonstrated high heat generation in the hybrid mode given the moisture-laden nature of crops to be handled. The hybrid heat source performed very well in terms of energy development and drying chamber heat-up time. A minimum heat-up time of 5.2 minutes was required by the hybrid heat source at a temperature and air velocity of 70^{o}C and 2m/s respectively. Both the drying temperature and air velocity were found to have significant influence on the dryer heat-up time and drying tray temperatures. Drying time had significant effect on the energy consumption of the dryer mainly due to variation in hourly solar heat. The peak energy consumption was observed at 4pm, a time corresponding to about optimum solar heat flux. From the results obtained, the hybrid dryer has prospects of drying a wide range of freshly harvested vegetables, roots and tubers, as well as fish products and other crops to any desired final moisture level given its high heat generation and efficient temperature control. In order to minimize the energy consumption of the hybrid dryer, a constant optimum drying temperature at a fairly high air velocity greater than or equal to 2ms^{-1} should be maintained.

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EFFECTS OF DIFFERENT SOIL TILLAGE CHARACTERISTICS ON THE GROWTH AND YIELD OF MAIZE (Zea Mays L.) IN SAMARU ZARIA, NIGERIA

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Abstract

The study was conducted to evaluate the performances of different animal drawn implements on the upland soils of Samaru, Zaria for three years (2008 – 2010). Two white Fulani bulls were used to pull mouldboard ridger and mould board plough implements at different depths and speed of operation. A 2 x 3 x 3 factorial experimental design was arranged in a Randomized Complete Block Design. The experimental design comprised of eighteen treatments replicated three times. Results show that grain yield, treatments T_8 ($I_1S_3d_2$) and T_{15} ($I_2S_2d_3$) resulted in the highest grain yield (4.71 t/ha and 4.89 t/ha) for the mouldboard ridger and mould board plough respectively. It was also found that, plant height varied with the implement used and depth of tillage considered, and the plant height increased with increase in tillage depth. The analysis of variance showed that tillage depth significantly affected the maize grain yield.

Keywords: *animal drawn implements, tillage methods, growth and yield, maize*

1.0 Introduction

Agriculture is the dominant economic activity in terms of employment and linkages with the rest of the economy in the world. Roughly 75% of Nigeria's land is arable, of which only about 40% is cultivated (NEEDS, 2004). Agriculture in most developing countries including Nigeria is predominantly at subsistence level dominated by small holder farmers (Umar, 1994). Thus these farmers cannot meet their food and fibre requirements which is due to their land size and increasing population. This increase in population in the world that is followed by higher food demands make mechanisation of agriculture almost compulsary. Maize (Zea Mays L.) is the third most important cereal crop after wheat and rice, as it contributes a major portion of staple food for world's rising population. It has greater nutritional value as it contains about 72% starch, 10% protein, 4.8% oil, 8.5% fiber, 3% sugar and 17% ash (Saif *et al.*, 2003). They further reported that, due to higher yield potential, short growing period, high value for food, forage and feed for livestock, poultry and a cheaper source of raw material for agro-based industries, maize is increasingly gaining an important position in the cropping system. The production of maize can be improved and enhanced using better inputs, proper production technology and appropriate tillage methods. Important factors like soil tillage and appropriate fertilizer application can improve soil physical properties and enhance maize yields. Leghari *et al* (2015) reported that selection of an appropriate tillage method can enhance grains production by about 25 percent.

Tillage practice modifies the soil structure by changing its physical properties such as moisture content, bulk density, and penetration resistance. Changes in the soil physical properties affect the seedling emergence, plant population density, root distribution and crop yield (Khan *et al.*, 2001). Among the crop production factors, tillage contributes up to 20% (Khurshid *et al.*, 2006). The nurturing objective is one of developing a desirable soil structure that promotes seed germination, plant emergence, and root growth (Hunt, 1995). The soil can be tilled using the availabe and affordable source of power. This can either be tractor or animal with the appropriate implement to achive the desired objective. Starkey (1986) reported that in much of sub-Saharan Africa, systematic attempts to introduce animal traction began between 1905 and 1945. Animal traction, in Nigeria dates as far back as 1920's in Daura, Katsina state, used in accomplishing variety of farm operations mainly upland and in particular ridging and transportation of farm produce (Suleiman, 2000). The first animal-drawn implement introduced in Nigeria was a wooden plough (Gwani, 1990), but from 1934, these implements were replaced by the popular Ransome EMCOT ridgers (Chaundhury and Musa, 1984). A number of researchers (Kaul, 1989; Husseini, 1998; Starkey, 1992; and Musa, 1989) have reported on the introduction and adoption level of animal draught technology in Nigeria in particular, and Africa in general. They all agreed that it is an appropriate, affordable and sustainable technology. Draught animal power can be economically and environmentally sustained and hence can go a long way towards increasing the productivity of labour, improve timeliness of field operations to exploit the short cropping sessions, and relieve the farmer from the drudgery of performing field tasks (Suleiman, 2000). Draught animals are being used all over the world to reduce drudgery and to intensify agricultural production. Small-scale farming is the most widely practiced type of agricultural production in most Sub-Saharan countries and about 80 % of the farmers in developing countries use human or animal power in the production of their food and income needs (Gebresenbet *et al.*, 1997). Before the introduction of tractors in the era of oil boom, animal power has had a long history in Nigerian agriculture (Gbadamosi and Magaji, 2004). Up to 84 million draught animals are used for crop production and transportation purposes in India (Cartman, 1994). With 60 % of farmers having less than 4 ha, tractor ownership is not economically viable, leaving draught animal power as the only alternative (Dave, 1999). Haque *et al.*, (2000) reported that apart from the ridgers, no other animal-drawn implement is used for crop production in Adamawa state of Nigeria. The animal-drawn mouldboard plough is widely used for primary tillage in the developing countries of Africa (Loukanov *et al.* 2005). Due to the contributions of animal traction to the production of different crops, this work, therefore, aimed to evaluate the effect of different animal-drawn implements on the growth and yield of maize in Zaria, Nigeria.

2.0 Materials and Methods

2.1 The study area

The field study was conducted on sandy loam soil at Samaru - Zaria (11^o 11´ N, 07^o 38´E and 685 m above sea level). Samaru is located in the Northern Guinea savanna zone of Nigeria with an average annual rainfall of 1,100 mm and is spread between May and October (Yusuf, 2003). Field experiments and laboratory works were conducted between June and October 2008, 2009 and 2010 cropping seasons.

2.2 Treatment and experimantal design

The study consisted of two animal - drawn tillage implements (T_1, mouldboard ridger and T_2, mouldboard plough), three different soil operating depths (d_1, 5 -10 cm, d_2, 11 -15 cm and d_3, 16 - 20 cm) as the range for palnting depth of different crops in the study area, and three operating speeds (S_1, 0.69 m/s, S_2, 0.97 m/s and S_3, 1.25 m/s) commonly used in literature. The combination of the implements, speed and depth resulted into eighteen treaments as presented below.

$T_1 = I_1S_1d_1$	$T_2 = I_1S_1d_2$	$T_3 = I_1S_1d_3$	$T_4 = I_1S_2d_1$	$T_5 = I_1S_2d_2$	$T_6 = I_1S_2d_3$
$T_7 = I_1S_3d_1$	$T_8 = I_1S_3d_2$	$T_9 = I_1S_3d_3$	$T_{10} = I_2S_1d_1$	$T_{11} = I_2S_1d_2$	$T_{12} = I_2S_1d_3$
$T_{13} = I_2S_2d_1$	$T_{14} = I_2S_2d_2$	$T_{15} = I_2S_2d_3$	$T_{16} = I_2S_3d_1$	$T_{17} = I_2S_3d_2$	$T_{18} = I_2S_3d_3$

Where: I_1 = Animal – drawn Emcot ridger

I_2 = Animal – drawn mouldboard plough

S_1 = Speed of 0.69 ms^{-1}

S_2 = Speed of 0.97 ms^{-1}

S_3 = Speed of 1.25 ms^{-1}

d_1 = Operating depth of 5 – 10 cm

d_2 = Operating depth 0f 11 – 15 cm

d_3 = Operating depth of 16 – 20 cm.

The treatments were randomly assigned in 2 x 3 x 3 factorial experiment arranged in a randomized complete block design in three replications. Each plot size was 5 m wide x 10 m long. The area of land used for the study was 0.36 ha.

2.3 Field experimentantion

Field experiments were conducted using two white Fulani bulls to operate the implements. This is because of their ease of control and response to verbal command. The implements considered in this study were animal-drawn mouldboard plough and ridger. This is because they are the most commonly used in the study area. Also same harnessing system was used throughout the study. The measuring devices used included spring type dynamometer, stopwatches, measuring tape, soil penetrometer, and electronic weighing balance. Common methods of agronomic practices (planting, fertilizer application, weeding and harvesting), data collection and analysis were applied to all the experimental treatments and maize crop (Sammaz – 12) variety which is commonly used by farmers in the study area was used as the test crop.

2.4 Data collection

Soil samples of the top soil (0 – 15 and 15 – 30 cm) were obtained from the experimental field by the use of auger, core samplers, cutting blade and nylon bags for the laboratory determination of percentage organic matter, particle size analysis, bulk density and soil moisture content. Growth parameters considered in the study include plant height, leaf area index and 1,000

- kernel weight. The seedlings emerged 6 – 8 days after planting on all the treatments. The plant height was measured using a meter rule from soil surface to the tip of the last leaf. Three plants randomly selected from each treatment and the mean value of plant height was recorded. Plant heights were measured as from 3 weeks after planting and followed in two weeks interval up to 9 weeks after planting. Leaf Area (LA), was used to determind the leaf area index, of individual leave area was estimated using equation 1 (Saxena and Singh, 1965 as reported by Yusuf, 2001).

$$LA = 0.75 \times Length \times Breath \quad (1)$$

The Leaf Area Index (LAI) was calculated using equation 2 (Watson, 1952, also reported by Yusuf (2001).

$$LAI = \frac{Total\ LA}{Total\ land\ area} \quad (2)$$

The 1,000 - kernel weight was determined by counting 100 seeds of the grain after harvest. Grain yield was determined after harvesting the crop by hand at the grain moisture content of about 15% db. The harvested maize grain was shelled manually and the grain for each plot was weighed to estimate the grain yield for that plot.

2.5 Data analysis

The field and laboratory data collected were analyzed statistically by Analysis of Variance (ANOVA) technique as reported by Gomez and Gomez, (1984). The standard error of each mean was calculated and presented in form of figures and/or tables.

3.0 Results and Discussions

3.1 Soil Condition

The physical properties and organic matter content of the soil samples are presented in Table 1. From the USDA triangle, the soil can be classified as sandy loam. The soil constituents consist of high sand fraction (62.8-67.8 %). This result confirms the observation of Yusuf (2001). The soil profile indicates moderate percentage of organic matter content. The soil organic matter decreased with increase in depth of soil profile as shown in Table 1. Tsimba et al. (1999) reported similar observation. The 0 – 15 cm depth of soil profile recorded values between 1.18 to 1.43% of the organic matter content while the corresponding value in 15 – 30 cm depth was 0.92 to 1.26%. This showed that the level of soil organic matter is moderate.

Table 1: Mean values of some soil physical properties of the experimental site (2008, 2009 and 2010)

Depth of soil profile[a] (cm)	Sand (%)	Silt (%)	Clay (%)	Organic Matter (%)	Soil classification[b]
2008					
0 – 15	62.8	20.2	17.2	1.18	Sandy loam
15 – 30	67.8	17.5	14.7	0.92	Sandy loam
2009					
0 – 15	65.3	17.5	17.2	1.26	Sandy loam
15 – 30	64.1	18.7	17.2	1.09	Sandy loam
2010					
0 – 15	64.0	18.3	17.3	1.43	Sandy loam
15 – 30	65.9	17.9	16.2	1.26	Sandy loam

[a] = Each value is a mean of three measurements
[b] = USDA, triangle in: Dunn *et al.*, (1980)

3.2 Crop Growth Parameters

3.2.1 Leaf Area Index

Table 2: Mean values of Leaf Area Index at 9 WAP

Treatment	Year		
	2008	2009	2010
T_1	912.89	1333.96	1357.04
T_2	1062.26	1663.81	1428.27
T_3	1186.56	1470.97	1570.43
T_4	765.52	1174.97	1416.96
T_5	835.50	1310.81	1482.77
T_6	1002.21	1502.12	1498.70
T_7	583.27	1468.29	1427.16
T_8	1001.47	1551.87	1517.27
T_9	744.98	1644.74	1443.01
T_{10}	712.72	1457.30	1092.49
T_{11}	952.82	1289.92	1336.27
T_{12}	1062.82	1324.06	1473.71
T_{13}	883.27	1091.81	1662.56
T_{14}	1085.39	1271.90	1724.15
T_{15}	1241.15	1221.61	1879.61
T_{16}	1147.87	1205.24	1686.49
T_{17}	791.79	1685.77	1893.40
T_{18}	1393.91	1237.75	1848.89

The mean values of the Leaf Area Index (LAI) for the different years under study is presented in Table 2. LAI was significantly affected ($P \leq 0.01$) by the tillage depth investigated in this study for the combined three years considered. LAI increased from 3 Weeks After Planting (WAP) to the peak value at 9 WAP. The increase in depth of tillage resulted to increased in LAI (Table 2). Similar result was reported by Yusuf (2001) and Rahman, et al. (2004). Mould board plough operating at depth d_3 (16 - 20 cm) representing treatment T_{18} showed superiority in the LAI values throughout the study years (2008 – 2010) over other tillage treatments. The implement type and tillage depth significantly ($P \leq 0.01$) affected the LAI. The interaction between implement and depth, speed and depth showed significant effect ($P \leq 0.01$) on LAI in the study years. It was also observed that, the interaction of implement, speed and depth was significant ($P \leq 0.05$) in 2008 and 2009 but not in 2010.

3.2.2 Plant Height

The effects of tillage treatment on plant height varied from year to year throughout the study period as shown in Table 3. Maize plant heights varied with the implement used and the depth of tillage considered in the study. Increased in tillage depth for both implements resulted in increased plant height. Tilling with the mould board plough at depth d_3 (16 – 20 cm) in 2009 field study produced the highest maize plant height when compared with other treatments. At 9 WAP, treatment T18 gave the highest mean value of plant height. A similar result on tillage treatment was obtained by Olofintoye (1989) who conducted a study on the effects of tillage and weed control methods on weed growth and performance of rice in the same area of study. This shows that, the deeper the soil is tilled, there is more tendency for higher root growth whic will extract more nutrients required for crop growth.

Statistical Analysis of variance for the study period showed that the implement, speed and depth of tillage significantly affected ($P \leq 0.01$) the plant height at 9 WAP. Also the interaction of implement, speed and the tillage depth significantly affected ($P \leq 0.01$) the maize plant height. Same observation was reported by Yusuf (2001) who said that, tillage treatments significantly affected ($P \leq 0.01$) the plant height of maize. Rahman *et al.;* (2004) also reported similar results on a sandy loam soil in Mymensingh, Bangladesh.

Table 3: Combined analysis of variance for plant height for the 3 – year period at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	21.834362	10.917181	0.98
Year (Y)	2	4014.782016	2007.391008	180.07**
Implement (I)	1	621.477099	621.477099	55.75**
Speed (S)	2	220.143374	110.071687	9.87**
Tillage depth (d)	2	2602.421276	1301.210638	116.72**
I x Y	2	3572.435926	1786.217963	160.23**
d x Y	4	553.040905	138.260226	12.40**
S x Y	4	1850.734239	462.683560	41.50**
I x S	2	526.842634	263.421317	23.63**
I x d	2	693.784239	346.892119	31.12**
S x d	4	2797.754609	699.438652	62.74**
I x S x d	4	4807.059053	1201.764763	107.80**
I x S x Y	4	131.049465	32.762366	2.94^{ns}
I x d x Y	4	349.067984	87.266996	7.83**
S x d x Y	8	1977.740000	247.217500	22.18**
I x S x d x Y	8	2492.014897	311.501862	27.94**
Error	106	1181.673790	11.147870	
Total	161	28413.85586		

** = significant at 0.01 probability level; ^{ns} = not significantly different

Table 4: Means and Standard Deviation of Crop Assessment Parameters as Affected by Different Tillage Treatments in the 3 – year study (2008 – 2010)

Treatments	Crop assessment parameters[a]									
	Plant height[b] (cm)			1000-Kernel weight[c] (g)			Maize grain yield[c] (t/ha)			Average yield (t/ha)
	2008	2009	2010	2008	2009	2010	2008	2009	2010	
T_1	132.43±6.21	150.47±2.01	116.06±1.90	166.93±9.25	160.30±5.90	164.91±1.05	4.00±5.76	4.48±1.12	3.71±4.00	4.06
T_2	132.00±8.40	134.31±1.60	119.10±1.64	182.95±14.57	177.00±5.18	164.74±1.83	2.82±13.01	3.17±2.35	3.10±3.02	3.03
T_3	144.67±2.85	147.11±1.54	120.17±2.07	166.37±16.20	172.94±1.78	174.22±1.22	4.48±0.83	4.60±3.09	4.32±4.84	4.47
T_4	119.77±3.38	131.29±0.54	119.04±1.47	148.23±6.04	170.02±0.85	168.86±1.32	3.38±12.41	3.87±2.43	3.77±2.41	3.67
T_5	129.56±4.25	138.29±1.01	124.29±2.16	156.07±13.99	146.95±0.67	171.28±1.68	3.29±11.67	3.76±2.24	3.87±1.94	3.64
T_6	153.39±0.37	153.08±0.52	129.26±1.40	156.12±14.64	196.53±2.17	183.37±1.89	4.42±4.34	4.77±4.62	4.68±1.73	4.62
T_7	132.29±1.80	144.50±1.80	127.28±3.68	134.33±3.59	147.73±1.74	155.10±1.15	1.56±8.28	2.01±2.21	2.11±3.37	1.89
T_8	134.94±0.73	143.28±0.62	127.43±1.04	200.54±3.96	192.21±0.76	180.44±1.02	4.61±1.16	4.97±0.71	4.61±7.42	4.71
T_9	105.78±0.78	132.04±1.13	131.82±1.35	141.95±6.80	141.31±0.71	173.18±1.89	2.81±5.37	2.97±1.17	3.90±0.92	3.23
T_{10}	96.49±7.19	132.86±0.81	127.94±0.37	148.25±7.62	185.96±1.08	161.11±1.30	2.54±10.55	2.71±0.99	2.74±1.81	2.66

T_{11}	143.76±0.71	152.93±0.75	132.83±1.13	140.86±9.15	171.80±1.10	182.54±0.50	4.53±3.51	4.90±2.18	4.64±1.77	4.69
T_{12}	131.86±5.90	134.59±0.75	138.47±2.10	157.26±11.14	186.21±1.36	169.04±1.05	2.71±10.90	2.91±2.21	3.23±2.08	2.95
T_{13}	113.88±5.95	127.81±1.53	135.49±1.87	122.97±7.15	166.84±2.76	164.06±0.76	2.71±7.77	2.80±3.09	2.98±4.98	2.83
T_{14}	137.08±3.20	146.04±0.69	142.36±1.32	158.52±15.46	149.30±0.60	171.84±1.89	3.33±12.16	3.72±1.56	3.59±3.48	3.55
T_{15}	142.98±2.24	142.88±0.31	144.88±1.82	169.64±6.47	171.91±1.81	188.20±0.83	4.55±3.35	5.03±1.41	4.90±1.71	4.89
T_{16}	133.09±6.75	147.06±0.41	142.97±1.16	138.74±7.23	186.41±0.96	180.83±1.74	4.19±13.98	4.89±5.74	4.38±2.43	4.49
T_{17}	102.24±6.09	127.33±0.97	147.20±1.22	169.70±7.95	190.51±0.70	170.63±0.87	3.11±5.67	3.51±1.12	3.48±2.04	3.37
T_{18}	143.81±12.43	154.89±0.78	155.70±0.92	162.89±11.04	176.65±0.47	173.20±1.03	3.19±4.27	3.60±1.15	3.54±1.75	3.44
$\bar{x}$	129.45	141.15	132.35	156.80	171.70	172.09	3.46	3.82	3.75	3.67
SD	15.82	9.03	11.10	18.41	16.88	8.58	0.88	0.93	0.75	0.84
CV (%)	12.218	6.396	8.385	11.740	9.832	4.985	25.394	24.396	20.043	22.876

3.2.3 1000-kernel Weight

The 1000-kernel weight for the 3 years of study (2008 to 2010) is presented in Table 4 From the Table, the mouldboard ridger, treatment T8 ($I_1S_3d_2$) had higher 1000-kernel weight than other treatments. Also for the mould board plough, treatment T15 ($I_2S_3d_2$) had the corresponding higher value. This may probably be due to good soil tilt which leads to small soil aggregates of the seed beds. Analysis of variance showed that, the depth of tillage and the interaction of implement, speed and tillage depth significantly affected ($P \leq 0.01$) the 1000-kernel weight for the years of study. The combined analysis of variance of 1000-kernel weight over the period of study also showed significant effect ($P \leq 0.01$) of the implement, speed and depth of tillage interaction on 1000-kernel weight.

3.3.4 Maize Grain Yield

The results for tillage treatments on maize grain yield are presented in Table 3. Increased in depth of tillage resulted to increase of maize grain yield as shown in Table 3. For the mouldboard ridger, treatment T8 ($I_1S_3d_2$) resulted in the highest average grain yield (4.71 t/ha) for the 3 – year study and the least treatment in terms of average maize grain yield is T7 (1.89 t/ha). For the mould board plough, the highest average maize grain yield was obtained in treatment T15 ($I_2S_2d_3$) as 4.89 t/ha and the least was in treatment T10 with average value of 2.66 t/ha for the 3 – year study. This may be because of the good seed and seedling environment created by the tillage treatment which enhanced crop growth and improved maize grain yield. Gomez (2011) also reported that ploughing depth significantly influenced maize grain yield.

The combined analysis of variance showed that, maize grain yield was significantly ($P \leq 0.01$) affected by the speed of operation and depth of tillage in the period under study. The results further showed that there was significant ($P \leq 0.05$) effect of the maize grain yield on the implements considered. The implement, speed and tillage depth interaction also significantly ($P \leq 0.01$) affected the maize grain yield.

4.0 Conclusion

From the results of this study, the following conclusions are drawn. Plant height varied with the implement used and depth of tillage considered, and that plant height increased with increase in tillage depth. The highest mean grain yield obtained was 4.71 t/ha for mouldboard ridgerat speed of 1.25 m/s and 11 - 15 cm depth of operation, and 4.89 t/ha for the mould board plough at the speed of 0.97 m/s and 16 20 cm depth. Finally, operating implement deeper resulted to higher maize grain yields.

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EFFECTS OF MOISTURE CONTENT AND SOLVENT TYPE ON OIL PROPERTIES AND YIELD OF FLUTED PUMPKIN SEED OIL

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ABSTRACT

The quantity of extractable oil obtained from oilseeds is usually influenced by the moisture content of the oil seeds at the time of extraction. This work was conducted to study the effect of moisture content and extraction solvent on the oil yield from fluted pumpkin seed (Telferiaoccidentalis).The oilseed were conditioned to three different moisture contents of 5, 8 and 10 %. The two extraction solvents used were n-hexane and petroleum ether, using the soxhlet equipment the extracted oils were also characterized. The highest oil yield of fluted pumpkin seeds was 49.40 % at 5 % moisture content, while the lowest oil yield of 34.19 % at 10 % moisture content using n-hexane solvent. In the case of petroleum ether, the results were 49.73% at 5% moisture content. The result of the physicochemical analysis showed that there is significant difference between n-haxane and petroleum ether; for n-hexane, the values of free fatty acid FFA(mg/KOH/g), saponification value SV(mg/g), Iodine value IV(g/100g), Peroxide value PV(mmol), Specific gravity SG, Refractive index RI, and Viscosity VIS values were15.98, 415.23, 96.45, 12.33, 0.82, 1.45, and 119.23, respectively, while petroleum ether had, 15, 415.15, 99.5, 12.55, 0.78, 1.48, and 121.32, respectively. It was concluded from this study that moisture content and solvent type had great influence in determining oil yield, also n-hexane extraction was more efficient. The highest oil yield was obtained at 5% moisture content using n-hexane.

Keywords: Moisture content, oil yield, fluted pumpkin seed, petroleum ether, n-hexane.

1.1 INTRODUCTION

Seeds have nutritive and calorific values which make them important in diets. They are also good sources of edible oils and fats (Odoemelam, 2005). Fats and oils are essential nutrients, comprising about 40% of the calories in the diet. Seed oils have extensive demands both for human consumption and for industrial applications (Kyari, 2008).

Edible oils can be obtained from animals and plants, Oils from plants are termed as vegetable oil. There is a universal demand for vegetable oil due to their increasing home and industrial purposes. Oil content of vegetable oil-bearing plants ranges between 3 and 70 % of the total weight of the nut, kernel and seed (Bachman 2004). The vegetable oil consumption is increasing compared to animal fat due to its health factors (Akinoso,2006).

1.1.1 Origin and Distribution of Fluted Pumpkin

Fluted pumpkins (*Telfairiaoccidentalis)* are tropical vinethat is grown in West Africa as a leafy vegetables and for its edible seeds. The following are its common names for the plant Ugu, Fluted gourd and Fluted pumpkin. *Telfairiaoccidentalis*belong to family member of the curcurbitaceaeand is indigenous to southern Nigeria (Akorodaand Adejoro, 1990).The fluted gourd grows in many nations of West Africa but is mainly cultivated in Nigeria, used primarily in soups and herbal medicines (Nwanna,2008). Fluted pumpkin gourd and seeds are shown in Plates **1.1.1** and **1.1.2.**

Plate 1.1.1: Fluted pumpkin gourd

Plate 1.1.2: Fluted pumpkin seeds

1.1.3 Composition and Uses of Fluted Pumpkin leafs, seeds and oil

The seeds of fluted pumpkin are valuable both as an oilseed (54%) and also as a protein source (27%) with a fairly well balanced amino acid composition (Hamed, *et al*.,2008).

The tender vine and foliage are used and consumed as pot herbs. Oil can be extracted from the seeds, which can be used to manufacture soap and is also use for cooking (Agatemor, 2006). The seeds are used as propagating materials eaten roasted, boiled or ground to paste as soup thickener (Odiaka, *et al*., 2008). The seeds of *Telfairiaoccidentalis* can be boiled and eaten whole, or fermented and added to soup as “ogili”. The fluted pumpkingourd has been traditionally used as blood tonic likely due to its high protein content by indigenous tribes, the shoots and leaves areconsumed as vegetables (Akoroda and Adejoro, 1990).

Other medicinal properties are as follows; the powdered seed is used to increase spermatogenesis and regenerate testicular damage (Alegbejo, 2012).Activated carbon that is produced from fluted pumpkin (*Telfairiaoccidentalis*) seed shell can be used for the removal of lead (II) ion from simulated wastewater. Activated carbon has been used as an adsorbent for removal of heavy metal pollutants from wastewater and has proven to be effective (Okoye, *et al*., 2010). Dietary incorporation of *Telfairiaoccidentlis* seeds into animal feeds can be used to supplement animal feed. Pumpkin seed oil can be transesterified to biodiesel with properties similar to those of diesel fuel and within the ASTM limits for biodiesel. Thus it can be used as alternative fuel for diesel engines, of particular advantage is the high flash point which makes it a safe fuel(Bello, *et al*., 2012).

One major problem usually encountered in processing oil from oilseed is to know the appropriate moisture content at which to obtain the best oil yield from the seed. This also varies with the type of oilseed used. Another problem is the type of solvent used and the effects on the oilyield as well as the quality of oil obtained. It is thus desirable to investigate these factors and their influence on the oilyield and quality of oil from fluted pumpkin seed, hence the need for this study.

1.2 MATERIALS AND METHOD

Fluted pumpkin gourd (*Telfairiaoccidentalis)* was purchased from local market in Minna Nigeria. The seeds were removed, washed cracked and sun dried for four days at temperature and relative humidity ranging between 24-30 ^{o}C and 30-40 %. Seed samples were thoroughly screened to remove stones, bad and rotten seeds.

1.2.1 Determination and conditioning of seed samples moisture content

The initial moisture content of the samples were determined on wet basis (wt) using oven drying method at 105°C as described by AOAC, (1990) standard methods, Moisture content was calculated from the relationship.

$$M.C = \frac{\mathrm{A-B}}{\mathrm{A}} \mathrm{x}\, 100$$

M.C = Moisture Content
A = Initial Moisture content
B = Final Moisture content

The seeds were then divided into three parts and conditioned to the desired moisture contents. Seeds were grounded into fine powder with an electric blender to increase the surface area for oil extraction. Extraction of oil was done in Agricultural and Bio-resources Engineering Laboratory. Oil samples were analysed in Crop Production Laboratory, Federal University of Technology, Minna, Niger State.

The initial moisture content of fluted pumpkinseeds after drying was determined to be 5 %, The samples were then divided into three A, B, and C. Calculated amount of distilled water were added to samples B, and C, sample were sealed in separate polythene bags and refrigerated for seven days to achieve the desired moisture content of 8 %, 10 % respectively while sample A was retained at the initial moisture content of 5 %. The quantity of water added was calculated from the following relation as given by Sacilik, *et al*.(2003).

$$Q = \frac{\text{Wi x (Mf} - \text{Mi)}}{(100 - \text{Mf})}$$

Q = is the quantity of water (g).
M_f = is the final moisture content of the sample in % wet basis.
M_i = is the initial moisture content of the sample in % wet basis.
W_i = initial mass of the sample in grams.

1.2.2 Oil extraction

A Completely Randomize Block Design statistics was used to conduct the experiment. Two factors, moisture content(3 levels) and solvent type(2 levels) were investigated. The oil extraction was carried out in three replicates for each of the moisture content level using the two solvents(2x3x3=18). Oil extraction was done using the soxhlet method, using the n-hexane and petroleum ether as solvent of extraction at the temperature of 50 ^oC. The most commonly used semi-continuous process for the extraction of lipids from foods (Obikili, 2010). According to Soxhlet procedure, oil and fat from solid material are extracted by repeated washing (percolation) with an organic solvent.

1.2.3 Determination of oil yield and physicochemical properties

Extraction of oil using soxhlet method was replicated on each of the seed sample and the oil was recovered using solvent evaporation. It was heated at the temperature that is higher, the solvent finally evaporates and leaving behind oil extracted, this process is known as distillation method. The process was done for all sample, the average percentage oil yield on each sample was obtained. This method was also used for oil yield determination for moringa seed by (Adejumo, *et al.*,2013). Oil yield in percentage was calculated as follows;

$$\%\ Oil\ yield = \frac{weight\ of\ extracted\ oil\ sample}{weight\ of\ seed\ samples} \times 100$$

The physicochemical properties of oil samples from fluted pumpkin seeds, at three moisture content, using two different solvents were determined, according to the method described by the AOAC (2000).

1.3 RESULTS AND DISCUSSION

1.3.1 Effect of moisture content and solvent type on oil yield from fluted pumpkin seed

Table 1.3.1 shows the mean percentage of oil yield from fluted pumpkin seeds at different moisture contentsusing the two solvent types.

Table 1.3.1: Mean percentage oil yield at different moisture content and solvent of fluted pumpkin seeds

Moisture content	Oil yield	
	n-hexane	petroleum ether
5	49.401	49.728
8	47.539	38.668
10	34.194	34.927

The results showed that the highest percentage of oil was obtained at 5 % moisture content irrespective of the solvent type used. The percentage ofoil yield decreased with increase in moisture content for all the samples. It has been shown that a decrease in moisture content and an increase in temperature improve oil yield (Singh *et al.,* 2000). Similar results have also been reported for neem seed and moringa seed (Orhevba, *et al.,* 2013: Adejumo *et al*., 2013). It has also been shown in literature that, n-hexane solvents provided better oil yield than petroleum ether solvents(Reginaldo *et al*., 2003)**.** The ANOVA (Table 1.3.2) below shows that both solvent and moisture have significant effect at($p \leq 0.05$) on the percentage of oil yield.

Table 1.3.2: **Analysis of Variance of oil yield due to variation of moisture and solvent on Pumpkin Seed**

Source	Sum of Square	Df	Mean Square	F	Sig.
Corrected Model	804.664[a]	5	160.933	167.266	.000
Intercept	26069.273	1	26069.273	27095.242	.000
SOLVENT	38.888	1	38.888	40.419	.000
MOISTURE	745.505	2	372.752	387.422	.000
SOLVENT * MOISTURE	20.271	2	10.135	10.534	.002
Error	11.546	12	.962		
Total	26885.483	18			
Corrected Total	816.210	17			

a. R Squared = .986 (Adjusted R Squared = .980)
b. [ns] = not significant at 5% level, [*]= significant at 5% level.

The result shows that there were significant differences between the mean percentage oil yield at three moisture content levels and two solvents. The result here is in agreement with other studies, it is also noted that higher percentage of oil yield was obtained from extraction performed with n-hexane solvent (49.401 %) at 5%, and least value of (34.194 %) at 10 % moisture content. However, those extracted using petroleum ether was 49.728 % at 5 %, and least value of 34.927 % at 10 % moisture content. Studies that compared the methods of extraction using pressing methods, bio-renewable solvent and traditional fossil solvent (hexane) by (Brossard-González, *et al*., 2010), Ribeiro *et al.* (2010), (Ferreira-Dias, *et al*., 2003) and (Drummond, *et al*., 2006), revealed similar results that n-hexane produced higher percentage of oil yield than other solvents. The seeds that were used in the experiment showed similar characteristics of oil content extracted using different solvent and moisture parameters to the ones reported by Drummond, *et al*. (2006), Melhorança, *et al*.(2010) and Rosseto, *et al*.(2012).

1.3.2 Characteristics of oil from fluted pumpkin using n-hexane and petroleum ether

The ANOVA data on the physicochemical properties of fluted pumpkin seed oil is shown in Table 1.3.3.

Table 1.3.3: Effect of solvent on physicochemical properties of fluted pumpkin seed oil

		Sum of square	df	Mean Square	F	Sig.
FFA(Mg/KOH /g)	Between Groups	3.197	1	3.197	17.975	0.013*
	Within Groups	.712	4	.178		
	Total	3.909	5			
SV(Mg/g	Between Groups	.232	1	.232	.017	0.903^{ns}
	Within Groups	55.374	4	13.843		
	Total	55.606	5			
IV (g/100g)	Between Groups	7.238	1	7.238	7.581	0.051^{ns}
	Within Groups	3.819	4	.955		
	Total	11.057	5			
PVmmol	Between Groups	1.162	1	1.162	16.395	0.015*
	Within Groups	.283	4	.071		
	Total	1.445	5			
RI	Between Groups	.000	1	.000	2.000	0.230^{ns}
	Within Groups	.001	4	.000		
	Total	.001	5			
SG	Between Groups	.003	1	.003	15.077	0.018*
	Within Groups	.001	4	.000		
	Total	.004	5			
VIS	Between Groups	.028	1	.028	.017	0.901^{ns}
	Within Groups	6.411	4	1.603		
	Total	6.439	5			

* = significant at 5% ($p \leq 0.05$), ^{ns} = not significant at 5% ($p \leq 0.05$).

The free fatty acid value of 14.67 using petroleum ether and 15.87 using n-hexane were significantly different at ($p \leq 0.05$). These values were lower than those obtained in earlier studies (Olatidoye, *et al*., 2011).The values are within the free fatty acid recommended limit for edibleoil, this oil cantherefore be used as edible oil. The Saponification values of pumpkin seed oils extracted using two solvents were not significantly different at ($p \leq 0.05$), saponification value using n-hexanehad (413.83 mg/KOH/g) and petroleum ether (415.17 mg/KOH/g). The saponofication value in this study was higher when compared to the saponification value of cocosnucifera oil 246 mgKOH/g(Eka*et al*., 2010). The Iodine value of pumpkin seed oil extracted using the two solvents were not significantly different at ($p \leq 0.05$). The iodine values in this study were higher when compared to the iodine values for the refined castor oil (87.72 g/100g) and unrefined castor oil (84.8 g/100g) as reported by Akubugwo, *et al.*(2008). These results suggest that pumpkin seed oil is suitable for biodiesel production. The refractive index of pumpkin seed oil extracted using the two solvents were significantly different at ($p \leq 0.05$). Specific gravity of pumpkin seed oil extracted using n-hexane 0.820 and petroleum ether (0.78) were significantly different at ($p \leq 0.05$). The specific gravity of the oil was higher compared to those of *Treculia Africana* oil (0.81), egusi (0.874),and lower when compared to the specific gravity of refined castor oil 0.9589 (Akpan, *et al.*,2006). The specific gravity of pumpkin seed oil is less than one which indicates that pumpkin seed oil is less dense than water. The viscosity of pumpkin seed oils were not significantly different, petroleum ether had viscosity (121.4) and n-Hexane (120.03).

1.4 CONCLUSION

The effects of moisture content variation on the oil yield and the solvents type used for oil extraction were investigated. It can be concluded that oil yield decreases with increase in moisture content, with the highest oil yield obtained at 5 %.The extraction with hexane solvent was significantly more efficient than the extraction with petroleum ether solvent regardless of the moisture content.The solvent type affects some physicochemical properties of the oil.

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