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EFFECT OF PLOUGHING DEPTH AND SPEED ON TRACTOR FUEL CONSUMPTION IN A SANDY-LOAM SOIL OF OYO STATE-NIGERIA

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ABSTRACT

Farm Tractor acquisition in Oyo State-Nigeria is fast growing despite its huge initial capital outlay. These tractors are primarily utilized for ploughing operations which represents the most costly single item in the budget of an arable farmer. Tractor fuel consumption constitutes a significant parameter that affects tractors performances for ploughing operations. The effect of ploughing speed and depth on tractors fuel consumption was therefore examined in a bid to establish their optimum operating conditions.

The soil characteristics of the study site were determined using laboratory tests. Ploughing operations, using ASABE standard D497.5 were carried out on 100 x 500 m research farmland using Massey Ferguson (MF 435, 100hp), Fiat (F130D, 100hp) and Steyr (CVT170, 100hp) tractors that were purchased in 2009. Field experiments were conducted at 5.5, 6.5 and 7.5 km/h ploughing speeds for ploughing depths of 20, 25 and 30cm. The fuel consumption was measure by estimating the quantity of diesel that fills the tractor fuel tank to capacity after each runs of the experiment. The results were subjected to statistical analysis using ANOVA and multiple regression analysis ($p<0.05$).

The soil type in the study site is predominantly sandy-loam. Mean fuel consumption for Fiat, MF and Steyr models were 23.35, 23.58 and 24.55 l/ha while average of 16.78, 22.02 and 32.67 l/ha of diesel were used to plough 20, 25 and 30cm depths respectively. Fuel consumption values increases with ploughing dept significantly, there is 31% increase from 20 to 25cm and 48% increase from 25 to 30cm depths. Mean fuel consumption at 5.5, 6.5 and 7.5 km/h ploughing speeds were 20.0, 24.25 and 27.23 l/ha respectively. Fuel consumption increased by 4.25 liters (21%) when speed is increased from 5.5 to 6.5 km/h and 2.98 liters (12%) when speed increases from 6.5 to 7.5 km/h. Mean fuel consumption (23.35, 23.58, 24.55) l/ha for MF, Fiat and Steyr tractors respectively were significantly different at the various speeds and ploughing depths ($0.87 \leq r^2 \leq 0.99$).

The most appropriate combination of ploughing operating parameters in terms of tractor fuel economy is achieved using Fiat tractors at 6.5 km/h ploughing speed and 25cm ploughing depth. Tractors' performance for ploughing operation depends significantly on ploughing speed, ploughing depth and tractor type. However, the depth of crop roots should determine the appropriate ploughing depth in order to minimize expenses on fuel.

KEYWORDS: Tractor performance, soil types, ploughing depth, ploughing speed, fuel consumption.

1. INTRODUCTION

In Nigeria, agricultural mechanization is one of the greatest contributions of technological advancements to agricultural production. The appropriate choice and subsequent proper use of mechanized inputs into agriculture has a direct and significant effect on the achievable levels of land productivity, labour productivity, the profitability of farming, the environment and the quality of life of people engaged in agriculture. Government at all levels considered acquisition and subsequent distribution of farming equipment especially tractors as a significant action that improves agricultural production, yet, no commensurable attention has been devoted to performance management of these equipments with respect to adequacy, appropriateness, economic efficiency and sustainability (Cecil *et al*, 2002).

Due to the global demand for food items, the increased costs of mechanization on the farm and the current disposition of financial institutions towards agricultural credits, it became very critical for existing farmers, farm managers and agricultural investors to make informed decisions based on figures, and improve the management of mechanization operations. Bamigboye and Ojolo (2002) opine that the cost of operating farm tractors can be reduced if the right tractor is used for the right operation as well as operating at manufacturers' recommended annual use.

The formulation of appropriate agricultural mechanization strategy that provides the basic conditions for largely self sustaining developments might not be effective without critical assessment of the economic implication of the requisite investment. Profit making is critical to the success and sustainability of any business venture and it is pertinent that agricultural mechanization follow the same trend for a meaningful economic and environmental impact.

The tractor is the main unit of farm machinery and ensures better quality of farm operations, timely completion of farm activities, better management supervision and dignity of labour (Sandeep and Kumar, 2006). Tillage activities in Oyo State-Nigeria especially for large scale farmers are achieved through the use of farm tractors and relevant equipment. The majority of the farm tractors acquired in Oyo State Nigeria are directed towards tillage operation among other uses. AL-Suhaibani S.A and A.E. Ghaly (2006) defines tillage as the process of creating a desirable soil condition for seed germination and growth. Tillage provides good weed control with low herbicide cost; allows the control of disease and insects by destroying them through burying of crop residues. Three things are involved in soil tillage which includes: the power source, the soil and the implement (Olatunji, 2007).

The tillage of soil is considered to be one of the biggest farm operations as it requires the most energy on the farm. Disc plough is widely used in Oyo State Nigeria by farmer as primary tillage tool. Ploughing operation is the mechanical manipulation of the soil aimed at improving soil conditions for crop production. It represents the most costly single item in the budget of an arable farmer. High levels of energy is required to cut and invert the soil, and the draft force required to plough also needs relatively high weight to give traction. (Adewuyi *et al*, 2006). The depth of ploughing depends on the crop to be cultivated, soil characteristics and also on the source of power available (Pandey, 2004).

Disc plough as the major tillage implement used in fields to substitute hoe and cutlass in Oyo State Nigeria is powered essentially by Massey Fergusson, Fiat and Steyr models of farm tractor being the commonly used farm tractors for ploughing operations having long service life and high efficiency among others (Adewoyin and Ajav, 2011). There are many parameters in tillage operation affecting fuel consumption of tractors, such as type and structure of soil, climate, relative humidity, tractor type, tractor size and tractor-implement relationship.

However, management planning and financial performance review of agricultural mechanization has suffered severe neglect especially by our local farmers and farm managers hence, it is perceived as a worthless and profitless business venture (Williams, 2009). However, apt investment and operational decision making are key management practices that are used to command profitability and sustainability of businesses by managers, therefore, efficient use of farm tractors and implement, and their contribution to a producer's relative cost of production is increasingly important (Aaron *et al*, 2003).

The steep rises in the price of tractors and other farm machines have lowered the purchasing power for farm machines by rural farmers and this trend is calling for management planning tool (Asoegwu and Asoegwu, 2007). This study places a particular attention on farm tractors for ploughing operation being the most explored primary tillage operation mode by farmers in the Oyo State Nigeria among several alternatives and, also it is considered as the most significant element of the total crop production systems with the largest fixed and operational costs.

Research has been conducted for measuring the effect of ploughing depth on average and instantaneous fuel consumption with three-share disc plough using fuel flow meter and electronic board (Fathollahzadeh et al, 2009), they reported that some of the factors that affects the fuel consumption of tractors during ploughing operation vary continuously in the farm. Al-Suhaibani S.A. and A.E. Ghaly (2010) investigated the effect of ploughing depth and forward speed on the performance of a medium size chisel plow operating in a sandy soil but the effect of ploughing depth and ploughing speed on the average fuel consumption for varieties of farm tractors operating in the same zone such as Oyo State Nigeria where there is high concentration of tractors and equipment as well as a large number of arable farmers has not been fully investigated and, or explored. In addition, there are no detailed studies in Nigeria related to the consideration of tractor fuel consumption in tillage operations using disc plough at various depths and ploughing speeds despite the fact that cost of fuel constitute over 70% of tractor's operational costs. Disc plough is widely used by Nigerian farmer and the performance data for the ploughing operation is essential to reduce cost of ploughing operation and make economic decisions.

In this research, tractor fuel consumption was measured at different ploughing depths and ploughing speeds.

1. MATERIALS AND METHODS

1.1 Location of Study

Nigeria is the largest country in Africa comprising of thirty six states and the Federal Capital Territory (FCT). It is categorized into eight (8) agro-ecological zones namely; semi-arid, dry sub-humid, sub-humid, humid, very-humid, ultra-humid, mountainous and plateau having various degree of climatic characteristics (FAO, 1991). Each of these zones is characterized by different land and climatic conditions aside the numerous socio-ethnical variations. This research work focused on Oyo State Nigeria where mechanized faming activities are relatively prevalent. The major occupation of the inhabitants is farming.

Oyo State is a typical southern guinea savannah with well drained sandy-loam soil, relatively light vegetation and sub-humid zone with annual rainfall ranging from 1000-1300mm. The climate of the area follows the tropical pattern with bi-modal rainfall peaks in July and September and the season runs from November till March every year with average annual temperature of about 32°C (FAO, 2001). The vegetation and the soil support the cultivation of maize, yam, cassava, legumes and tobacco. The research farmland of the Oyo State Agricultural Development Programme (OYSADEP), located in the northern area of Saki was selected. The farm is fully mechanized with a decent numbers of newly acquired farm equipment. The location of the study site is as shown in Figure 1.

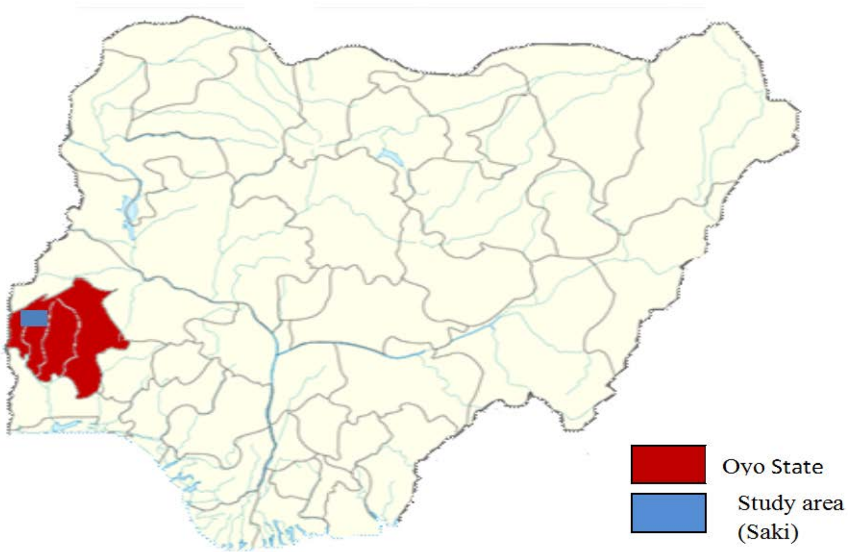

Figure 1. Map of Nigeria showing Oyo state and the study area

2.2 Sample Size and Sampling Techniques

Primary research data were collected using actual field experiments conducted on research farms via well designed completely randomized block designs using computer and statistical tools. The field experiments were conducted on a carefully measured and mapped five hectares farmland having 100 meters by 500 meters dimension on the three (3) research farms. Ploughing time, Ploughing speed, Ploughing depth and fuel consumption were recorded in three replications for each run of the experiment. There were twenty seven (27) runs for each of the three (3) tractor types with three (3) replications resulting in Two Hundred and Forty Three (243) runs. These data were coded in a randomized complete block with both discrete and numeric input variables.

2.3 Experimental Procedure

The field experiments were carried out on the research farmland of the Oyo State Agricultural Development Programme at Saki, Oyo State. Pre-experiment training was conducted for the research assistants with the aim of understanding the research purpose, procedures and ensures adequate understanding of the function of each assistant on the field. The research field was measured, marked and mapped out with pegs to create a 100m length by 500m field. A medium size (100hp), fully instrumented Massey Fergusson, Fiat and Steyr models of farm tractors purchased in 2010 were used to carry out the ploughing operations at the depth of 10, 20 and 30cm for each of 5.5, 6.5 and 7.5km/h tractor speeds. The specifications of each tractor are in Table 1.

Table 1. Farm Tractors Specification

Specifications	Massey Fergusson	Fiat	Steyr
Model	MF 435	F130 D	CVT 170
Type of Engine	4-Cylinder	4-Cylinder	4-Cylinder
Type of Fuel	Diesel	Diesel	Diesel
Type of Steering System	Power-assisted	Power-assisted	Power-assisted
Transmission	8X2 4WD	8X2 4WD	8X2 4WD
Type of Injector Pump	In-line Injector	In-line Injector	In-line Injector
Power Output (hp)	110	100	100
Fuel Tank Capacity (L)	70	70	70
Rated Engine Speed (rpm)	2600	2600	2500
Type of Cooling System	Water-cooled	Water-cooled	Water-cooled

Front Tyre Size	6.0- 16	6.0- 16	6.0- 16
Front Inflation Pressure (psi)	32	32	32
Rear Tyre Size	15.4-28	14-28	16.5-28
Rear Inflation Pressure (psi)	28	28	28

Source: Field Experiment 2011

Each run of the ploughing operation experiment was carried out of a 400m length (4 - to and fro along the 100m field) with three replications each. The same disc plough set with given working width, tilt angle and disc angles was used for the ploughing. Ploughing depth and acquiring tractor speed were adjusted uniformly and stabilized in an area with length of approximately 10 m before the target field length. The speeds of ploughing were determined using the tractor hand throttle and constant gear ratio (monitored on the tractor's dash board) and the ploughing depths were selected and fixed using the tractor depth controller. The ploughing depth was measured using a steel measuring tape with the undisturbed soil surface as a reference (Fig. 2-3).

The fuel tank of tractors was filled to capacity at the commencement of each run of the ploughing operation experiments. Quantity of diesel consumed by each tractor for the ploughing operations were estimated at the end of each run by measuring the amount of fuel required to refill the fuel tank to capacity using measuring cylinders. Three replications of each runs were recorded for each tractor at the varying plough depth and speeds.

Figure 2. The ploughing operation in progress

Figure 3. Measuring ploughing effective width of cut

2. RESULTS AND DISCUSSION

The results of the soil analysis tests carried out on the research farmland is shown in Table 2. The soil is found to be predominantly sandy-loam, almost neutral and has high water retention ability with average moisture content of 16.70% dry basis and 1160 kg/m^3 bulk density. Air temperature measured 23-25 °C during the experiment. This bulk density is slightly higher than the 1102 kg/m^3 reported by Fathollahzadeh *et al*, (2009) on the sandy soils of Tehran, Iran. This is accounted for by the variation in the soil texture and moisture content. Vegetation is sparsely populated in the research location and the soil is nearly neutral with pH level of 7.1

Table 2. Soil Analysis Tests on Research Farm

Variables	Soil Characteristics
pH Level	7.1
% Sand	57
% Silt	19
% Clay	24
Soil Type	Sandy-Loam

Source: Field experiments, 2010

The average fuel consumption for Fiat, Mercy Ferguson and Steyr models of tractor are 23.35, 23.58 and 24.55 l/ha respectively. The fuel consumption of these three tractors were measured for ploughing depths of 15, 25 and 30 cm with 16.70% moisture content, 7.1 pH and 1,206 kg/m^3 bulk density. The summary of the fuel consumption of the three commonly used farm tractors in Oyo State-Nigeria at the various ploughing depth and ploughing speed is presented in Table 3. The operation of the disc plough requires average of 16.79, 22.02 and 32.67 l/ha of diesel for ploughing depths of 15, 25 and 30cm respectively. Analysis of variance and Duncan multiple range tests reveals that tractor fuel consumption increases significantly with increase in ploughing depth at 5% significance level.

Table 3. Average Fuel Consumption of Tractors at Various Ploughing Speed and Depths

	Ploughing Speed (Km/h)			Ploughing Depth (cm)			Tractor Type		
	5.5	6.5	7.5	20	25	30	Fiat	MF	Steyr
$\mathbf{F_c}$	20.00	24.25	27.23	16.79	22.02	32.67	23.35	23.58	24.55
$\mathbf{S_d}$	6.23	7.97	7.93	1.10	6.44	4.02	7.62	7.98	8.29

F_c = Fuel Consumption (l/ha), S_d = Standard Deviation, MF = Massey Ferguson

The fuel consumption value increased by 5.23 liters (31%) when ploughing depth increased from 20 to 30cm while it increased by 10.65 liters (48%) when ploughing depth increases from 25 to 30cm. The increase in fuel consumption when ploughing depth was increased from 20 to 25cm was higher than the increase in fuel consumption when ploughing depth is increased from 25 to 30cm. The linear relationship between tractor fuel consumption and ploughing depth is represented as equation 1.

$$F_c = 1.59d - 15.85 \ (R^2 = 0.966) \qquad (1)$$

Where; F_c - fuel consumption (l/ha) and d - ploughing depth (cm).

Farm tractors' average fuel consumption at ploughing speed of 5.5, 6.6 and 7.5km/h were 20.00, 24.25 and 27.23 l/ha respectively. The average fuel consumption of farm tractors increased with increase in ploughing speed. An increase of tractor ploughing speed from 5.5 to 6.5 km/h resulted in increase of fuel consumption by 4.25 liters(21%) while increase in ploughing speed from 6.5 to 7.5 km/h increased tractor fuel consumption by 2.98 liters (12%). Fuel consumption increased with ploughing speed of farm tractors, the linear relationship is represented by equation 2.

$$F_c = 2.57s + 7.11 \ (R^2 = 0.973) \qquad (2)$$

Where; F_c = fuel consumption (l/ha) and s = ploughing speed (km/h)

The three-dimensional surface relationship between tractor fuel consumption, ploughing depth and ploughing speed is represented as shown in figure 4. The fuel consumption of farm tractors increases with ploughing depth and ploughing speed however the effect of increasing the ploughing depth within the 30 cm top soil depth on tractor fuel consumption is greater than the effect of increasing the tractor ploughing speed from 5.5 to 7.5 km/h.

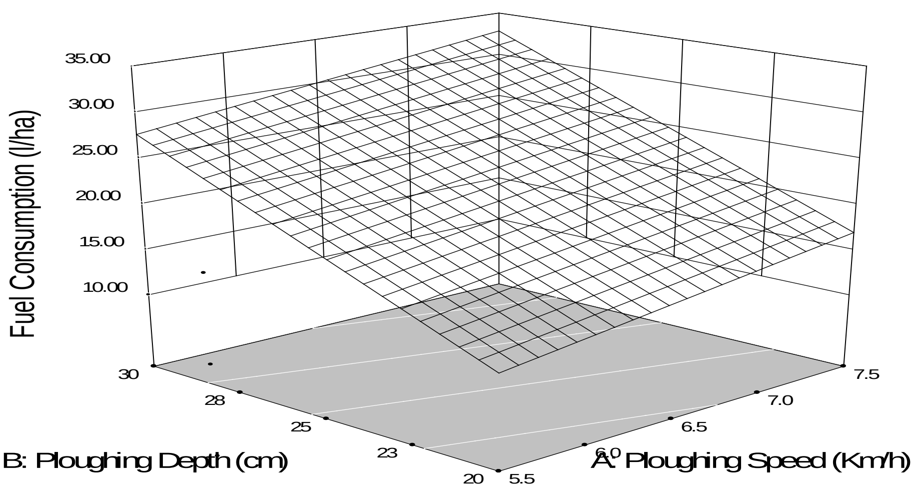

Figure 4. The effect of ploughing speed and ploughing depth on tractor fuel consumption

The effect of ploughing depth and speed on the fuel consumption of farm tractor during ploughing operation on the sandy-loam soil of Oyo State Nigeria was examined in this study. The results reveal that the fuel consumption of farm tractor varies with changes in ploughing speed and depth and the model that gives the best fit is a linear relationship represented in equation 3.

$$F_C = 23.83 + 2.57s + 7.94 + 0.42sd \ (R^2 = 0.965) \qquad (3)$$

Where; F_C –fuel consumption (l/ha), s-ploughing speed (km/h), d-ploughing depth (cm)

The mean fuel consumption of Fiat, MF and Steyr being the commonly used farm tractor in Oyo State-Nigeria as a function of the ploughing depth and ploughing speed is shown in Figure 5. Ploughing depth and speed were varied in this experiment as effective factors that impact the fuel consumption of farm tractors. There are other parameters that affect tractors' fuel consumption during ploughing operation such as compression ratio, plant residue, tractor's size and variation in tractor engine configurations.

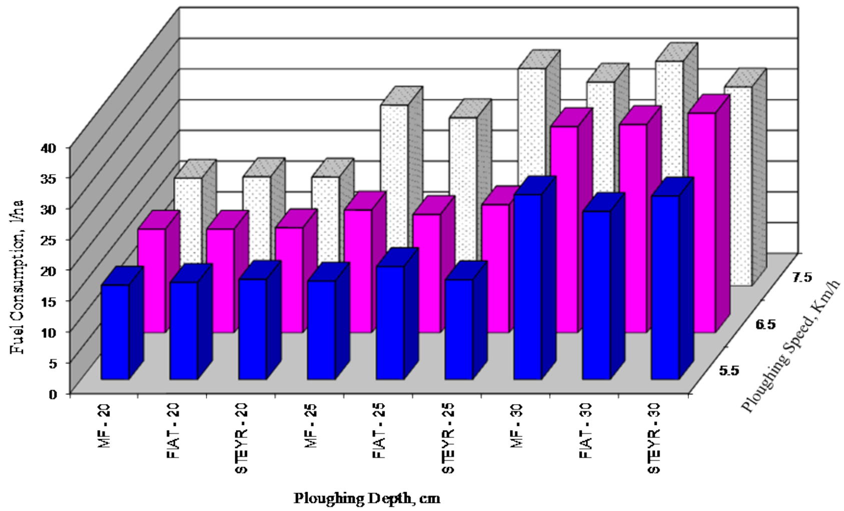

Figure 5. Effect of ploughing depth and speed on the fuel consumption of some commonly used farm tractors on the sandy-loam soil of Oyo state – Nigeria

Fathollahzadeh et al, (2009) examined the effect of ploughing depth on the instantaneous tractor fuel consumption with three-share disc plough using a 72.3kw John Deere 3140 tractor in Iran and they reported that the tractor consumed average of 19.66, 24.71 and 28.64 liters of fuel per hectare for ploughing depth of 15, 23 and 30 cm respectively on a loam-clay soil. The variation in the fuel consumption with ploughing depth agrees with the findings of this work though the value of the fuel consumption in this study are higher than that reported by Fathollahzadeh et al, (2009) because bigger tractors were used in this study and it is expected that bigger tractor will consume more fuel that smaller ones.

Analysis of variance shows that ploughing speed and ploughing depth varies significantly with tractor fuel consumption. The average fuel consumption of 23.35, 23.58 and 24.55 for Fiat, MF and Steyr respectively are however not significantly different ($p \leq 0.05$), this is shown in Table 4. This agrees with the findings of Ahaneku et al, (2009) on the comparative evaluation of three models of Mahildra tractor. They reported that the fuel consumption parameter did not show any significant difference when operated at the same conditions.

Table 4. Analysis of Variance for Tractor Fuel Consumption during Ploughing Operations at various depths and speeds

Sourcce of Variance	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	11423.17	4	2855.79	174.78	< 0.0001
Ploughing Speed	1071.60	1	1071.60	65.58	< 0.0001
Ploughing Depth	10204.75	1	10204.75	624.53	< 0.0001
Tractor type	146.82	2	73.41	4.49	0.0122
Residual	3888.86	238	16.34		
Lack of Fit	3140.53	72	43.62	9.68	< 0.6001
Pure Error	748.33	166	4.51		
Cor Total	15312.03	242			

Source: Field experiment, 2010

Kheiralla *et al*. (2007) measured fuel consumption for a disc plough with three shares attached to a 64kw MF3060 tractor in various conditions. They reported fuel consumption values of 20.6 and 22.7 for 17.4 and 23.4 cm depths respectively. Although the conditions were different, average fuel consumption values obtained in this study are close to those reported by Kheiralla *et al*. (2007) The observed trend signifies that fuel consumption varies with ploughing speed and depth among other factors that affects fuel consumption during ploughing as reported by Srisvastava, 1993 and McLaughlin, 1993. These researchers observed that soil texture, soil moisture content, soil compression ratio, plant residue and bulk density affects tractor fuel consumption during ploughing operation.

Shallow seed placement (less than 25 mm) is recommended for most crops that are directly seeded (Collins and Fowler, 1996). However, the depth of the crop roots should determine plowing depths, while the availability of time and implement width will determine the speed required to finish the work on time (Mustafa and Turgut, 2007). The results obtained from this study indicated that the ploughing depth has more effect on the tractor fuel consumption than the ploughing speed. Therefore, the depth of plowing should be determined based on the root length of crop. Increasing the ploughing speed will improve the quality of the seedbed and will not increase the fuels consumption proportionally.

3. CONCLUSIONS

The effect of ploughing depth and ploughing speed on the fuel consumption of commonly used farm tractors in Oyo State- Nigeria was investigated. The results indicated that increase in ploughing depth and ploughing speed significantly increases tractor fuel consumption. However, ploughing depth is the most impactful factor in the determination of tractor fuel consumption during ploughing operations.

The depth of ploughing operation should be determined based on the root type, length and size of crop to be cultivate, while the availability of time, soil texture and implement width will determine the speed required to finish the ploughing operation. The results obtained from this study indicate that the ploughing depth has more effect on the fuel consumption of farm tractors than the ploughing speed. Therefore, the depth of plowing should be determined based on the root length of crop in other to optimize cost of fuel.

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ANTHROPOMETRY DIMENSIONS AND PROTECTIVE WEARS FOR FOOT AND HEAD: A CASE STUDY OF SELECTED POLYTECHNIC STUDENTS IN THE SOUTH ZONE OF NIGERIA

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ABSTRACT

Human body compositions change with age and other related factors, and as such the anthropometric dimensions developed from one region may not be appropriate to be used when designing machines and fittings for people living in another region. This study presents the anthropometric data of Nigerian polytechnic students, which helps to develop and modify foot-and-head protective wears suitable for the people of the region. Eight anthropometric data useful for the design of foot-and-head protective were selected and measured from 800(400 male and 400 female) subjects within the age of 18-30 years. Data obtained was analyzed using independent samples T-test by SPSS (version 18.0). The measurements were compared between two genders and among other ethnic populations of the world. The results showed that male were larger in all the mean dimensions and significant difference was only noticed on foot length dimension for both genders at ($p>0.05$). The results also indicate differences among various foot-and-head dimensions while comparing with other ethnic populations of the world. It is recommended that the study should be extended to different tertiary institutions in our country in order to generate design database for efficient production of foot-and-head facilities and fittings for Nigerian polytechnic students.

KEYWORDS: Foot and head, protective wears, male and female, polytechnic students, anthropometric dimensions.

1. INTRODUCTION

Many studies have shown a mismatch between anthropometric dimensions and protective wears produced for foot – and – head in many countries of the world. New materials and design techniques allow for the creation of more sophiscated foot – and – head protective equipment that has the potential for providing significant improvement in protection level. But in order to maximize the advantages offered by these new products, it is essential to have an understanding of the anthropometric variability of the population that must be protected. Hsiao and Halperin (1998) confirmed that inadequate fit of personal protective equipment can expose workers to injury devices which cannot guarantee the health and safety of workers.

Wearing unfitted shoes lead to foot disorders, mental impacts, dexterity and comfort reduction, increasing energy consumption and decreasing the subject efficiency of performing tasks (Simon, 2004). Zhizhong et al. (2007) discovered differences in body dimensions of elderly Chinese and the Japanese. They found out that the elderly Japanese had larger head dimensions and extremities than their Chinese counterparts; whereas there is larger dimension of body trunk for the Chinese elderly compared to Japanese elderly.

At present, helmets and foot wears are playing vital roles on our bodies not only for beautification but also for safety. Few years ago, Nigerian government came up with white elephant project of passing the bill of wearing helmets by bike users into law without considering the anthropometric head measurements of the target users. The law could not be effective because the helmets being used were not produced with the anthropometric head dimensions of the target users. Most times, these helmets cause discomfort, headache and burden to the users. Head contains the brain which is the centre of reasoning and for this cause; every step should be taken to ensure that head dimensions are included in the design of head protective wears to ensure that exertion of burden is reduced to the barest minimum.

In Nigeria, researches on foot-and-head anthropometry are scanty or virtually non-existence. Millions of workers in Nigeria including students rely on protective equipment to reduce the risk of occupational diseases and injuries on workshops and farms. The ability to achieve proper foot – and – head fittings for Nigerian population is essential for providing adequate protection to workers. Xiao et al. (1998) measured 41 head – and – face dimensions on 393 Chinese adults. From the collected data, they were able to create regression equations to predict head – and – face dimensions from seven basic measurements collected in 1998. Quamra et al. (1980) also generated regression equation for estimation of stature from foot length. The inspection of the equations reveals that for a given foot length, men are predicted to be taller than women, and hence foot length is greater relative to stature in women than in men.

Left and right feet have almost one quarter of the bones in the body making it an integral part of the body. These bones are joined together to form joints which are firmly held together with the layers of 126 muscles and ligaments (Kanaani et al; 2010). When these muscles become overstretched possibly due to the variability in footwear design techniques, might cause repetitive motion injuries that can further weaken the ankles and muscles.

The objectives of this study are to develop foot-and-head anthropometric database for Nigerian polytechnic students for better design, determine the level of statistical significance of mean anthropometric dimensions of male and female Nigerian polytechnic students, and compare the differences in foot – and – head bodily proportions among four ethnic populations of the world.

2. MATERIALS AND METHODS

2.1 Sample

The sampling strata consisted of 800 students of Auchi, Ogwashi-uku, Ozoro and Bori Polytechnics in Edo, Delta and Rivers states which are located in the South South Zone of Nigeria respectively. A group of 100 male and 100 female students within the age range of 18 – 30 years were selected across each of the four polytechnics based on their willingness and readiness to participate in this study.

2.2 Instruments

Traditional anthropometric instruments were used and these included anthropometer, a steel measuring tape, digital venier caliper, caliper and digital height gauge. The anthropometer, calipers and digital height gauge were manufactured by GPM in Switzerland. The tape is manufactured by Lufkin in the United States.

2.3 Anthropometric Variables Considered

Eight anthropometric variables were considered and collected in this study as shown in Fig. 1. The variables selected were related to head, foot, weight and stature of human body. Weight and stature were taken because they form a set of useful basic body descriptors allowing this data set to be compared to others. Accuracy and reliability of the measurements were achieved by undergoing through a specific training with a certified anthropometrics specialist and practice in performing measurements at the pilot study carried out previously.

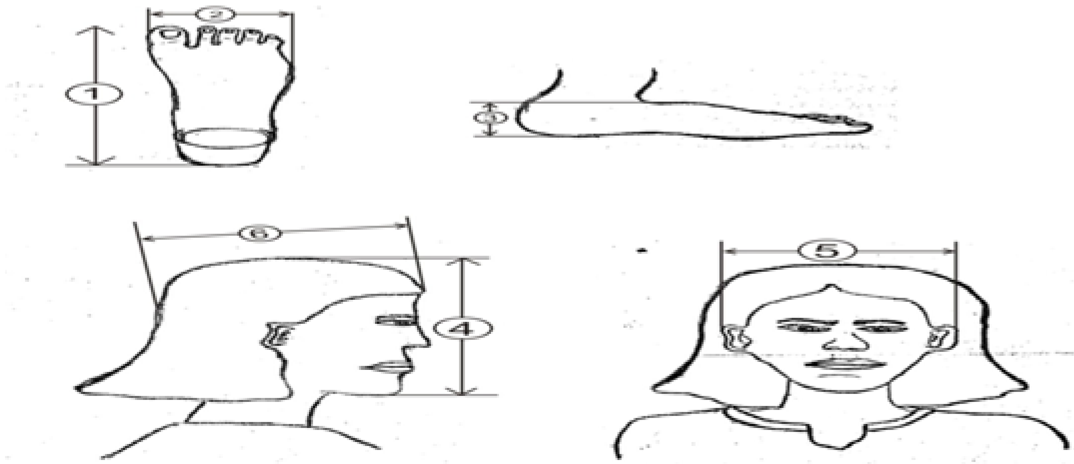

Fig. 1. Selected Anthropometric Variables
(1) Foot length (2) Foot breadth (3) Foot height (4) Head height (5) Head breadth (6) Head length

2.4 Data Analysis

The data were examined using SPSS analysis to determine the descriptive statistics (mean, standard deviation, standard error of mean, coefficient of variation, minimum, maximum, 5th, 50th and 95th percentiles). The data obtained from male and female students were compared for both genders using simple T-test (2-tailed) at 5% level of significance.

3. RESULTS AND DISCUSSION

The foot-and-head anthropometric variables of 800 Polytechnic students in the South South of Nigeria: 400 males and 400 females are measured and the comparative analysis presented in Fig. 2 and 3 and Tables 1 and 2.

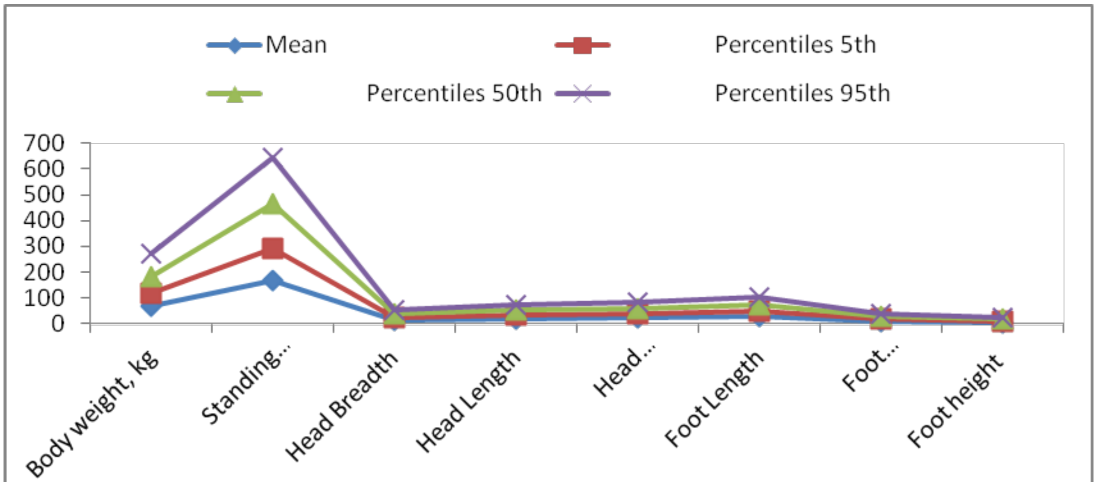

Fig. 2. Comparative presentation of different head and foot dimensions of male students

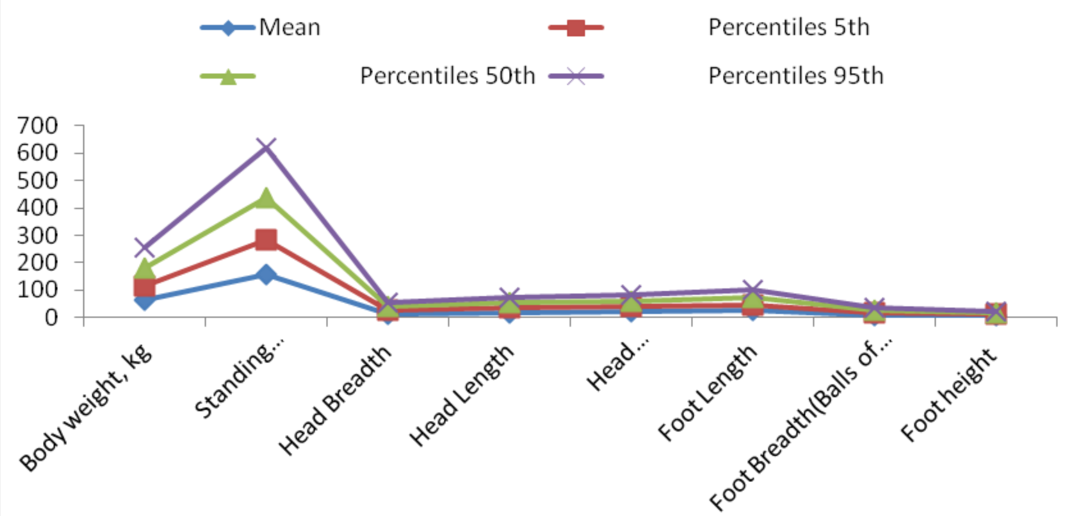

Fig.3. Comparative presentation of different head and foot dimensions of female students

Table 1. Foot and Head Anthropometric Data of Nigerian Male Polytechnic Students

Body Dimension	Mean	Std. Error of Mean	Std. Dev	Min	Max	Percentiles		
						5th	50th	95th
Head Breadth	12.5	0.2	0.8	11.4	14.1	11.4	12.5	14.1
Head Length	17.8	0.3	1.4	15	20.2	15	17.8	20.2
Head Length (maximum)	20.8	0.4	1.7	17.8	23	17.8	20.5	23
Foot Length	25.7	0.4	2.0	21.9	28.5	21.9	25.6	28.5
Foot Breadth (Balls of Foot)	9.1	0.3	1.1	7.6	11.4	7.6	9.0	11.4
Foot height	5.6	0.2	0.4	4.5	5.8	4.5	5.8	5.8

Table 2. Foot and Head Anthropometric Data of Nigerian Female Polytechnic Students

Body Dimension	Mean	Std. Error of Mean	Std. Dev	Min	Max	Percentiles		
						5th	50th	95th
Head Breadth	13.1	0.1	0.7	11.9	14.1	11.9	13	14.1
Head Length	18.2	0.3	1.1	16.7	20.0	16.7	18.4	20
Head Length (maximum)	20.6	0.3	1.5	18.4	23.4	18.4	20.2	23.4
Foot Length	25.1	0.6	2.4	20.3	29.0	20.3	25.4	29
Foot Breadth (Balls of Foot)	8.5	0.2	0.7	6.9	10.0	6.9	8.7	10
Foot height	5.3	0.1	0.4	4.7	5.8	4.7	5.3	5.8

Body dimensions which also included foot - and – head measurements are reported to change due to age, nutritional intake, race, gender among others (Agrawal et al; 2010). To investigate these differences, statistical T – test analysis were used to compare anthropometric variables of male and female gender at 0.05 significance and the results are provided in Table 3.

Table 3: T-Test Analysis of male and female anthropometric data of Nigerian polytechnic students

Body Dimensions	Mean Male	Mean Female	N	Tcal	Df	sig. (2-tailed)	Decision p>0.05
Body Weight(kg)	66.7	62.7	800	1.344	799	0.195	NS
Standing Height(stature)	167.3	157	800	0.84	799	0.42	NS
Head Breadth	13.1	12.5	800	-1.798	799	0.088	NS
Head Length	18.2	17.8	800	-1.143	799	0.267	NS
Head height	20.8	20.6	800	0.432	799	0.671	NS
Foot Length	25.7	25.1	800	-0.901	799	0.379	NS
Foot Breadth (Balls of Foot)	9.1	8.5	800	2.038	799	0.056	S
Foot Height	5.6	4.8	800	1.600	799	0.154	NS

Note: all dimensions in cm except mentioned

The result of T – test analysis for both genders demonstrate differences between males and females foot – and – head dimensions. Male were larger in all the dimensions. Furthermore, significant difference was only noticed between the male and female foot breadth dimensions at (P > 0.05). Thus, designers and manufacturers of foot – and – head protective of this population groups should give consideration to data generated when designing any product.

The mean foot length of male and female students were 25.7cm and 25.1cm respectively, which is useful in the design of accelerator pedal, clutch pedal, brake pedal and similar other foot-operated controls. For efficient and effective design of helmets and other related head wears, the mean head breadth of 13.1cm, head length of 18.2cm and head height of 20.6cm for male polytechnic students and mean head breadth of 12.5cm, head length of 17.8cm and head height of 20.8cm for female polytechnic students respectively should be considered.

The comparison of bodily proportion among four ethnic populations of the world is shown in Table 4.

Table 4. Comparison of mean of foot- and- head proportions to the mean stature for present study and other ethnic population of the world

Measurement (cm)	Nigeria (Present study)		Malays (Karmegam, et al; 2011)		Chinese (Karmegam, et al; 2011)		Indians (Karmegam, et al; 2011)	
	Male	Female	Male	Female	Male	Female	Male	Female
Head breadth	0.0834	0.07472	0.0856	0.0982	0.0909	0.0921	0.0882	0.0913
Head length	0.1159	0.1064	0.1020	0.1146	0.1064	0.1117	0.1079	0.1168
Head height	0.1243	0.1312	0.1367	0.1454	0.1448	0.1417	0.1366	0.1389
Foot length	0.1536	0.1599	0.1519	0.1466	0.1497	0.1459	0.1526	0.1497
Foot breadth	0.0544	0.0541	0.0556	0.0553	0.0571	0.0545	0.0571	0.0552

The present study (Nigerian) has the lowest foot breadth, head breadth and head height but the largest foot length. The result also shows that the present study (Nigerian) has largest head length among males and relatively lowest head length among females. More so, the Chinese male has the greatest head breadth followed by Indian males whereas among females, Malays have the largest head breadth followed by Chinese. However, Chinese males have similar foot breadth with Indian males but among females, Malays has the largest foot breadth. The Chinese females generally tend to be smallest in both foot length and head length whereas Indian females have the largest head length among the ethnic populations. Head height of Chinese male was observed to be largest followed by Malays and Indians with close similarities in values. Among females, Malays has the highest values of head height followed by Chinese and Indians; Nigerians (present study) being the least.

The study presents compilation of foot – and – head anthropometric data of male and female selected Polytechnic students in Nigeria that would be used as a guide for designing and modifying of accelerator pedals, clutch pedals, brake pedals, helmets and foot operated controls and other similar products for foot –and- head protections.

4. CONCLUSIONS AND RECOMMENDATIONS

According to the research findings in this study, the following details were concluded. The comparison of foot-and-head anthropometry between male and female students of Nigerian Polytechnics, could be concluded that male students have highest values in all foot-and-head sizes more than their female counterpart; with only foot breadth been statistically significant at ($P>0.05$).

The characteristics of bodily proportion among the four different ethnic populations of the world for both genders are not similar. Significant differences exist among them. These anthropometric variables can be utilized in the design of foot and head protective, pedal for accelerators, clutch pedals, brake pedals, foot wears, caps and other foot - and – head fittings and facilities. It is recommended that extensive surveys for both male and female students of south south Nigerian Polytechnics be extended to other tertiary institutions of the country in order to generate design database for safe and efficient production of foot wears, foot operated machines, head protection facilities and fittings for Nigerian students.

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DETERIORATION OF CELOSIA (*Celosea argentea*) AND PEPPER (*Capsicum frutescens*) IN A METAL –IN – WALL EVAPORATIVE COOLER

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ABSTRACT

Due to the high rate of deterioration of fruits and vegetables particularly after harvesting in Nigeria, there is need for the development of an efficient storage structure for such highly perishable products. A metal in wall evaporative cooler was evaluated using fresh pepper and celosia to ascertain the optimum period that they could be stored without losing their essential nutritive values. The metal-bin walled evaporative cooling system consists of a brick wall, a cooling chamber (metallic box) and a coarse sand which act as the evaporating medium. The study revealed that there were continuous decrease in the food quality parameters such as ash content from 2.95% to 1.83% for celosia and 1.03% to 0.17% for pepper, fat content decreased from 1.80% to 1.04% for celosia and 1.14% to 0.89% for pepper, carbohydrate content decreased from 4.06% to 0.03% for celosia and 7.88% to 3.66% for pepper, protein content decreased from 4.77% to 4.51% for celosia and 2.61% to 2.05 for pepper and fibre content decreased from 2.73% to 2.49% for celosia and 1.09% to 0.80% for pepper, while the value of moisture content increased from 83.69% to 90.10% for celosia and 86.25% to 92.43% for pepper with increase in storage days. It was discovered that the cooling chamber had an average temperature drop of about 7° C when compared the ambient temperature and an average relative humidity drop of about 4% was experienced throughout the period of the study. The maximum storage days of celosia inside the cooler was 7 days while that of pepper inside the cooler was 10 days for both of them to retain their optimal nutritive value.

1. INTRODUCTION

A significant part of the world agricultural food production is fruits and vegetables, even though their production volumes are small when compared with grains, legumes and tuber crops. They remain important sources of digestible carbohydrates, minerals and vitamins, particularly vitamins A and C. In addition, they provide roughage (indigestible carbohydrates) which is needed for normal healthy digestion (Salunkhe and Kadam 1995). Recent researches have proven that nutrients in fruits and vegetables do more than just prevent deficiency diseases for instance beriberi or rickets, findings reveal that certain vitamins or vitamin precursors in produce, notably vitamin C; beta-carotene as well as polyphenols are powerful antioxidants (Consumer Reports on Health, 1998).

The shelf-life of vegetables is related to some biochemical processes that take place after harvest. Physiological actions such as respiration involves heat emission resulting in temperature increase and consequently accelerates metabolic processes and decay phenomena (Sánchez-Mata *et al*. 2003). Green vegetables have high respiration rate which limits their shelf-life after harvest to a maximum of 1-4 weeks. This is partly attributed to the high metabolic activity of the leaves and in some cases the seeds inside some of the fruits (Wills *et al*. 1999). However, at later stages of ripening, the degradation process increases with the hydrolysis of starch and the consumption of soluble sugars on respiration (Muñoz-Delgado 1985).

As a measure to improve the shelf-life of vegetables, several researchers have recommended the storage of these products at 4-10^{o}C (Wills *et al*. 1999). Modified or controlled atmosphere storage is also a useful technique for extending shelf-life of vegetables, especially for those that deteriorate quickly (Sánchez-Mata *et al*. 2003). Kadder (1997) reported that in general, oxygen level should be kept under 5% to obtain decreased respiration activity and in turn cause reduction of oxidize activities, such as polyphenol-oxidase, ascorbate-oxidase and glycolic-oxidase (Sánchez-Mata *et al*.2003). Low oxygen levels can also induce the suppression of genes that codify maturation associated enzymes, such as cellulose, polygalacturonase, acid invertase, sucrose-phosphate-synthase and amine cyclopropane-1-carboxylate-oxidase (Kanellis *et al*. 1991).

The study is aimed at evaluating the deterioration of celosia and pepper stored inside metal in-wall evaporative cooler and thereby estimating the storage period of the produce.

2. MATERIALS AND METHODS

2.1 Experimental Location

The experiment was carried out using an already designed and constructed metal-in-wall evaporative cooling structure located at the department of Agricultural Engineering, The Federal University of Technology Akure in Akure south local government area, Ondo State, Nigeria which is between the Latitude of 30^{o} North and Longitude 15^{o} West. Readings were taken and recorded for both the air conditions inside the evaporaive cooling system and ambient conditions simultaneously. Measurements included temperature using digital thermometer, relative humidity using digital hydrometer, moisture content using standard gravimetric method and air movement using digital anemometer. Deterioration of the stored produce was determined using standard methods of proximate analysis as suggested by AOAC (1990).

2.2 Description of the Structure

The metal bin wall evaporative cooling system consists of a brick wall, a cooling chamber (metallic box) and a coarse sand which act as the evaporating medium due to its wide availability in the area. The dimension of the evaporative cooler is 600mm × 600mm × 600mm while the entire dimension of the whole cooling system is 1500mm × 1100mm × 600mm. The coarse sand used was obtained from river bed. This isometric view of the cooler and the internal features are shown in Figures 1, 2 and 3 respectively. The metallic box was installed into the brick wall while the clearance between the brick wall and the metallic box was filled with the coarse sand above the height of the metallic box. The coarse sand was kept moistened daily, therefore as evaporation takes place through the coarse sand, there is a resultant cooling of the produce stored inside the cooling chamber. The design and construction of the evaporative cooler has been reported by Falayi and Jongbo (2011).

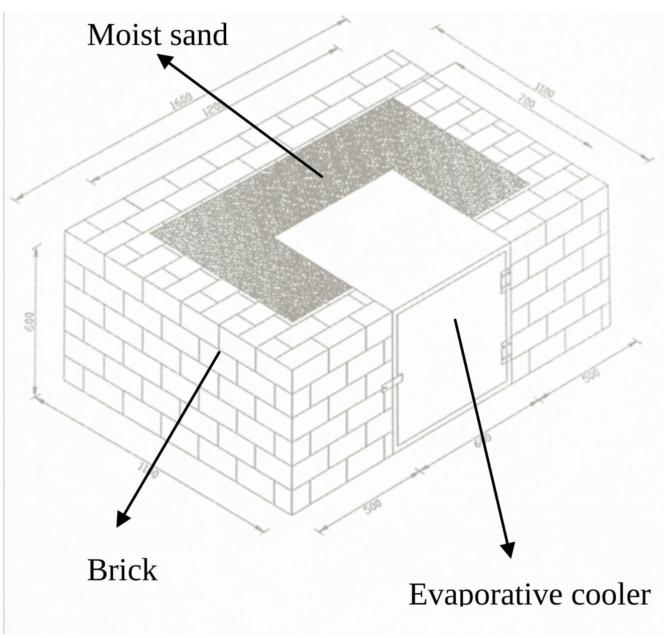

Figure 1. Isometric view of the storage structure

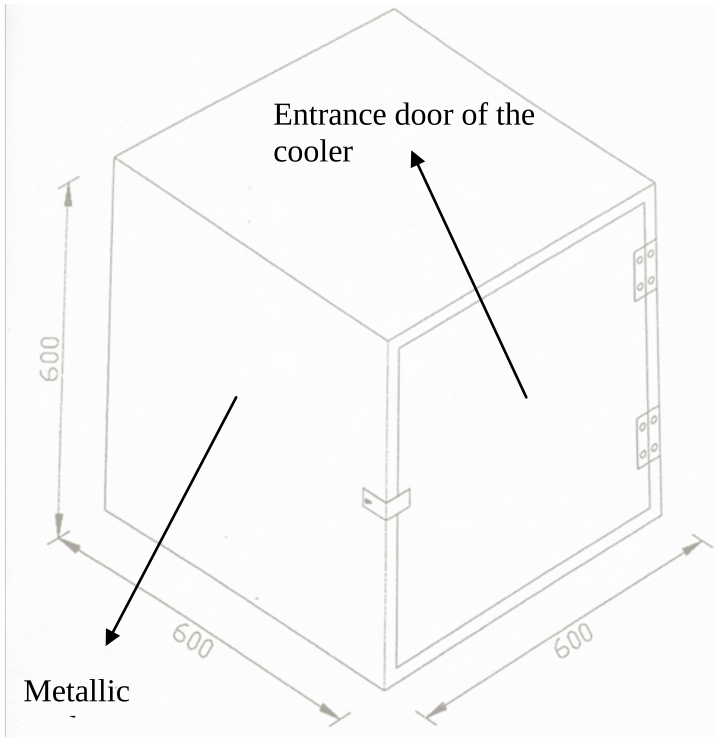

Figure 2. Isometric view of the cooling chamber

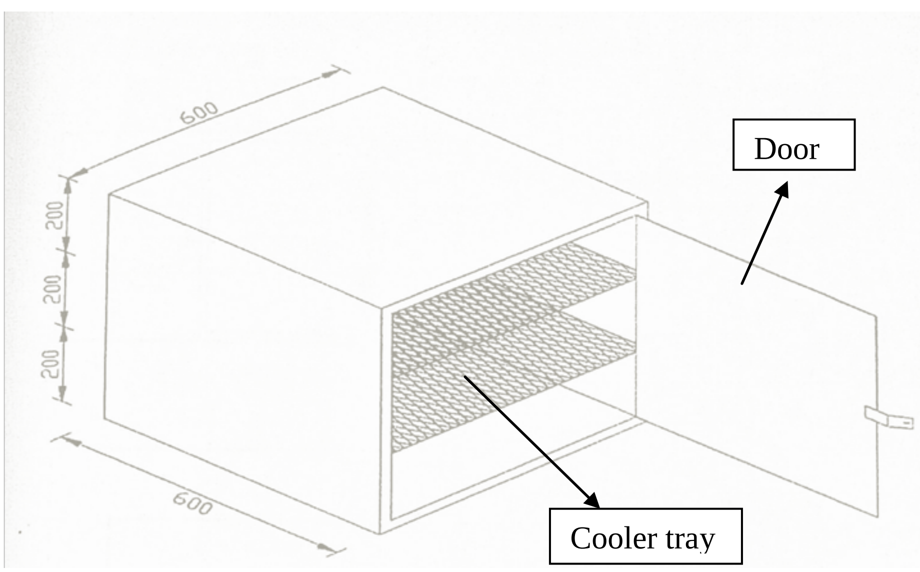

Figure 3. Arrangement of the tray inside the cooling chamber

2.3 Performance Evaluation

Samples of pepper and celosia used for this study were obtained from Agricultural Engineering Farm and Crop Soil and Pest Farm located within Federal University of Technology, Akure. The samples were first assessed for the required nutritional qualities and then prepared and stored in the evaporative cooler. Samples of the vegetables were taken every day and assessed for their nutritional qualities using proximate analysis until the entire samples got deteriorated. Parameters such as Moisture content, Fat content, Ash content, Fibre content, Protein content and Carbohydrate content were assessed using proximate analysis. In addition to the nutritional quality parameters being assessed, the temperature and the relative humidity of the storage system were monitored throughout the storage period. Data obtained from the tests were subjected to appropriate statistical analysis such as analysis of variance (ANOVA), regression analysis and test of significance using Excel software package.

3. RESULTS AND DISCUSSION

3.1 Moisture Content

The results of the average moisture content of the products are as shown in Figure 4. It was observed that moisture content of the stored products in structure increased from 83.69% to 90.10% for celosia while that of pepper increased from 86.25% to 92.43%. The increase in moisture content obviously was as a result of increased relative humidity. This corresponds to the report that moisture content of vegetables on wet basis is between 92.8% and 62.9% % (Javid et al., 2011). Also, according to Anthony and Effiong (1998), the maximum value of moisture content in vegetables is 90% which implied that the maximum storage days of celosia is 20 days while that of pepper is 16 days for the product to maintain adequate moisture content. The regression equations show a high correlation coefficient (R^2=0.92 and 0.95 for celosia and pepper respectively).

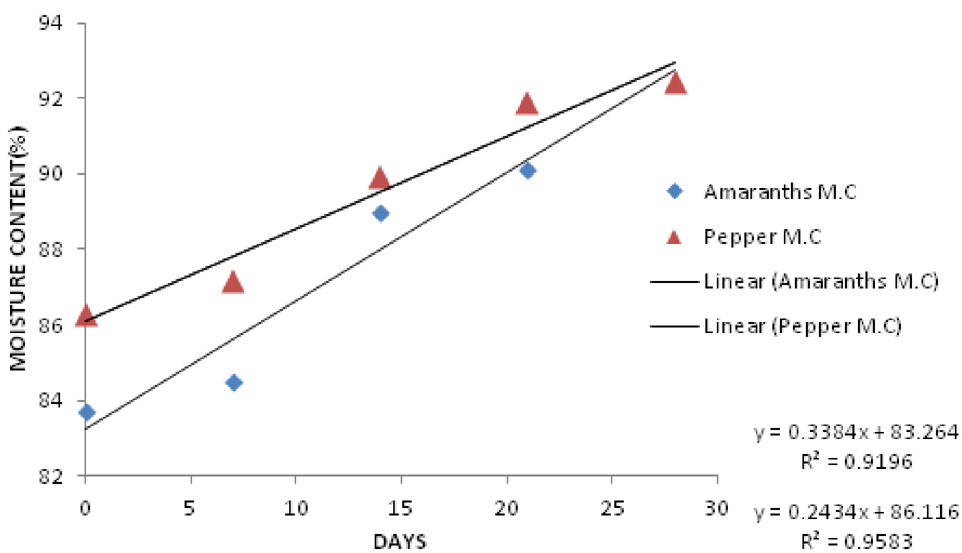

Figure 4. Relationship between moisture content and no of days

3.2 Ash Content

The results of the ash content showed that there was gradual decrease in the ash content as the storage period increased. The ash content decreased from 2.95% to 1.83% for celosia and ash content for pepper deceased from 1.03% to 0.17% which implied that 37.97% of the values of ash content were lost from celosia within three weeks and 83.50% of the values of ash content were lost from pepper. These values are by no means small when one is concerned with nutritional values. Using the recommendation of Anthony and Effiong 1998, the minimum standard for ash content in vegetables is that it must be 30% less from the initial content which are 2.07% for celosia and 0.721% for pepper. It was also reported that the ash content, which is a measure of the mineral content of food, had values ranging from 8.10 - 6.30% (Nnamani et al., 2009). Omale and Ugwu (2011) lately asserted that the ash content of vegetables is between 4.00% to 12.53%. Lockett had also reported high ash content in some green vegetables used by the lactating mother such as bitter leaves, *Veronia colorata* (15.9%) and *Moringa oleifera* (15.1%) (Lockeett *et al*., 2000). From the regression graph of Figure 5, it shows that for both equations of the crops, the maximum storage days of celosia is 15 days while that of pepper is 10 days in terms of ash content. The R^2 value was very high.

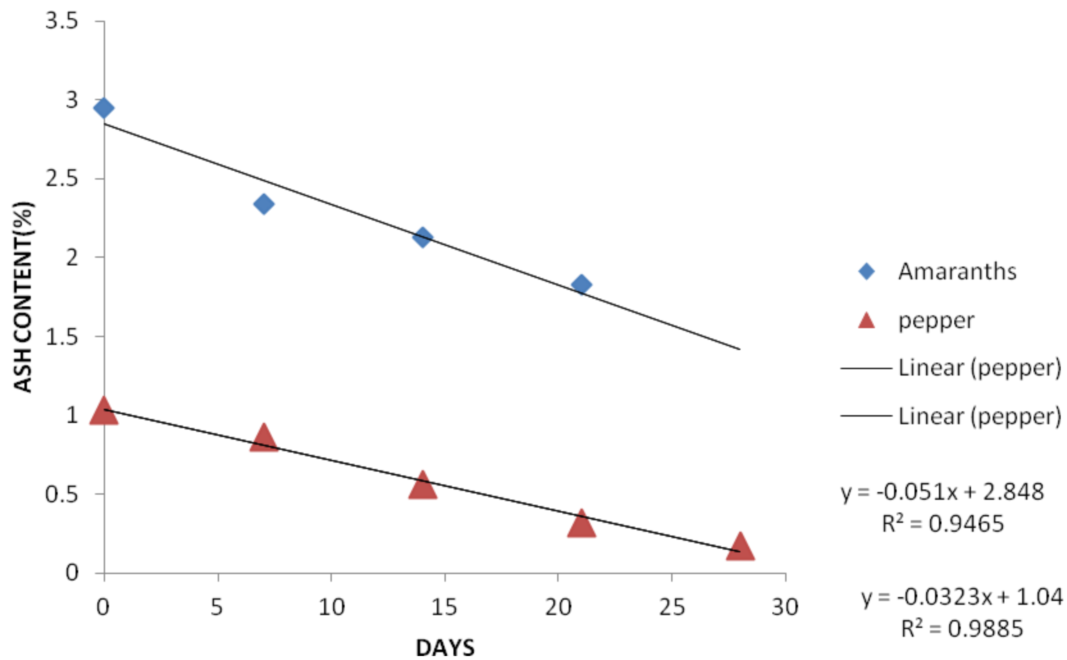

Figure 5. Relationship between ash content and no of days

3.3 Protein Content

The result of the protein content for the products is as shown in Figure 6. Protein content decreased from 4.77% to 4.51% for celosia while pepper decreased 2.61% to 2.05% showing that 5.45% and 21.46% of the values of protein content were lost in celosia and pepper respectively. As the period of storage increases, the protein content of the samples decreases which may be due to the difference in variety and environmental conditions. Nnamani et al. (2009) reported that Crude protein in vegetables had values ranging from 8.74 - 5.12%. He observed further that the amount of protein which is about 75% (when converted) of the total nitrogen in the leafy vegetables is variable, ranging from 5 – 10% of fresh weight or 13 - 30% for dry weight basis. These percentages are higher than the 3 – 8% and 11 – 28% results reported by Oyenuga and Fetuga (1975).

Omale and Ugwu (2011**)** estimated the crude protein content in some selected vegetables parts to be between 0.04 ± 0.03%and 2.67 ± 0.58%. Nevertheless, the protein contents determined for vegetable samples by Javid et al. (2011) were found to range from 7.8% to 16.9%. According to Anthony and Effiong 1998, the minimum standard for protein content in vegetables is that it must be 30% less from the initial content which are 3.33% for celosia and 1.827% for pepper. From the regression graph of Figure 6, it shows that for both equations of the crops, the maximum storage days of celosia is 122 days while that of pepper is 44 days in terms of protein content. The R^2 value is high.

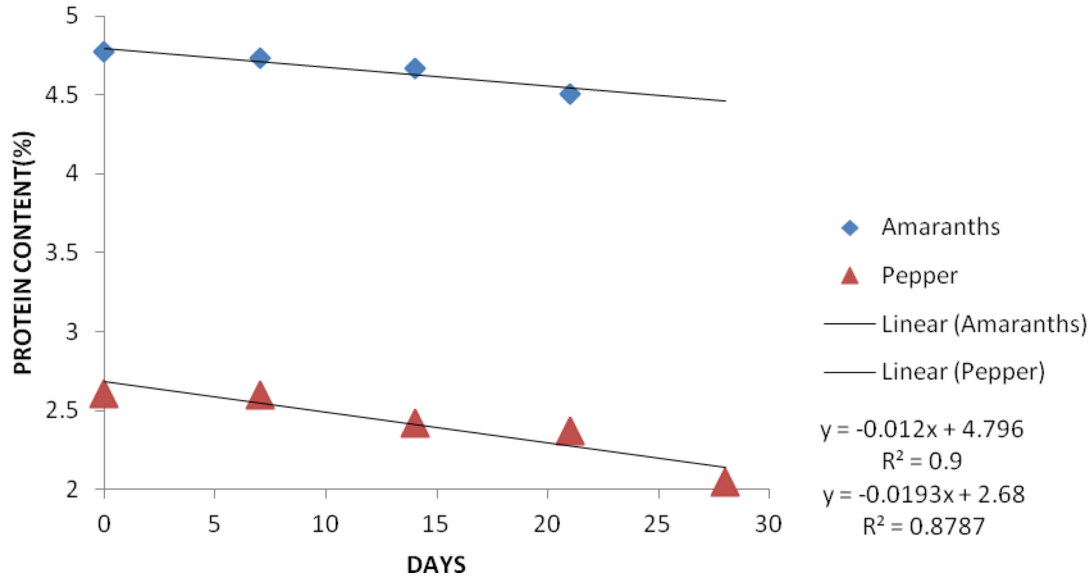

Figure 6. Relationship between protein content and no of days

3.4 Fat Content

Fat content reduced from 1.80% to 1.04% celosia while fat content also decreased from 1.14% to 0.89% for pepper in Figure 7, this shows that 42.22% and 21.93% of the values of fat content were lost in celosia and pepper respectively. As the period of storage increases, the fat content of the samples decreases. Also using Anthony and Effiong 1998, the minimum standard for fat content in vegetables is that it must be 30% less from the initial content which are 1.26% for celosia and 0.728% for pepper but research conducted has also shown the crude fat content of *some vegetables* ranged from 3.50 to 2.10% (Ajayi et al., 2006). From the regression graph of Figure 7, it shows that for both equations of the crops, the maximum storage days of celosia is 18 days while that of pepper is 46 days in terms of fat content. The R^2 value is very high.

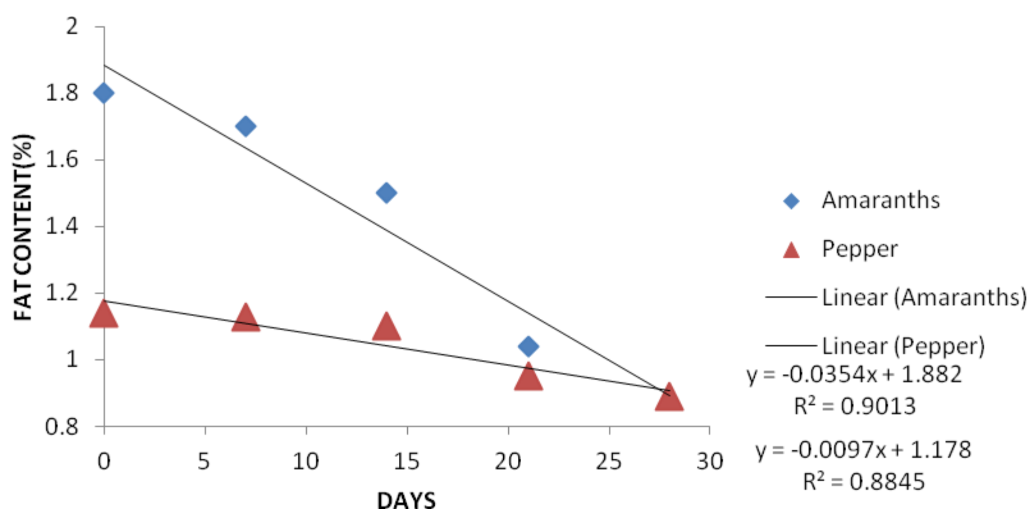

Figure 7. Relationship between fat content and no of days

3.5 Fibre Content

Fibre content of celosia and pepper decreased from 2.73% to 2.49% and 1.09% to 0.80% respectively in Figure 8, which implied that 8.79% and 26.61% of fibre content were lost in celosia and pepper, respectively. The fibre content of the samples decreased with increase in storage period. According to Anthony and Effiong 1998, the minimum standard for fibre content in vegetables is that it must be 30% less from the initial content which are 1.911% for celosia and 0.763% for pepper. Nnamani et al. (2009) reported that the fibre content of leafy vegetables ranges from 2.50 - 4.50%. These exceeded the fibre content of *T. triangulare* (2.0%) *T. occidentalis* (1.7%) and *C. argentea* (1.8%) (Akachukwu and Fawusi, 1995).

Figure 8 shows that for both equations of the crops, the maximum storage days of celosia is 74 days while that of pepper is 28 days in terms of fibre content. The coefficient of correlation (R^2) is very high.

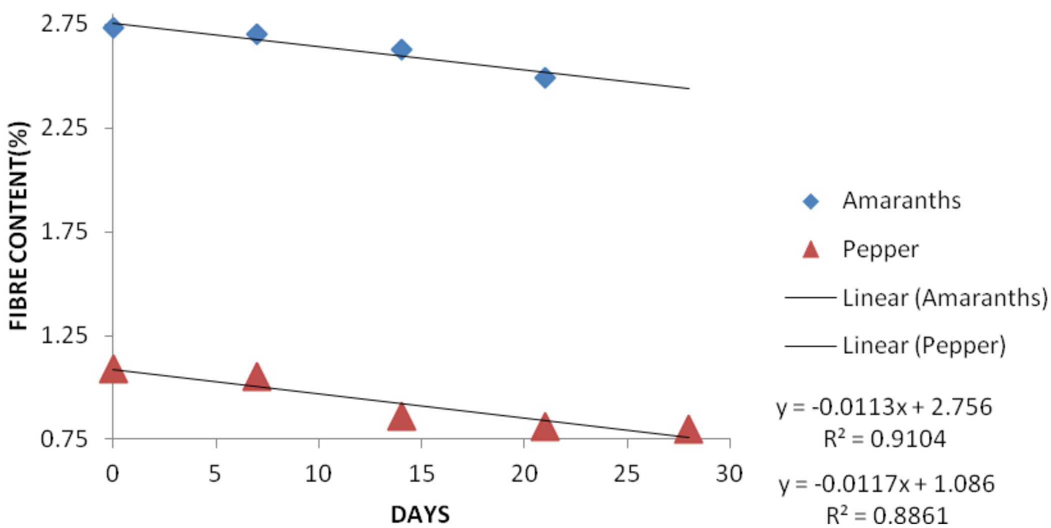

Figure 8. Relationship between fibre content and no of days

3.6 Carbohydrate Content

The carbohydrate content decreased from 4.06% to 0.03% for celosia and 7.88% to 3.66% for pepper as shown in figure 9, showing that 99.26% and 53.55% of the values of carbohydrate content were lost in celosia and pepper, respectively. As the period of storage increases, the carbohydrate content of the samples decreases. Previous research showed that the carbohydrate level of the underutilized indigenous vegetable ranged from 58.94% in *Z. zanthoxyloides* to 66.20% in *A. cissampeloides*. (Nnamani et al. 2009). According to Anthony and Effiong 1998, the minimum standard for protein content in vegetables is that it must be 30% less from the initial content which are 2.842% for celosia and 5.516% for pepper. From the regression graph of Figure 9, it shows that for both equations of the crops, the maximum storage days of celosia is 122 days while that of pepper is 44 days in terms of carbohydrate content. The R^2 value is high.

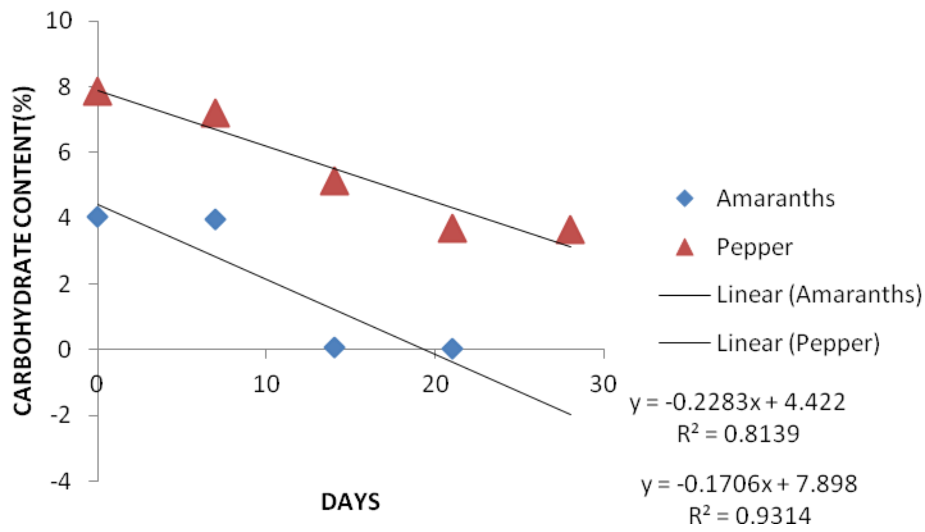

Figure 9. Relationship between carbohydrate content and no of days

3.7 Variation in Temperature and Relative Humidity

Variations in temperature of the evaporative cooling chamber and ambient storage were recorded as shown Figures 10, 11 and 12. The temperature inside the cooling chamber was significantly lower than the ambient temperature. The cooling chamber had an average temperature drop of about 7° C when compared the ambient temperature. As expected, the temperature inside the cooler was lowest in the morning followed by evening temperature, while temperature during the afternoon was highest throughout the period of study as shown in Figure 11. The average relative humidity inside the cool chamber was found to be significantly higher than the outside ambient relative humidity as shown in Figures 13, 14 and 15. A further analysis showed that an average relative humidity drop of about 4% was experienced throughout the period of the study which is similar to the result of Odey *et al* (2005). Also as expected, the relative humidity inside the cooler was highest in the morning period and lowest in the afternoon throughout the period of the study as shown in Figure 14.

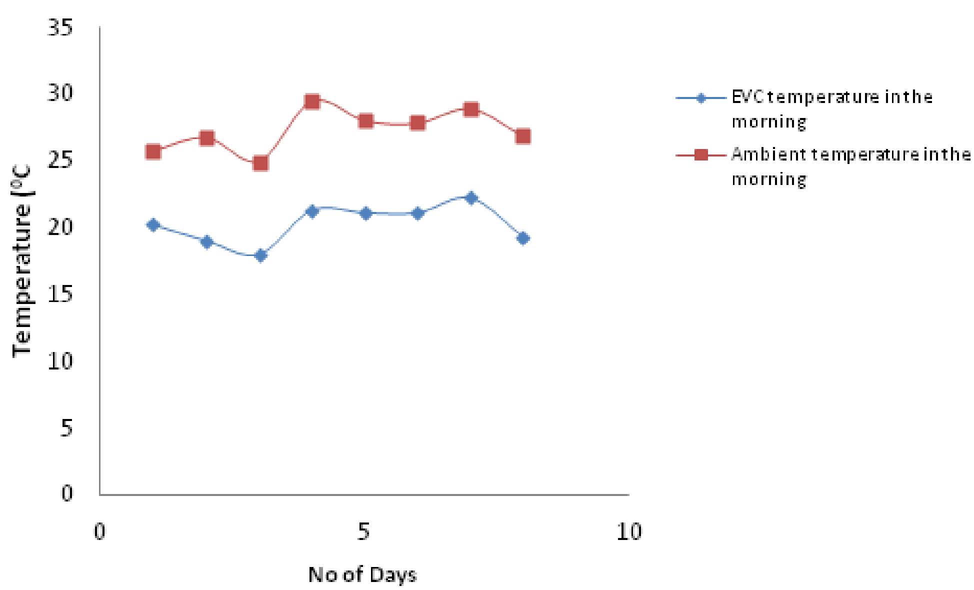

Figure 10. Relationship between temperature inside the cooler and ambient temperature in the morning

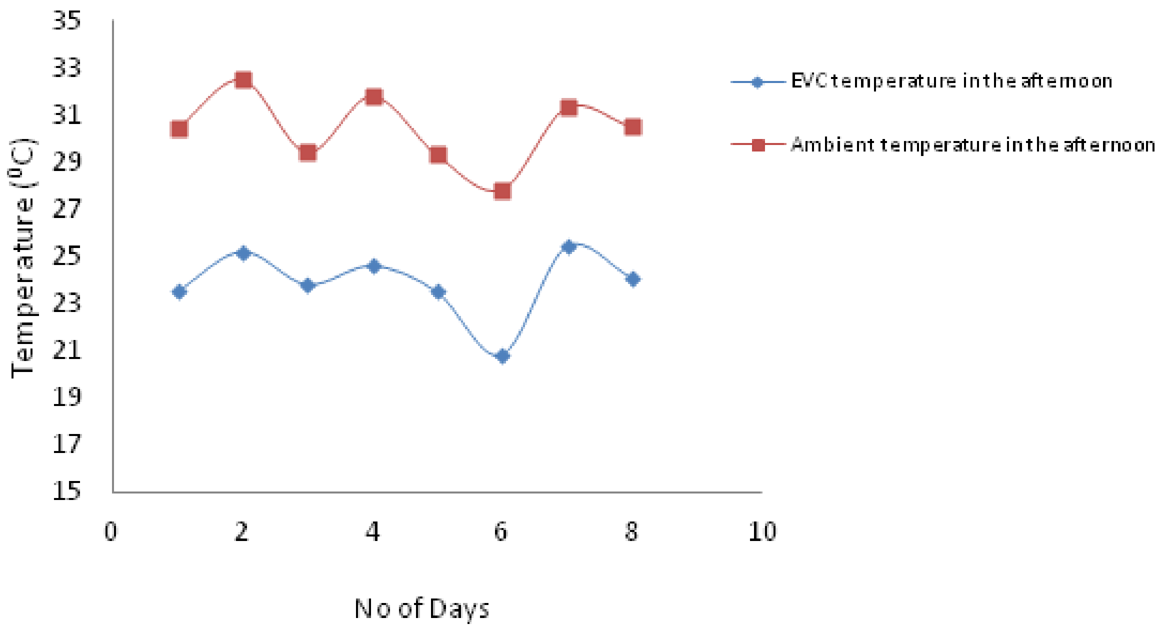

Figure 11. Relationship between temperature inside the cooler and ambient temperature in the afternoon

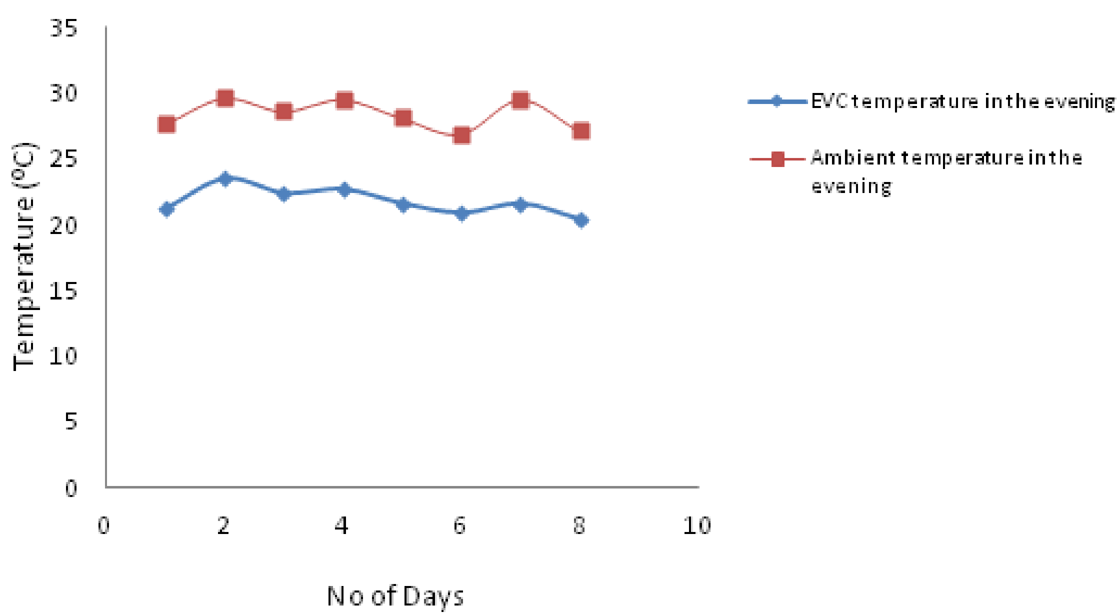

Figure 12. Relationship between temperature inside the cooler and ambient temperature in the evening

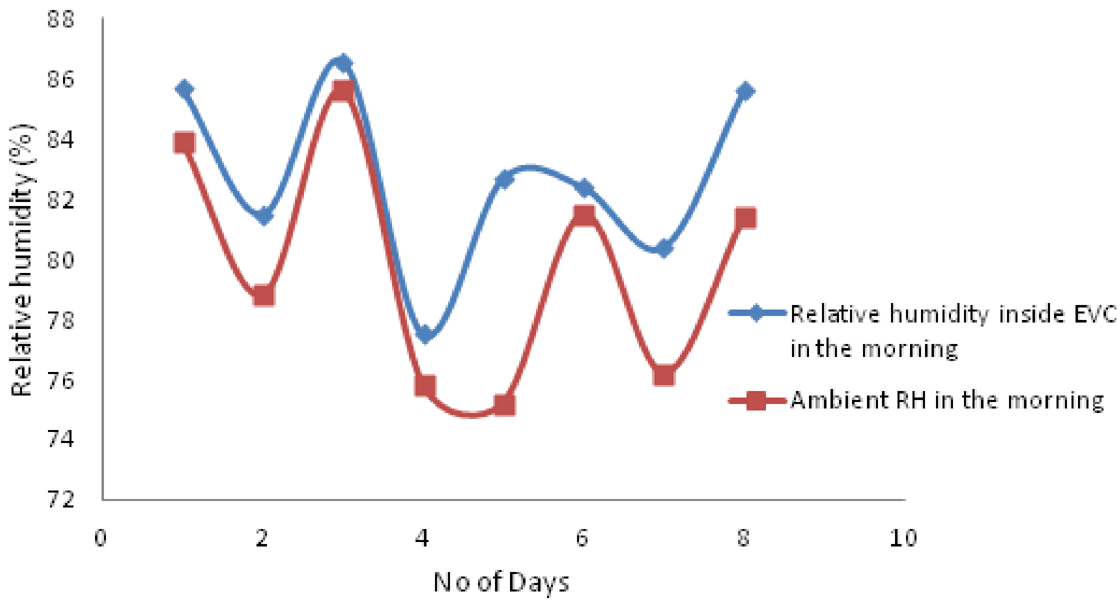

Figure 13. Relationship between relative humidity inside the EVC and ambient relative humidity

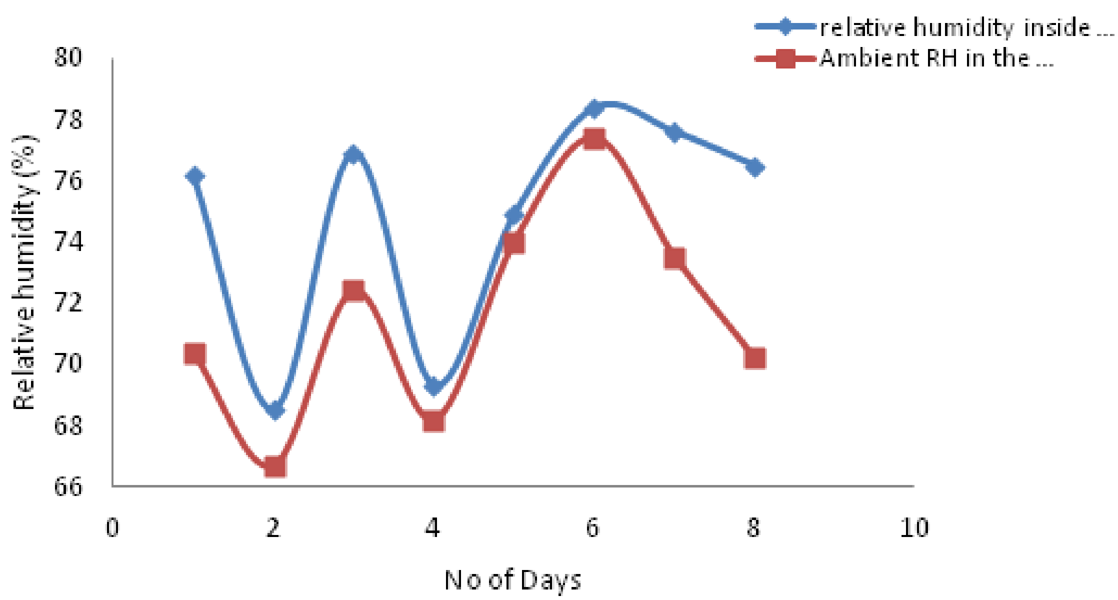

Figure 14. Relationship between relative humidity inside the EVC and ambient

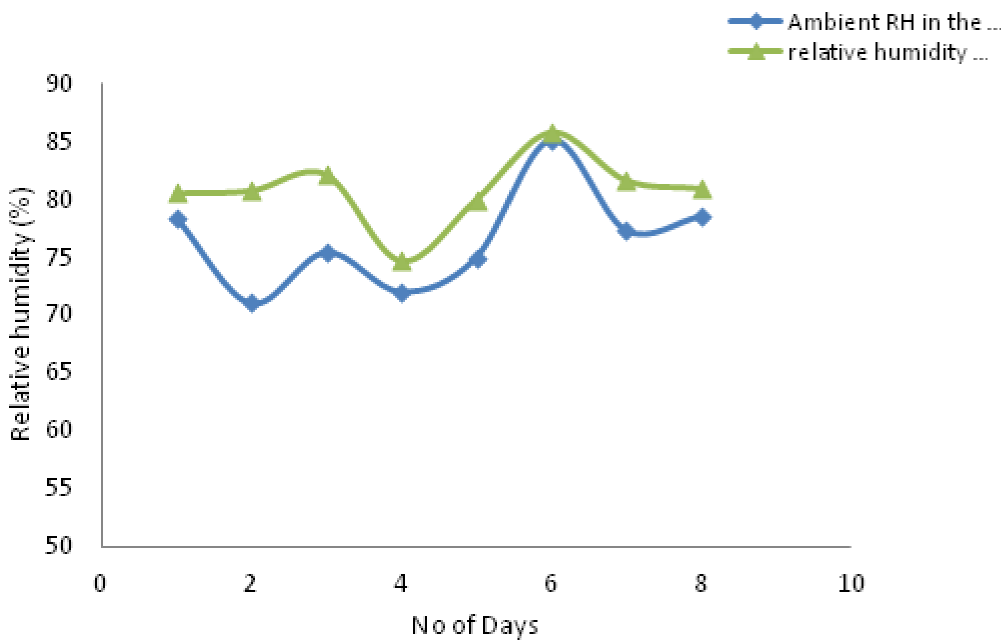

Figure 15. Relationship between the relative humidity inside the EVC ambient

4. CONCLUSION

Important information has been generated on nutrition properties of the samples of Amaranths and pepper during storage inside a metal-in-wall evaporative cooler. Quality parameters such as ash content, protein, fat content, fibre content and carbohydrate content were also evaluated using proximate analysis. It can be concluded that these qualities parameters generally reduce with time during storage in the cooler. The ash content reduced from 2.95% to 1.83% and 1.03% to 0.17% for celosia and pepper respectively. Also, protein content reduced from 9.77 to 4.51 and 2.61 to 2.05% for celosia and pepper respectively. Fat content reduced from 1.80 to 1.04 and 1.14 to 0.89% for celosia and pepper respectively. Fibre content also reduced from 2.73 to 2.49% and 1.09 to 0.80% for celosia and pepper respectively. Carbohydrate content reduced from 4.06 to 0.03% and 7.88 to 3.66%. The maximum storage days were 7 and 10 days for celosia and pepper respectively for both of them to retain their optimal nutritive value. The average temperature and relative humidity drop was about 7^0C and 4% respectively.

The storage structure is very economical since it requires no electrical or mechanical power to run. The storage structure is therefore considered suitable for small scale farmers in the rural areas of Nigeria to alleviate the problems of deterioration of their highly perishable crops and increase their financial benefits.

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DEVELOPMENT OF A CASSAVA PELLETING MACHINE

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ABSTRACT

An electrically operated cassava pelleting machine was designed, fabricated and tested. The Cassava pelleting machine was developed with efficiency and low cost in mind. It also aimed at eliminating the problem of transporting Cassava product and also for the production of pellets for animal feeds. The single screw shaft was chosen based on the ease of fabrication, availability of the components parts and simplicity of operation. The machine has an efficiency of 98.66% and the machine capacity is about 80kg.

KEYWORDS: Cassava, pelleting, development, machine, efficiency, design.

1. INTRODUCTION

Cassava is a major source of carbohydrate in most developing nations of the world. In Nigeria, the crop can be processed into ‘garri’, ‘lafun’, pellets and chops for the direct paki ‘pupuru’, ‘fufu’, cassava pellets and chips for the direct human and livestock consumption. In Ghana, it is eaten boiled. It could be pounded to be eaten with soup in addition to some of the processed form in Nigeria. Apart from human food, Cassava is also used for animal feed and alcohol production (El-Sharkawy and Cook, 1987).

Cassava pelleting is an unfermented dried cassava product obtained by compressing raw dried Cassava under appropriate processing conditions resulting in the formation of dried bulky products suitable for the animal feed industry with an average length of 3cm. The pelleting of Cassava product is becoming increasingly popular because it decreases volumes by about 25 percent.

Although there is no export-based pelleting project in Nigeria, it would be relevant to mark that over 90 percent of Cassava chips that are exported to the European Union (EU) enter as pellets. Hence as the export of Cassava increase, this should be kept in view. Thailand started cassava chips export as raw chips but because of environmental concerns most of the chips are now exported as pellets (Hillocks, 2002). Arrangements are far advanced to build the first pelleting factory in the country.

Pelleting is an extrusion process, which is simply the operation of shaping a plastic or dough-like material by forcing its through a restriction or die. Example of hand operations for pelleting food includes the rolling of noodles and pie crust dough, finger stuffing of chopped meat through animal horns into natural casing, pressing of soft foods through hand ricers to produce string-like particles, and crunking of hand-powered meat grinders. As started above a pelleting machine can be used to pellet any food items that can be formed in dough like fashion or manner (Hillocks, 2002).

Fish farming in Nigeria is an industry that is growing rapidly due to the amount of investors venturing into the industry. The major problem the local farmers face is in the rise in price of fish feed. Local farmers are now producing feed for their fishes by themselves, since they cannot afford to buy feed in the market because of the scale of their farming and the capital they are operating. But they can afford to buy cassava pellets from local producers or as will purchase a cassava pelleting machine for the production of their own pellet. Cassava pellets being one of the major feed used in the fishing and livestock industries, the need of an efficient cassava pelleting machine cannot be over emphasis. It is in the light of this that I have decided to design and fabricate a cassava pelleting machine which is very efficient and a moderately priced machine.

Pelleting is an act of making finished ground compound feed into little hard objects. With steam binders under pressure or with liquid binders (Frank, 1959). Pelleting most time has no nutritional value but is cost effective. It was introduced in the United States of America feed mill industry in the mid 1920s, so as to improve feed utilization, increase the density of the feed and improve the handling characteristics. Pellet production was stimulated by the need to improve the uniformity in the shape and size of cassava chips required by the users and animal feed producers. In addition, during transportation, loading and unloading of chips, dust generation causes serious air pollution, placing pressure on the importers in Europe to improve the nature of Cassava pellets handled by the ports (Anon, 2003).

Cassava pellets can be produced by using two methods. The first is production of Cassava pellets from Cassava root. Cassava pellet produced by this method is an unfermented dried Cassava product obtained by compressing raw Cassava root under appropriate processing conditions resulting in the formation of dried, bulky produce suitable for the animal feed industry and for exportation with an average length of 3cm. The essential operations of this method are as follows:

- Sorting and weighing: The raw Cassava is sorted out to remove unwholesome roots and foreign materials before weighing
- Washing and peeling: The Cassava roots are washed in potable water and manually peeled with knives
- Grating: The peeled roots are milled into mash using grating machine.
- Dewatering: The wet mash is dewatered to suitable moisture content usually 12% mist, using hydraulic press.
- Pelleting: The dewatered mash is then feed into a pelleting machine to form pellets of predetermined shape and size.
- Cooling: The pellet are allowed to cool to ambient temperature prior to packaging
- Packaging: The pellets are packaged in light density polyethylene bags or double lined polyethylene bags and it is read for sale or for exportation.

These essential operations can be achieved by simple machines which can be fabricated locally. The process flow-chart is shown in Figure 1.

Cassava tubers
↓
Sorting and weighing
↓
Washing and peeling
↓
Grating
↓
Dewatering
↓
Pelleting
↓
Drying
↓
Packaging

Figure 1. Flowchart production of cassava pellet form raw cassava root. (Miller, 1999)

The second method is through chips. It is also an unfermented dried Cassava pellet production obtained by compressing raw Cassava root under appropriate processing conditions resulting into pellets for the animal feed industry or export. Here the crops are first treated to get the required preconditioned form.

The essential operations of this method are listed below.

- Sorting and weighing: The Cassava chips are sorted to remove damaged chips and foreign material before weighing.
- Grinding: The chips after sorting and weighing are now grinded to reduce the particle size of the chips into powered form. Pelleting need finely ground materials. This reduces the energy cost of pelleting and reduces machine wear because material flow better in the pelleting machine barrel with less friction
- Conditioning: The product from the grinder is in powdered form and has to be conditioned to attain an appropriate moisture content level.
- Pelleting: The conditioned mash is then fed into a pelleting machine to form pellets of predetermined shape and size
- Cooling: After pelleting the pellets are cooled with a cooler to bring the temperature of the pellets down to ambient temperature
- Packaging: The pellets are package in light density polyethylene bag or double line polyethylene and ready for sale or for exportation.

The process flow chart for the production of Cassava pellet from Cassava chips is shown in Figure 2.

Cassava chips
↓
Grinding
↓
Conditioning
↓
Pelleting
↓
Drying
↓
Packaging

Figure 2. Flowchart Productions of Cassava pellets form Cassava chips (Miller, 1999).

Whichever method of production that is used requires pelleting. The objective of this study is to develop a pelleting machine using local materials.

2. MATERIALS AND METHOD

2.1 Design Considerations

The following design considerations form the basis of this design:

(i) The machine should be simple but rugged, and comparatively inexpensive
(ii) The dewatered Cassava must be feed constantly so that there is a consistent and uniform operation of the pelleting machine.
(iii) The speed of the shaft must be reduced by using a v-belt.

(iv) The pitch of the screw conveyor is larger in the inlet compared throughout the screw so as to maximize transportation, in the barrel of the machine.
(v) There should be increase in pressure and temperature in the barrel of the pelleting machine so as to push the pellet out of the die or extrusion plate and also cook the Cassava pellets.
(vi) The assembly of the machine is made simple for easier maintenance
(vii) The parts of the machine are locally, sourced and inexpensive.

2.2 Description of the Machine

The Cassava peeling machine is as shown in Figures 3 and 4. The machine is to be powered by an electric motor through a belt and pulley arrangement. The connection to power supply can be modified to use gasoline engine in local areas or places where there are no electricity supply. The design here is however based on the use of electric motor for power supply. A 4hp 1500 rpm single phase electric motor is recommended for this machine. The motor shaft is connected in linked to a v-belt, which reduces the speed to which is they operational speed of the screw conveyor.

Especially, the machine consists of a shaft carrying the screw conveyor of varying pitch mounted in the barrel of the pelleting machine. A spherical plate with little openings in it called the die or extrusion plate is screwed on the end part of the barrel. The shaft with the screw conveyor is mounted on the machines frame with a roller bearing at the feed end and self aligning similar bearings at the beginning of the shaft for better support.

The barrel is a cylindrical vessel with opening in the bearing where the hopper is being welded upon it is from this opening that the feedstock enters the barrel of the machine. The pitch of the screw conveyor at the inlet (i.e. directly below the opening where the hopper is mounted) is larger maximize transportation of feedstock as it enters the barrel. The pitch of the conveyor at the middle and end (i.e. kneading and final cooking zone) is decrease and the pressure is also increased for uniform pellets of pellets in the die or extrusion plate.

There is knife arrangement at the face of the die that can be adjusted to cut pellets of different lengths as they are coming out of the machine. The electric motor is mounted on a sit that is welded vertically below the shaft. The type of belt used is A-belt of length 54 cm. The entire machine is sitting on a frame that is made up of mild steel having four legs. The extrusion plate or die is attached to the end of the barrel by a circular flange joint held in place of four (4) bolt, so that the plate can be change with other plates having different holes diameter for producing different sizes of pellet and for maintenance and cleaning of the machine.

2.3 Operation of the Machine

When the machine is on and running, the preconditioned cassava is fed in through the hopper from the hoper there is transportation of the feedstock by means of a screw conveyor. The conveyor pushes the feedstock through the various cooking zone in the barrel and an increased temperature and pressure forces it out through the die thereby the pellets taking the size of the hole on the die. The knife arrangement at the face of the die cuts the pellets as it comes out from the machine to the required length that has been preset. The pellet is then dried and cooled, and its ready for packaging and storage.

2.4 General Design Considerations

Engineering design involves the activities that lead to proper decisions on effective development of machines and engineering processes. In the design of cassava pelleting machine, the physical properties of cassava are considered. Some factors such as the machine noise, vibration, arrangement of the components, placement of controls and the total physical efforts required to arrive at the through put capacity are considered. The comfort and operator's safety as well as higher efficiency and reliability of the machine are all taken into consideration.

2.5 Experiments to Determine Design Parameters

Relevant parameters for estimation of power requirement of the machine were determined as ready information about them could not be obtained otherwise, the experiment include the determination of relevant parameters for the design of a Cassava pelleting machine for Cassava pellet production preconditioned Cassava is used.

The first experiment was to determine the optimal speed of the pelting machine. The apparatus used in conducting this experiment included the following, weighing balance, stop watch, recording equipment, preconditioned Cassava. Preconditioned Cassava which I prepared was used in this experiment. The preconditioned Cassava weighing 25 kg was fed into the Cassava pelleting machine rotating at an initial speed of 220 rpm. The time for pelting the cassava was recorded by the use of a stop watch. The experiment was repeated with different speeds of 230 rpm, 240 rpm, 250 rpm, 260 rpm, 270 rpm respectively and the corresponding pelting time was recorded. Table 1 shows the result of the experiment.

The second experiment was to determine the Cassava pelleting machine efficiency, capacity and percentage of Cassava pellets formed. The equipment used in conducting the experiment included weighing balance, pre-conditioned Cassava, recording equipment and stop watch. Preconditioned Cassava with an initial weight of 30 kg was fed into the hopper of the pelleting machine rotating at an optimal speed of 250 rpm. After pellets were formed, the pelleting time was taken by means of a stop watch and recorded. The experiment was repeated with different weights of 35 kg, 40 kg, 45 kg, 50 kg, 55 kg, 60 kg and 65 kg respectively.

Figure 3. Plan View of the Cassava Pelleting Machine

Figure 4. Front view of the machine

Figures 5: End view of the Machine

Figure 6: Dried cassava pellets

3. RESULTS AND DISCUSSION

Experiments were conducted on the pelting machine to evaluate its performance. The results obtained during the experiments are shown in Table 1 and the graphs showing the relationship between pelleting time and speed of the machine is shown in Figure 6.

Table 1: Speed of machine and time of pelleting for 25kg

S/No	Speed (rpm)	Weight of conditioned Cassava (Kg)	Time of Pelleting (min)
1	230	25	21.5
2	240	25	20.8
3	250	25	19.4
4	260	25	19.2
5	270	25	19.0

From Table 1, it is seen that the optimal speed is 250rpm because from the speed of 250rpm upwards, the pelleting time is approximately the same.

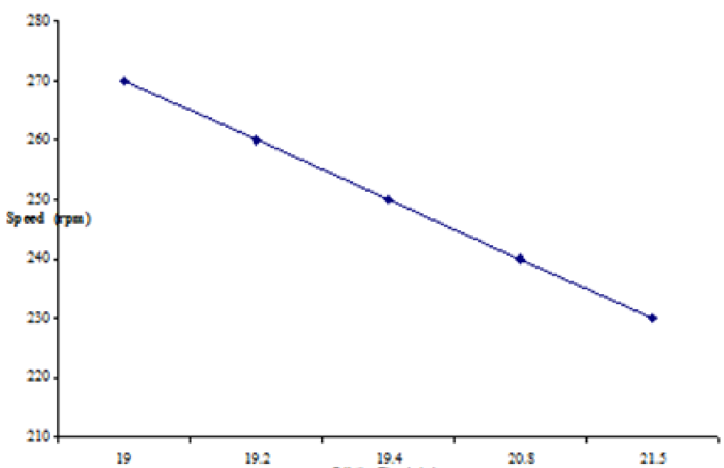

Figure 6. Pelleting time (min) against speed of the machine (rpm)

Table 2. Amount of pellets formed at speed of 250rpm

S/N	Speed (rpm)	Weight of preconditioned cassava (kg)	Amount of pellets formed (kg)	Pelleting time (min)
1.	250	30	29.5	23.65
2.	250	35	34.5	27.55
3.	250	40	19.2	31.26
4.	250	45	44.3	35.10
5.	250	50	49.7	38.48
6.	250	55	44.2	41.34
7.	250	60	59.0	44.47
8.	250	65	64.2	48.47
		380	374.9	290.55

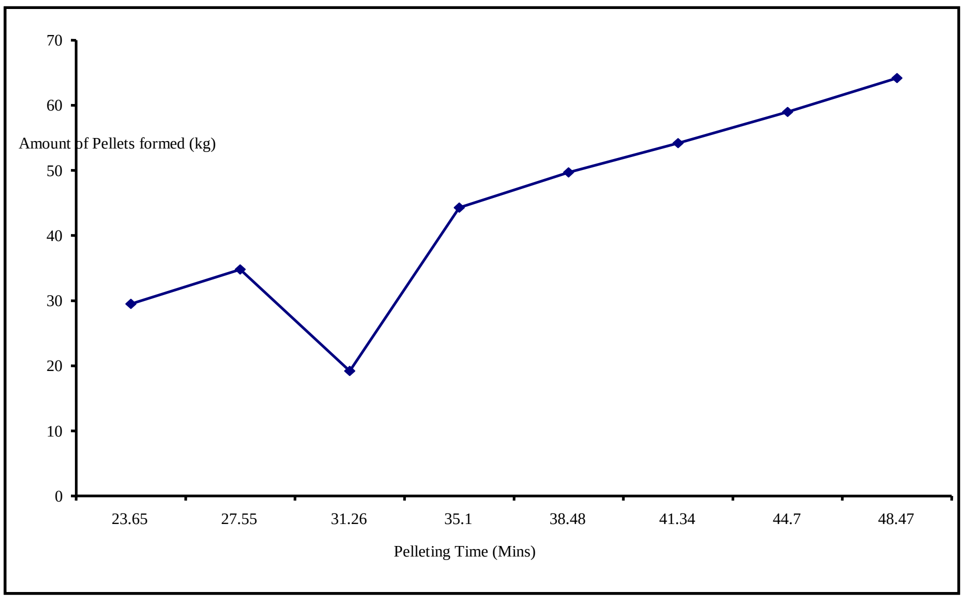

Figure 7. Graph of pelleting time against amount of pellets formed

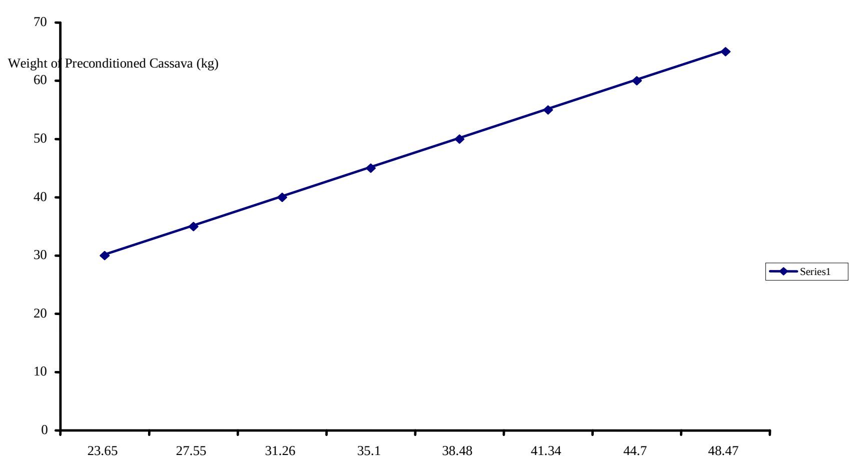

Figure 8. Graph of pelleting time against weight of preconditioned cassava

From Figure 8, the graph of the time of pelleting against the weight of preconditioned Cassava shows that an increase in the weight of preconditioned cassava increase the time of pelleting at a constant speed.

Preliminary Test Factor

$$\text{Capacity of machine} = \frac{\text{Total amount of preconditioned cassava}}{\text{Total time (in hr)}}$$

$$\text{Pelleting efficiency} = \frac{\text{Total amount of cassava pellet formed x 100}}{\text{Total weight of preconditioned cassava}}$$

From equation above

$$\text{Capacity of the machine} = \frac{\text{Total amount of preconditioned cassava (kg)}}{\text{Total time (hrs)}}$$

From Table 2.
Total amount of preconditioned cassava = 380kg
Total pelleting time = 290.55min = 290.55/60 = 4.82hrs
Therefore, the capacity of the machine = 380/4.82 = 78.84kg/hr

$$\text{Pelleting efficiency} = \frac{\text{Total amount of pellets formed x 100}}{\text{Total weight of preconditioned cassava}}$$

$$= (374.9 \text{ x } 100) / 380 = 98.66\%$$

4. CONCLUSION

This paper presents the development of a cassava pelleting machine for producing cassava pellets. The feed material (preconditioned cassava) is forced along by a varying pitch screw conveyor against a restricted opening known as the extrusion plate or die. The screw conveyor pitches at the discharge outlet have been sized properly to achieve the desired compression ratio. Pains are taken to properly size all the machine components that will be subjected to tangible forces to ensure that this robust and reliable machine is produced.

The machine capacity is purposely made small in order to achieve the desired objective, a suitable machine that is highly efficient and affordable by an average Nigerian and usable in rural areas, where there is no electricity since the machine can be operated by the use of gasoline engines.

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DEVELOPMENT OF A NUT/FIBRE SEPARATOR

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ABSTRACT

A palm nut/fibre separator was designed and evaluated in this study. The machine consists of a hopper, the compartment for breaking the de-oiled mash (consolidated mixture of fibre and nut i.e cake), equipped with breaking arms, screw auger for conveyance of the nut, screen for separation of the fibre and discharge chutes for nuts and fibre. It was evaluated by investigating the effect of drying time, shaft speed and loading rate on its separation efficiency so as to ascertain its inclusion in the process line for palm-nut processing. Palm cake obtained from the extraction of palm oil in a screw press was dried at interval of 3 days (3, 6, 9 and 12 days) for two weeks. Samples of the cake were run in the machine at loading rates of 1 kg, 1.5 kg and 2 kg and shaft speeds of 400, 500 and 600 rpm. The separation efficiency of the machine was determined at each combination of the factors.

Results shows that increase in the drying time and shaft speeds at each of the loading rates increased the separation efficiency of the machine. The highest separation efficiency (78.90%) was obtained at 500 rpm rotational speed, 12 days of drying and at both 1.5 kg and 2 kg loading rates. It could be concluded that such conditions of speed and loading rate should be adhered to in order to introduce the machine in the palm-nut processing line. The inclusion of the machine in the process line will improve the output of the processors and hence their economy.

KEYWORDS: Palm nut, fibre, properties, separation, machine, efficiency.

1. INTRODUCTION

Processing of oil palm fruit into oil yields palm nut and fibre as by- products. The palm nut when further processed yields shell, kernel oil and palm kernel cake, which have numerous domestic and industrial applications (Owolarafe *et al*., 2002). Separation of nuts from fibre during the traditional aqueous oil extraction is a critical operation yet to be perfectly mechanized at the small scale level. Digested palm fruit (mash) is mixed with water in a cemented pit and, agitated using bowl. The oil in form of emulsion floating on the water surface is first scooped and collected in a bucket. The nuts which sink at the bottom of the pit are then brought out using hand-woven baskets. By rocking the baskets back and forth for some time, the fibre which has low density floats on the top of the nuts. The processor uses hand to pack the fibre out of the basket while pouring out the nuts on the ground, thus separating the nuts from fibre. The operation is time-consuming tedious and hazardous (Taiwo *et al*., 2000).

In the intermediate technology where small scale presses (especially hydraulic press) are used in extraction of the crude palm oil, the residual material after oil extraction is consolidated into a hard cake (containing fibre, nut and traces of solid oil). Breaking the cake to separate the nut and fibre has always been a difficult task. Although, different versions of nut/fibre separator have been developed and utilized (Sanni *et al*., 2009; Beveridge *et al*., 2009), field observations (Beveridge *et al*., 2009) indicated that the machines are not efficient with a lot of time consumed in recycling the palm fruit cake into the machine. Many processors have abandoned such machines and resorted to manual operation of using knives and hands (Beveridge *et al*., 2009; Owolarafe and Oni, 2011).

Therefore, this study undertook the development of a nut/fibre separator to solve the problem.

2. METHODOLOGY

This involved using appropriate design principle in the design of the components of the machine. It also covered fabrication and assembly of the components as well as evaluation of the assembled machine.

2.1 Design Principle and Consideration

The nut fibre separator breaks the cake by impact and based on size differences separates the nut and fibre on a screen. Thus, the system of paddle breaker as employed in pneumatic separator in the large scale plants was adopted. The factors that were considered critical to the design of the fibre/nut separator are ease of operation of the machine, power requirement, safety/operational health hazard, hygiene/operational cleanliness, simplicity of design, durability, and affordability.

2.2 Design of Components of the Machine

Based on the design principle suggested above, the nut/fibre separator consists of the hopper, screening auger, nut polishing drum, discharge chute for the fibre, discharge chute for the nut, housing unit and standing frame. To achieve effective design of the components of the machine, a series of experiments were carried out to the determine properties of the fibre/nut cake, relevant to the design principles employed.

2.2.1 Determination of Properties of the Palm Fruit Cake and Nut

The properties of the palm fruit cake determined include true density, bulk density and angle of repose. The true density of the cake was determined by the water displacement method. This was determined by using the method adopted by some researchers (Akaaimo and Raji, 2006; Sessiz *et al*., 2007 and Owolarafe *et al*., 2007). Some quantity of palm fruit cake was weighed and wrapped in nylon and then lowered into a graduated cylinder of known volume of water; the net volumetric displacement was noted. The true density of the cake was calculated using the equation below.

$$\rho_T = M/V \qquad 1$$

Where, ρ_T is true density $\left(kg/m^3 \right)$, M is Mass (kg) and V is Volume (m^3)

This procedure was replicated ten times.

For the bulk density measurement, an empty cylindrical container of a predetermined volume was filled with palm fruit cake; the bulk weight was recorded. The bulk density was then computed using equation below:

$$\rho_B = W_v / V_m \qquad 2$$

Where, ρ_B is Bulk density kg/m^3, W_V is weight of known volume (kg) and V_m is Volume of material (m^3). This was replicated twenty times.

The properties determined for the nut include size, sphericity and roundness index. The determination of these parameters is important for the specification of the screening aperture for the nuts; hence measurements of all size and shape indices were replicated fifty times. The nut sizes in terms of the three axial dimensions were determined using a vernier caliper and a micrometer screw gauge. The sphericity was then calculated using the relationship below (Aseogwu *et al.*, 2006; Sacilik *et al.*, 2003; Ogunsina and Bamigboye, 2007) as:

$$S_p = \frac{(abc)^{1/3}}{a} \times 100 \qquad 3$$

Where a, b, and c are length, width and thickness of the palm nut respectively.

Roundness of the palm nut was determined using standard method adopted by Ogunsina and Bamigboye (2007), Sacilik *et al.* (2003), and Akaaimo and Raji (2006). A nut was placed on a sheet of tracing paper in its natural rest position and the edges were carefully traced out with the aid of a sharp pencil. Using a circular template, the smallest circumscribing circle for each of the traces was constructed, this was denoted A_c. The largest projected area of each trace A_p was determined using a flexible rope to go round each of these traces and the circumference was read from a linear scale. The roundness index was then determined from equation below (Mohsenin, 1986)

$$\frac{A_p}{A_c} \qquad 4$$

The coefficient of friction and angle of repose are important for the specification of the discharge chute. The coefficients of static friction for the nut and fibre were determined with respect to mild steel sheet using an inclined plane apparatus. The inclined plane apparatus was gently raised and the angle of inclination to the horizontal at which the nuts began to slide was read from a protractor that was attached to the apparatus. The tangent of this angle is the coefficient of static friction (Faborode and Omotade, 1993; Garnayaka *et al*, 2008). This experiment was replicated twenty times.

The dynamic angle of repose also known as the emptying angle of the palm fruit cake was determined on mild steel surface using the method described by Owolarafe *et al.* (2007), Solomon and Zewdu (2009) and Sacilik *et al.* (2003) . A regular cylindrical container opened at both ends was placed on the flat mild surface and filled from the top with palm nuts. The container was then gradually lifted up from the surface. This gradual lifting was continued until a conical heap was formed. The dynamic angle of repose was then calculated from the height and the base radius of the heap. This experiment was replicated ten times.

2.2.2 Components of the Machine

The isometric, orthographic and exploded views of the palm nut/ fibre separator are shown in Figs 1, 2 and 3, respectively.

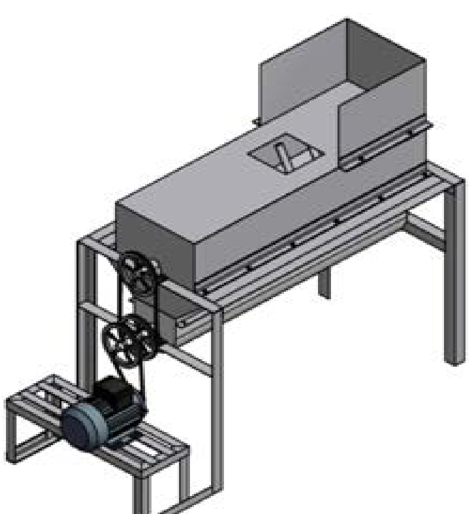


Fig. 1: Isometric drawing of the palm nut/fibre separator

PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	1	Frame	Welded Steel Mild
2	1	Cake housing	Steel, Mild
3	1	Discharge Chute	Default
4	1	Separating Unit	Welded Steel Mild
5	4	Bearing house	Steel
6	1	Hopper	Steel, Mild
7	1	Beater Shaft	Steel, Mild
8	4	Rolling bearing 71806 C GB/T 292-94	Steel, Mild
9	1	Auger Shaft	Default
10	1	AC Motor	
11	1	V-Belt	Rubber
12	1	Grooved Pulley1	Steel
13	1	Grooved Pulley2	Steel
14	2	Grooved Pulley D	Steel
15	1	Discharge Chute for Nuts	Steel, Mild

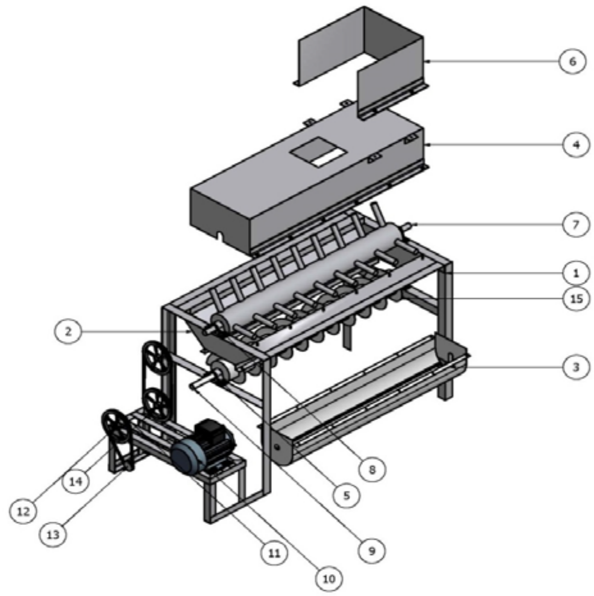
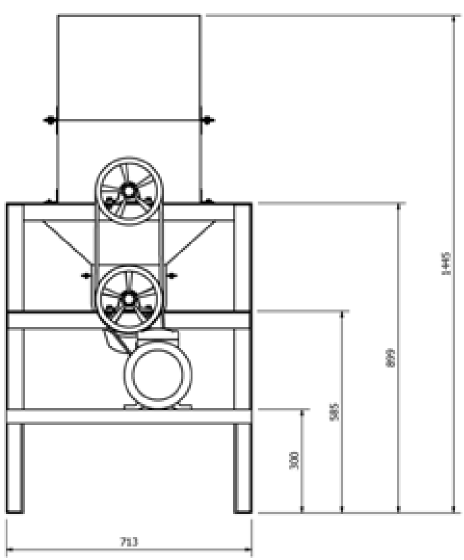


Fig. 2: Exploded view of the machine showing its constructional features



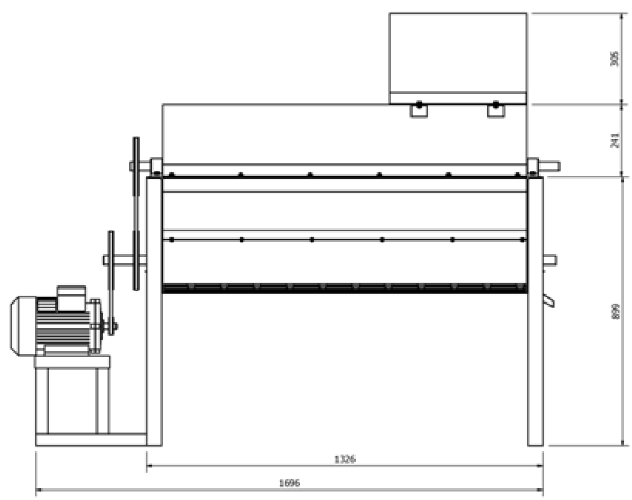


Fig. 3(a)

Fig. 3 (b)

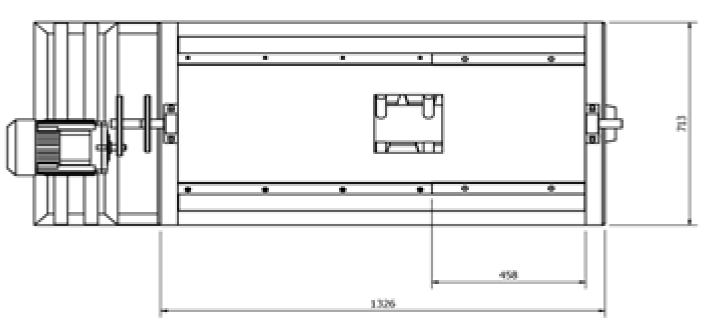


Fig. 3(c)

Fig. 3: Orthographic views of the machine: a, side view; b, front elevation; c, plan view

i. The Hopper

The hopper is the compartment of the machine into which the fibre/nut cake is introduced to the separating chamber. It was made from gauge 16 mild steel sheets; the angle of the sides of the hopper was at 90° to the horizontal. The hopper is opened at one side to allow for the feeding of the cake into the separating chamber through a slot that is located at the top of the separating chamber. The average bulk density determined was used in specifying the volume that will contain about 2 kg of the fibre/nut cake per unit loading of the hopper.

ii. The Separating Chamber

This is the part of the machine that incorporates the cake breaking paddle. It was also made from gauge 16 metal sheets. The upper and lower parts of the separating chamber have a rectangular cross section. The upper part of this separating chamber was provided with a slot through which the cake is introduced into the chamber manually by hand.

iii. The Polishing Drum

The polishing drum serves as the housing in which the screening auger conveyor that is used in conveying the nut is located. The clearance between the wall of the polishing drum and the shaft used in conveying is fixed at 10 mm which is less than the least axial dimension of nuts as determined in the experiment to allow the fibre pass through easily and prevent the nuts from getting stuck. It is made from mild steel. The pitch of the auger conveyor and the pitch diameter were determined from the axial dimensions of the nut to be conveyed. Also the slots on the screening auger were the maximum required for the fibre to pass through without allowing the nuts to drop.

iv. The Discharge Chute for the Nut

This is used for collection of the nut after separation. It was inclined at an angle to the horizontal to facilitate the ease with which the nut will fall through the polishing drum. It was also made from a mild steel sheet.

v. The Discharge Chute for the Fibre

The discharge chute for fibre is used for the collection of the fibre after separation. It is like a downward extension of the polishing drum. It was fixed at an angle of 90° the horizontal to aid the removal of the fibre from the polishing drum. It was made from mild steel.

vi. The Cake-Breaking Paddle

The cake- breaking paddle is used in detaching the fibre from the nut. It was fabricated by attaching paddles at intervals on the shaft that is mounted on a bearing and connected to a prime mover.

vii. Design of the Auger Conveyor

The auger conveyor is the part of the machine that separates the detached fibre from the nut. According to Spivakovsky and Dyachkov (1982), an auger conveyor consists of a shaft-mounted screw rotating in a trough and a drive unit setting the shaft in rotary motion. For slow moving abrasive material as required by the machine being designed, a screw pitch of 0.8D is required.

viii. Selection of Belts/Gears Transmission Device

The A type V-belt was used in the transmission of the power and torque to drive the system, while the shaft for the paddle breaker was also linked to the shaft for the auger conveyor using a speed ratio of 2:1.

ix. Power Transmission Shaft Design

The strength analysis of the shaft and shaft design is as shown below. The maximum loading rate and speed (2kg and 600 rpm), respectively were used in designing the shaft. The load diagram is shown in Fig. 4.

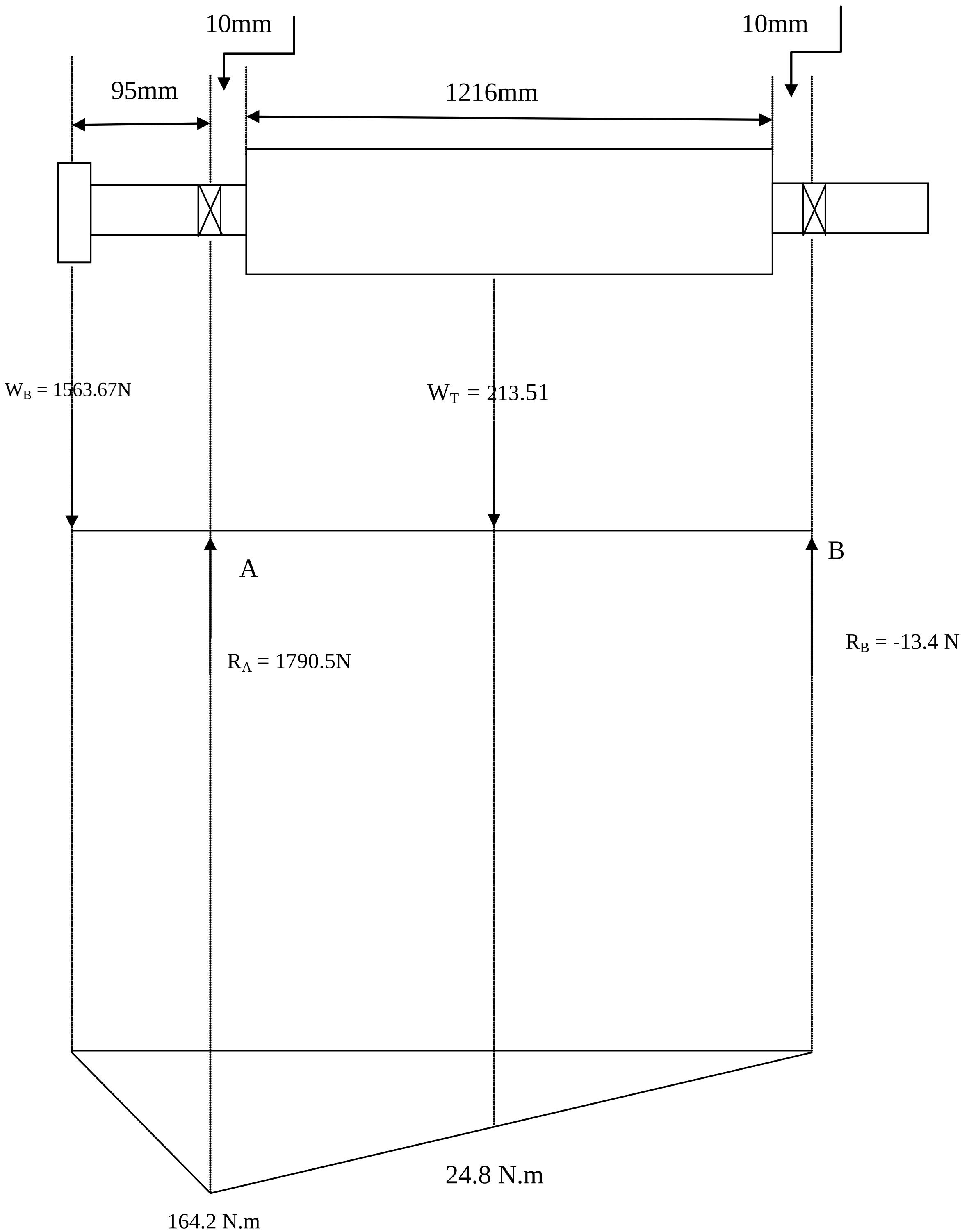


Fig 4: An analysis of the total load on the shaft

The properties of the Shaft material are:
For shaft without keyway allowable shear stress, $S_s = 55 \times 10^6$ N/m^2 (Hall *et al.*, 1983).
Length of shaft, L_s = 1546mm
Density of steel = 7622 kg/m^3

For a rotating shaft with gradually applied load, the bending fatigue factor
K_b = 1.5 and the torsional fatigue factor, K_t = 1.0 (Hall *et al.*, 1983).
The Loads on the shaft are due to:

i. Mass of the shaft itself = 9.0 kg
Weight of the shaft = 9.0 x 9.81 m/s^2
= 88.29N.

ii. Beaters:
Mass of beaters = 10.76 kg
Weight of beaters = 10.76 x 9.81m/s^2 = 105. 6N

iii. Fibre/nut cake: the maximum mass of the cake that will be load on the machine is 2kg
Weight of the fibre/nut cake = 2kg x 9.81m/s^2 = 19.62 N
W_T = Weight of beaters + weight of the shaft + weight of fibre/nut cake
W_T = 213.51

iv. Load from the transmission belt is calculated using;
$M_t = (T_1 - T_2)R$, N.m (5) (Hall *et al.*, 1983).
The torsional moment acting on a shaft can be determined from
$M_t = (9550 \text{ X kW})/(\text{rev} / \text{min})\ N.m$ (Hall *et al.*, 1983).
M_t = 35.18 N.m
Ratio of belt tension is 1:3
T_2 = 390.84 N
T_1 = 1172.53 N
Total load due to the belt, $W_B = T_1 + T_2$ = 1563.37 N

An analysis of the total load on the shaft is shown in the Fig. 1
Sum of upward forces = sum of downward forces

$$W_T + W_B = R_A + R_B \tag{6}$$

Where, R_A and R_B are reactions at the two supports
Taking moments about point A,
Sum of clockwise moments = sum of anticlockwise moments
R_B = -13.4 N
From eq (6) $R_A = W_T + W_B - R_B$
R_A = 1790.5N
Therefore maximum bending moment M_B = 164.2N
The required shaft diameter is determined by employing the formula

$$d^3 = \frac{16}{\pi S_s\,(1-K^4)} \sqrt{\left(K_b\ M_b + \frac{\propto F_a\ d_o\ (1+K^2)}{8}\right)^2 + (K_t\, M_t)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ [16]$$

Where, F_a is axial force = 0, $\propto$ is column-action factor, $K = d_i/d_o$ = 0.127/0.130 = 0.98
d_i is shaft inside diameter, m, d_o is shaft outside diameter, m.
d^3 = 0.0002992m
d = 66.9 mm

2.3 Operation of the Machine

The fibre/nut cake is fed into the system through the slot on the separating chamber; the cake comes in contact with the separating shaft which is made of short fingerlike studs welded on a rotating shaft. The shaft beats against the cake and detaches the fibre from the nut by impact. The separated fibre and nut fall down by gravity on the conveying auger mechanism. The screening auger while conveying the nuts and the fibre separates the fibre from the nuts through screens which acts as the barrel for the auger while the nuts are conveyed all through to the end of the conveying mechanism. The nuts are polished through the aid of a brush situated at a point just before their discharge outlet from the machine.

2.4. Performance Evaluation of the Machine

The machine was evaluated with both fresh and dried nut/fibre cake to ascertain the effect of drying on the efficiency of the nut/fibre separator. The fresh nut/fibre cake was dried for two weeks and run in the machine at intervals of 3 days. A specific amount of the cake was taken and fed through the hopper when the machine was running. The amounst of fibre and nut separated were weighed after separation. The amount of fibre separated with nut at the nut discharge end was separated manually. Similarly the amount of nut separated with fibre at the fibre discharge end was also separated manually. The resulted fibre and nut were added to the fibre and nut cleanly separated to obtain total fibre content and total nut content, respectively. The efficiency of the machine was calculated using equation 5 below:

$$C_S = \left(\frac{\text{Weight of nut separated}}{\text{Total nut content}}\right) * \left(\frac{\text{Weight of fiber separated}}{\text{Total fiber content}}\right) \qquad 5$$

Where C_s = separation efficiency

The machine was evaluated at three shaft speeds (400, 500 and 600 rpm) and three loading rates (1.0 kg, 1.5 kg and 2.0 kg) based on preliminary laboratory investigations. Table 1 shows the experimental design that was used for the machine evaluation.

Table 1: Experimental Design

Factors	Levels
Drying time (days)	3, 6, 9, 12
Loading rate (kg)	1.0, 1.5, 2.0
Shaft speed (rpm)	0, 500, 600

3. RESULTS AND DISCUSSION

The results of the properties of the cake and the evaluation of the machine are discussed below:

3.1 Physical Properties of Palm Nut Take

Table 2 shows the average values of the physical properties of the materials determined. The bulk density of the cake, which is very necessary for the specification of the volume of the hopper, was found to have a mean value of 0.3561 kg/m^3. The axial dimension of the thickness of the palm nut which represents the smallest dimension of the palm nut was also found to have a mean value of 18 mm and used in fixing the spacing between the fingerlike stud on the cake breaking paddle such that the nuts will not get stuck between the fingerlike studs. Also, the axial dimensions were used in fixing the width of the slots on the barrel of the auger such that it will screen out the fibre during conveyance but not the nut. Furthermore, from the values of the coefficient of static friction of the fibre and nut, which were 1.37 and 0.599, respectively, the minimum value of the angle at which the discharge chute of both the fibre and nut was inclined was determined.

Table 2: Some Physical Properties of the Fibre/Nut Cake

Physical property	Number of observation	Unit	Mean value	Minimum value	Maximum value	Standard deviation
Length (nut)	50	mm	28.81	20.70	40.70	4.3
Thickness (nut)	50	mm	17.98	13.00	24.50	2.61
Width(nut)	50	mm	23.04	18.00	28.40	2.6
Bulk density (cake)	20	kg/m^3	0.3561	0.3265	0.3877	0.0219
Angle of repose(cake)	10	°	33.86	31.77	36.43	1.66

Coefficient of static friction of nuts	20		0.599	0.32	0.87	0.141
Coefficient of static friction of fibre	20	°	1.37	0.97	2.05	0.27

3.2 Effect of Processing and Machine Parameters on the Efficiency of the Machine

The effect of drying time, shaft speed and loading rate on the separation efficiency of the machine is discussed below.

3.2.1 Effect of Drying on the Efficiency of the Machine

Figures 5, 6 and 7 show the separation efficiencies of the machine at various drying stages and drying rates. It could be observed that separation efficiency of the machine increased with increase in drying time at different speeds and different loading rates. For instance, the separation efficiency at the speed of 400 rpm for 1kg loading rate increased from 27.50% for fresh cake to 71.00% for the dried cake after 12 days of drying. Therefore, low moisture content of the cake enhanced loosening of the cake by the cake breaking arm thereby facilitating separation as reflected.

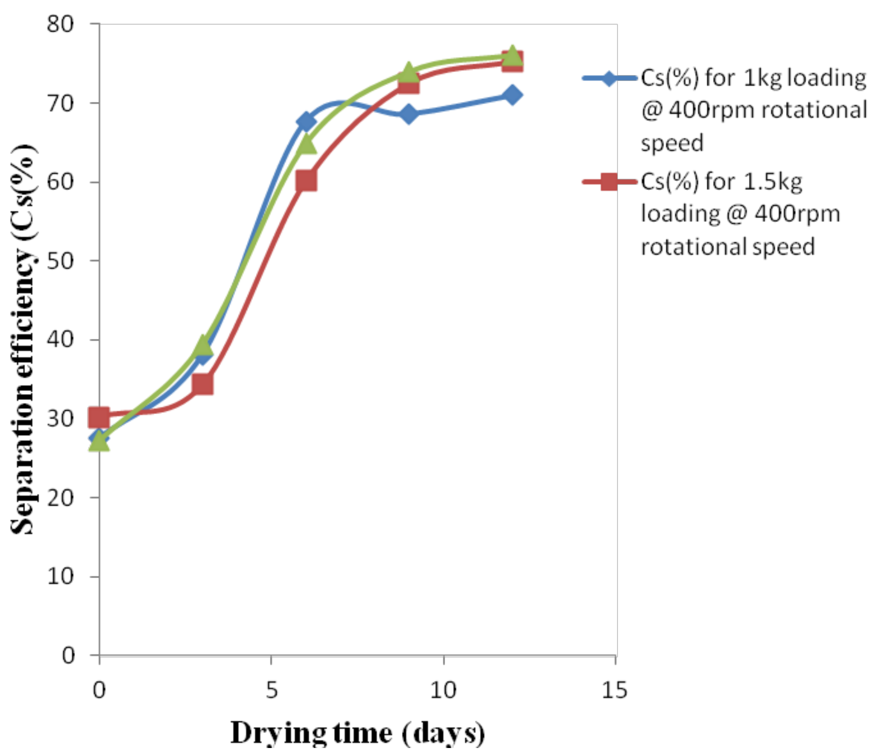


Fig. 5: Effect of drying time on separation efficiency of nut/fibre at 400 rpm and various loading rates

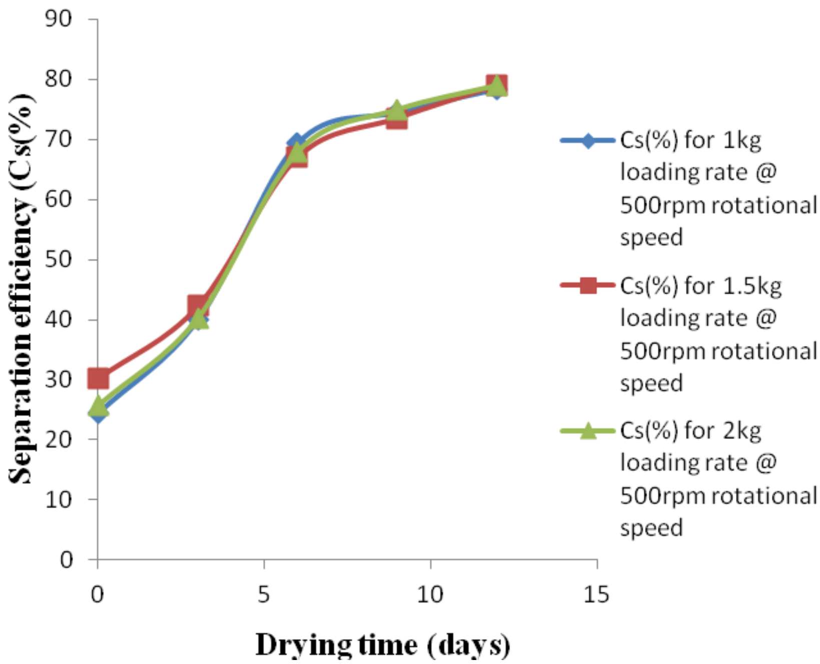


Fig. 6: Effect of drying time on separation efficiency of nut/fibre at 500 rpm and various loading rates

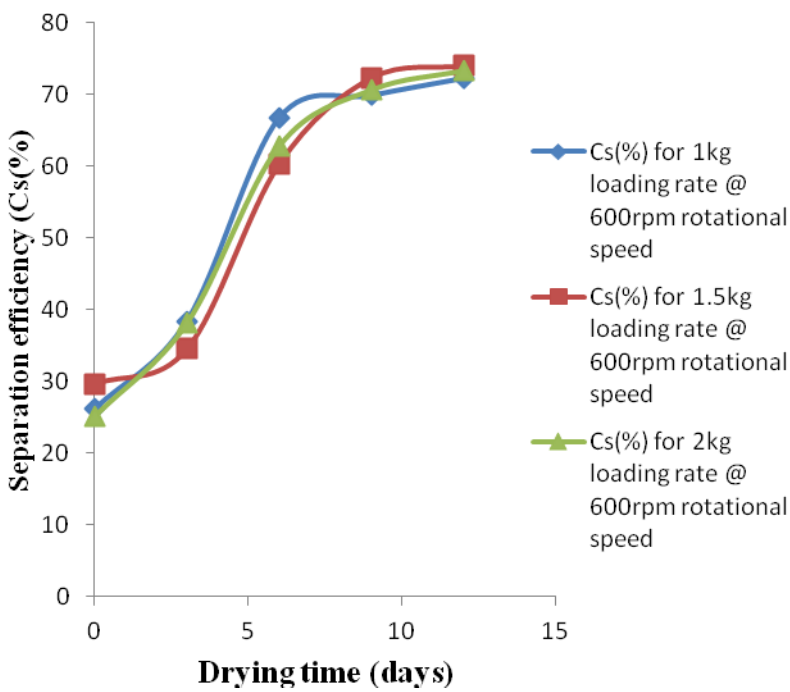


Fig. 7: Effect of drying time on separation efficiency of nut/fibre at 600 rpm and various loading rates

3.2.2 Effect of Speed on the Efficiency of the Machine

Tables 3, 4 and 5 show the separation efficiency of the machine at various speeds of rotation. It can be seen that the separation efficiency was 27.17% for fresh cake and 76.00% for dried cake at 400 rpm at 2 kg loading rate. Also at 500 rpm an increase was observed in the separation efficiency of the machine especially for the dried cake while at 600 rpm, there was a slight decrease in the efficiency of the machine. This can also be observed by comparing the highest efficiencies in Figs 5, 6 and 7. This means that the machine can only work perfectly at a maximum speed of 500 rpm,

Table 3. Separation efficiencies at 1 kg loading rate with various speeds of rotation

Speed (rpm)	400	500	600
Fresh nut/fibre mixture (Cs(%))	27.50	24.50	26.10
Dry nut/fibre mixture (Cs(%))	71.00	78.30	72.30

Table 4: Separation efficiencies at 1.5 kg loading rate with various speeds of rotation

Speed (rpm)	400	500	600
Fresh nut/fibre mixture (Cs(%))	30.20	30.30	29.60
Dry nut/fibre mixture (Cs(%))	75.30	78.90	74.00

Table 5. Separation efficiencies at 2 kg loading rate with various speeds of rotation

Speed (rpm)	400	500	600
Fresh nut/fibre mixture (Cs(%))	27.17	25.80	25.10
Dry nut/fibre mixture (Cs(%))	76.00	78.90	73.30

3.2.3 Effect of Loading Rate on the Efficiency of the Machine

Tables 6, 7 and 8 show the separation efficiency of the machine at various loading rates (i.e 1, 1.5 and 2 kg). It could be observed that the separation efficiency of the machine increased at various loading rates for 400 and 500 rpm rotational speed but dropped at 600 rpm. The indication is that loading rate of 2 kg appears to be the optimum for the operation of the prototype. This may be attributed to the possibility of the low loading rates (i.e 1.0 and 1.5 kg) not providing enough material within the separation chamber for conveyance to the discharge outlets.

Table 6 . Separation efficiencies at 400 rpm with various loading rates

Loading rate (kg)	1.00	1.50	2.00
Fresh nut/fibre mixture (Cs(%))	27.50	30.20	27.17
Dry nut/fibre mixture (Cs(%))	71.00	75.30	76.00

Table 7 . Separation efficiencies at 500 rpm with various loading rates

Loading rate(kg)	1.00 kg	1.50 kg	2.00 kg
Fresh nut/fibre mixture (Cs(%))	24.50	30.30	25.80
Dry nut/fibre mixture (Cs(%))	78.30	78.90	78.90

Table 8. Separation efficiencies at 600 rpm with various loading rates

Loading rate(kg)	1.00	1.50	2.00
Fresh nut/fibre mixture (Cs(%))	26.10	29.60	25.10
Dry nut/fibre mixture (Cs(%))	72.30	74.00	73.30

Statistical analysis (SAS, 2007) of the effect of the evaluation parameters on the efficiency of the machine indicates that the effects of drying time and speed were significant ($p<0.01$). The effect of loading rate do not have significant effect on the efficiency of the machine. Furthermore the interactive effects of drying time and loading rate, and drying time and speed were also observed to be significant ($p<0.01$).

4. CONCLUSION

A nut- fibre separator utilizing impact force to break the palm fruit cake and employing the differences in the sizes of the nut and fibre in separating the mixture was developed in this study. The performance evaluation of the machine indicates highest separation efficiency (79%) with dried cake while running at about 500 rpm. The machine has the potential for inclusion in the process line for palm fruit and there is room to improve on its efficiency. However an appropriate drying scheme may be necessary for palm fruit cake (after oil extraction) to be able to utilize the machine effectively.

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ENERGY RELATIONSHIPS FOR THE DESIGN OF BIOGAS REACTORS OPERATING ON ANIMAL WASTE

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ABSTRACT

Biogas reactors are anaerobic vessels which utilize biological treatment processes for the production of biogas and for organic waste stabilization. In terms of waste stabilization, the treatment efficiency of the system is established by the amount of reduction in the biodegradable component of the waste measured as chemical oxygen demand (COD) or volatile solids. As a source of renewable energy, the economic viability is measured by the net amount of useful energy realizable from the process. This is established by carrying out an energy balance. Components of the energy balance include the energy to maintain the reactor at the desired operating temperature including that for influent heating, the energy for pumping the slurry, for mixing, for gas scrubbing and for compression of the gas prior to storage. The energy output of the system is the energy content of the produced biogas. Presented in this paper is a set of relationships that are used in the estimation of these energy requirements.

KEYWORDS: Biogas reactors, anaerobic digestion, waste stabilization, energy requirements.

1. INTRODUCTION

Biogas reactors are anaerobic vessels which utilize biological processes in the absence of oxygen for the generation of biogas and waste stabilization. The waste stabilization efficiency of the reactor is measured by the chemical oxygen demand (COD) or the volatile solids (VS) reduction. The economic viability is, however, established by carrying out an energy balance to determine the net energy output of the system. The components of such energy balances would include: the energy to maintain the system at a desired operating temperature, the energy for pumping the influent slurry, for mixing the reactor content and for scrubbing and compression of the generated biogas prior to storage. These are, of course, all input components. The energy output of the system is the energy content of methane in the biogas (ignoring the fertilizer and the feed value of digested slurry).

Heating is often required to maintain the digester at the optimum operating temperature of 35^{o}C and 55^{o}C for mesophilic and thermophilic operations, respectively. The supplied heat must be sufficient to compensate for heat losses due to conduction, convection and radiation as well as losses through the evolved biogas, influent and effluent substrates. Where gravity feeding is not employed, energy must be expended in pumping the influent slurry into the reactor. Mixing is essential for a number of reasons – maintenance of uniform operating conditions throughout the reactor such as temperature, volatile fatty acid (VFA) concentration, etc., dispersion of potential metabolic inhibitors and toxicants, breaking up of coarse substrates particles to provide larger surface areas for bacterial attack, provision of good fluid consistency for reliable effluent flow, prevention of scum and crust formation on the liquid surface, etc (Echiegu, 1989).

Biogas, the useful energy output of biogas reactors, is generally composed of methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S), carbon monoxide (CO), ammonia (NH_3) and water (H_2O) and mercapatans (Hashimoto, *et. al.*, 1979; Smith, 1981; Loehr, 1984; and Echiegu, 1989). The main combustible component of biogas is methane. Other components have the effects of either diluting the gas (e.g. CO_2), causing inhibition of the anaerobic bacteria in the system (H_2S and NH_3) or causing corrosion problems (CO and H_2S). These undesirable components of the gas must be removed by scrubbing to enhance the usefulness of the biogas. This calls for energy input. Also, the biogas must be compressed before storage to reduce the bulk of materials to be stored. This again is an energy-demanding process.

Presented in this paper are the mathematical relationships used in the estimation of the various energy components employed in the design of biogas reactors. Special attention is paid to reactors utilizing animal wastes as substrates.

2. HEATING ENERGY REQUIREMENTS

The total energy requirements for the maintenance of a reactor at a given operating temperature (T_r) when the ambient temperature is T_a is determined by carrying out a stesdy-state energy balance as follows:

$$Q_h + Q_s + Q_{rx} + Q_m - Q_c - Q_i - Q_Y - Q_w = 0 \qquad (1)$$

Where Q_h is the heat energy to be supplied, Q_s is the heat gain from solar radiation, Q_{rx} heat of reaction for methane fermentation, Q_m mechanical heat gain due to mixing, Q_c conduction heat loss through the walls of the reactor, Q_i thermal energy required to heat the influent slurry, Q_y heat loss due to biogas removal and Q_w the latent and sensible heat losses due to moisture content of the biogas.

2.1 Heat Gain due to Solar Radiation

This is estimated from the following relationships (Echiegu, *et, al.* 1990):

$$Q_s = \sum_{i=1}^{n}\left[(I_b R_b)A_i\alpha_i + \left(I_d F_s + I_h\lambda F_g\right)A_s\alpha_g + IA_c\alpha_t\right] \qquad (2)$$

Where Q_s is the solar radiant heat gain (W), I_b, I_d, and I are the hourly beam, diffuse and total solar radiation on a horizontal surface, α_s and α_t are the surface absorptivity (for solar radiation) of the side and top of the reactor, R_b the ratio of beam radiation on the vertical surface to that on the horizontal surface, λ the ground reflectance (albedo, usually 0.2 for grassed surface), F_s surface to sky view factor (0.5 for vertical surface) and F_g surface to ground view factor (0.5 for horizontal surface).

The ratio R_b is given by Duffie and Beckman (1980) as:

$$R_b = \frac{[-\sin(\delta)\cos(\phi)\cos(\beta) + \cos(\delta)\sin(\phi)\cos(\beta)\cos(\omega) + \cos(\delta)]}{[\cos(\delta)\cos(\phi)\cos(\omega) + \sin(\delta)\sin(\phi)]} \qquad (3)$$

Where δ is the angle of declination, ϕ is the latitude (+ve for northern hemisphere and vice versa), β is the orientation of the surface (-ve due east) and ω the hour angle (-ve for hours before noon).

2.2 Heat of Reaction and Mechanical Heat Generation

Walsh *et. al.* (1980) working on a culture of thermophilic bacteria had determined a heat generation rate of 1.4 to 5.7 kilowatts per cubic metre (kW/m^3) of reactor volume. They also determined that 34.4 watts of heat is generated per kW of electrical power input during the mixing process, while Echiegu (1989), using the data of Ben-Hassan (1986) estimated a heat generation rate of 2.4 W/kW of electrical energy input. Thus by assuming an average heat of reaction rate of 3.6 W/L and heat generation rate of 2.4 W/kW, Q_{rx} and Q_m can be determined from:

$$Q_{rx} = 3.6\,V \qquad (4)$$

$$Q_m = 2.4\,R \qquad (5)$$

Where *V* is the reactor volume (L) and *R* is the rating of the electric motor used in the mixing used in the mixing process (kW). Heat of reaction and mechanical heat generation are however generally considered negligible (Chen and Hashimoto, 1981; Hill, 1983).

2.3 Conduction Heat Loses

This is estimated from the sum of the heat losses from the walls above (Q_{ca}) and below the ground (Q_{cb}), the top (Q_{ct}) and base (Q_{cf}) of the reactor, i.e.:

$$Q_c = Q_{ca} + Q_{cb} + Q_{ct} + Q_{cf} \tag{6}$$

where all the heat loses are in Watts (W). Alternatively, equation (6) can be expressed as:

$$Q_c = \sum_{i=1}^{n} [U_i A_i (T_r - T_{ai})] \tag{7}$$

Where U_i is the overall heat transfer coefficient of surface *i* of the reactor (W/m^2.^{o}C), A_i area of surface *i* of the reactor perpendicular to the direction of heat of heat flow (m^2), T_r reactor operating temperature (^{o}C), T_{ai} ambient temperature of the medium surrounding the given surface (^{o}C), *i* the surface under consideration (above or below the ground, top or bottom) and *n* is the number of sides. For parts of the reactor buried below the ground level, the heat transfer coefficient depends on whether the walls are above or below the ground water level. If the ground water level is not known, Metcalf and Eddy (1979) suggested that the sides of the rector should be assumed surrounded by dry earth while the floor should be assumed surrounded by saturated earth. Since the heat loss from the reactor warm up the adjacent earth, it is assumed that forms an insulating blanket 1.5 to 3.0 m thick before a stable ambient earth temperature is reached. Typical values of overall heat transfer coefficient for concrete-walled biogas reactors are shown in Table 1.

Table 1: Typical U-Values for Computing Biogas Reactor Heat Losses (Metcalf and Eddy, 1979)

Item	U, W/m^2 ^{o}C
Plain Concrete Wall (above ground)	
300 mm thick with air space and facing	1.80 – 2.40
300 mm thick wall with insulation	0.60 – 0.80
Plain Concrete Walls (below ground)	
Surrounded by dry earth	0.57 – 0.68
Surrounded by moist earth	1.10 – 0.80
Plain concrete reactors, base in contact with moist earth	0.68 – 0.85
Floating Covers	
With 35 mm wood deck, built-up roofing and no insulation.	1.80 – 2.00
With 25 mm insulating board installed under roofing.	0.90 – 1.00
Fixed Concrete Covers	
100 mm thick, un-insulated and covered with built-up roofing.	4.00 – 5.00
100 mm thick covered and insulated with 25 mm insulating board.	1.20 – 1.60
Vertical air space > 19 mm thick	5.11

For steady state heating energy requirement estimates, the ambient temperature is assumed constant. However, it is known that both ambient and ground temperature vary in a diurnal and seasonal cycle. A dynamic estimation of heating energy requirements would involve the use of a dynamic temperature functions such as that given by Hill (1983) i.e.:

Annual

$$\bar{\bar{T}}_d = \left(\frac{T_{y\,max} + T_{y\,min}}{2}\right) + \left(\frac{T_{y\,max} - T_{y\,min}}{2}\right)\sin[0.0172142 \text{ x } (N - 113.24)] \qquad (8)$$

Diurnal

$$\bar{\bar{T}}_h = \left(\frac{T_{d\,max} + T_{d\,min}}{2}\right) + \left(\frac{T_{d\,max} - T_{d\,min}}{2}\right)\left\{\sin[0.2617994 \text{ x } (h + 13)] + \sin 0.261799\left(\frac{h+13}{3}\right)^2\right\} \qquad (9)$$

where T_d is the average temperature (°C) for day N (N = 1 on January 1), $T_{y\,max}$ is the annual maximum daily temperature (°C), $T_{y\,min}$ annual minimum daily temperature (°C), T_h average temperature for the hour ending h (h = 1 at 1.00 am), $T_{d\,max}$ maximum temperature for the day (°C), $T_{d\,min}$ minimum temperature for the day (°C). Similar expression can also be found for ground temperature.

2.4 Heat to Raise the Influent Substrate to Reactor Operating Temperature

For steady-state conditions, this is estimated from:

$$Q_i = \bar{v}_s \rho_s C_{ps}(T_r - T_s) \qquad (10)$$

where Q_i is the heat energy require to heat the influent slurry (W), $\bar{v}_s$ volumetric flow rate of substrate (m^3/s), ρ_s slurry density (kg/m^3), C_{ps} the heat capacity of the slurry (J/kg °C), T_s the average temperature of the influent slurry (°C).

The density of most liquid waste such as food processing waste or domestic sewage may be taken as that of water. For animal waste, Tunney (1981) gave the following relationship for density:

$$\rho_s = 1002.5 + 3.85 \text{ TS} \qquad (11)$$

where TS is the percentage total solid content of the waste. The heat capacity of dilute substrate may also be taken as equal to that of water. For animal waste, the relationship developed by Chen and Hashimoto (1981) may be used:

$$C_{ps} = 4.17[1.0 - 0.00812\, TS] \qquad (12)$$

The hydraulic loading rate is determined by the hydraulic retention time (the theoretical time the substrate is designed to spend in the reactor, usually from a few hours to up to 40 days) and the volume of the reactor i.e.:

$$\bar{v}_s = \frac{V}{\theta} \qquad (13)$$

where, V is the volume of the reactor (m^3) and θ is the hydraulic retention time (s).

2.5 Heat Loss due to the Moisture Content of the Biogas

This consists of both the latent and sensible heat and is estimated from equations (14) and (15) respectively as follows:

$$Q_{wL} = \frac{L_w M_w}{3600} \qquad (14)$$

$$Q_{ws} = \frac{M_w C_{pw}(T_r - T_a)}{3600} \qquad (15)$$

where Q_{wL} and Q_{ws} are the latent and sensible heat losses (W) due to the moisture content of the biogas, respectively, L_w the heat of vaporization of water (2260 J/g), M_w mass rate of moisture removal (g/h) and C_{pw} heat capacity of water (4.2 J/g °C). The relationship between saturation moisture content, M_{sw} and the reactor operating temperature, T_r can be expressed by the following empirical relation formulated using data of Hill (1983):

$$M_{sw} = e^{(1.46+0.059T_r)} \tag{16}$$

where M_{sw} is the saturation moisture content (g/m^3 of biogas). The mass rate of moisture removal is then obtained from the product of volumetric rate of biogas production (γ_g) and the saturation moisture content, i.e.:

$$M_w = \gamma_g M_{sw} \tag{17}$$

where γ_g is the biogas production rate, (m^3/h).

2.6 Heat Loss due to Biogas Removal

This is estimated from the following relationship:

$$Q_\gamma = \frac{\left[(\gamma C_p \rho)_{CO_2} + (\gamma C_p \rho)_{CH_4}\right](T_r - T_a)}{3600} \tag{18}$$

where γ is the rate of gas production (m^3/h), C_p the specific heat capacity (J/kg ^{o}C), ρ density (kg/m^3), CO_2 and CH_4 refers to parameters for carbon dioxide and methane, respectively. The densities of CO_2 and CH_4 are 1.960 and 0.714 kg/m^3 respectively while their specific haet capacities are respectively 878.4 and 2217.6 J/kg ^{o}C (CRC, 1980). The estimation of biogas production rate is discussed later.

2.7 Net heating Energy Requirements

The net heating energy requirement is determined by solving for Q_h in equation (1) taking into consideration all the negligible components. The capacity of the heating equipment required is determined from:

$$Q_T = \frac{100 Q_h}{\eta} \tag{19}$$

where η is the efficiency of the heat source in percentage (%).

3. ENERGY REQUIREMENTS

3.1 Energy Requirement in Slurry Pumping

This is estimated from:

$$Q_P = \frac{\bar{v}_s \Delta P}{3600} \tag{20}$$

where Q_p is the power requirements (W), $\bar{v}_s$ slurry flow rate (m^3/h) and ΔP is the pressure drop (pumping head in Pa). The pressure drop is a function of slurry density, pipe length and diameter, mean flow velocity and Manning's friction factor. Chen and Hashimoto (1981) gave a detailed method of estimating pressure drop for pseudoplastic fluids such as animal waste.

3.2 Energy Requirement for Mixing

This can be determined from the following relationships (Echiegu, 1989; Reynolds, 1973).

<u>For gas recirculation</u>

$$Q_{mix} = 9.804 \rho_s \bar{v}_a H_s \tag{21}$$

$$Q_{mix} = \frac{\bar{\upsilon}_g}{256.4 \log\left(\frac{0.3048\ H_d + 34}{34}\right)} \tag{22}$$

For mechanical mixing

$$Q_{mix} = 0.935\mu_c^{0.3} m^{0.298} \tag{23}$$

where $\bar{\nu}_a$ is the recirculation air flow rate (m^3/s), H_s height of liquid slurry in the reactor (m), ρ_s slurry density (m^3/kg), $\bar{\upsilon}_g$ is specific volume flow rate of re-circulation gas (m^3/min per m^3 of reactor volume), H_d the submerged depth of diffusers (m), μ_c the viscosity of the slurry (centipoises) and m the mixed liquor suspended solid concentration (kg/m^3)

3.3 Energy Requirement for Gas Compression

Perry and Chilton (1973) estimated that 4.94 W is required for the adiabatic compression of 1.0m^3 of methane from 101 to 861 kPa (Hill, 1983). The following relationship, therefore, can be used to estimate the compression energy requirement.

$$Q_{comp} = 4.94\gamma_g \text{ x t} \tag{24}$$

where Q_{comp} is the compression power requirements (W), γ_g the methane production rate (m^3/h) and t is the hours of operation of the compressor in a day (h). Although the value of 4.94 W is for the compression of methane, this gas forms more than 60 % of the total value of the biogas. This relationship can therefore be applied for the compression of biogas.

3.4 Energy Requirement for Gas Scrubbing

The energy required for CO_2 scrubbing using water (considered most economical) was given by Ashare *et. al.* (1978) as 5.88 W/m^3 of biogas produced per day. The total daily biogas production rate γ_T (m^3/d) is obtained from the total methane production $\gamma_{T_{CH_4}}$(m^3/d) i.e. the product of volumetric methane production (m^3/m^3.d see Section 8) and the volume of the reactor. Since methane constitutes about 60 % of biogas, the total daily biogas yield will be 1.67$\gamma_{T_{CH_4}}$. Thus the power requirement for CO_2 scrubbing will be given by:

$$Q_{scrub} = 9.82\gamma_{T_{CH_4}} \tag{25}$$

3.5 Total Daily Energy Input

This is obtained as the product of the sum of all the energy input components in watts and the number of seconds per day.

$$\xi_i = 0.864\ [Q_h + Q_F + Q_{mix} + Q_{comp} + Q_{scrub}] \tag{26}$$

Where ξ_i is the energy input (MJ/d)

4. BIOGAS AND ENERGY OUTPUT

4.1 Biogas Output

The rate of biogas production is estimated in a number of ways. Data on biogas production as a function of volatile solids destroyed (consumed or stabilized) are found in the literature (Hashimoto *et. al.*, 1979; Loehr, 1979; Echiegu, 1989 and 1992). Knowing the loading rate to be employed (kg VS/d), and the treatment efficiency of the system, the amount of Vs destroyed and hence biogas production can be estimated. Usually, methane constitutes about 60% while CO_2 constitutes about 40 % of the biogas.

Methane production rate can also be estimated by calculating the methane equivalent of the net COD reduction i.e. the difference between the total COD removed and COD converted into biomass (anaerobic bacterial cells). The equivalent equation is given by Benefield and Randall (1980) and Kugleman and Jerris (1981) as:

$$\gamma_{CH_4} = \gamma_o [\Delta S - 1.42\Delta X] \tag{27}$$

where γ_{CH_4} is the methane production rate (L/h), γ_o litres of methane produced per gram COD at STP (0.35 L/g COD), ΔS ultimate COD removal rate (g/L) and equals $\bar{v}_h(S_o - S)$, $\bar{v}_h$ the influent flow rate (L/h), $(S_o - S)$ is the COD reduction (g/L), daily cell mass production (g cell/ultimate BOD per day) and 1.42 the ultimate BOD per gram cell.

An empirical relationship developed by Chen and Hashimoto (1979a) can also be used for the prediction of methane production, i.e.:

$$\gamma_{CH_4} = \frac{\beta_o S_o V}{\theta}\left[1 - \frac{K}{\theta\mu_m - 1 + K}\right] \tag{28}$$

where β_o is the ultimate methane yield (L/g VS added as the retention time, tend to infinity), S_o the influent VS concentration (g/L), θ the retention time (h), K the kinetic parameter and μ_m the maximum specific growth rate (h^{-1}). The ultimate methane yield is a function of type and bio-degradability of the substrate. Typical values are given in table 2.

Table 2: Typical values of Ultimate Methane Yield (β_o) of some agricultural waste**.**

Substrate	β_o, m^3 per kg VS added
Beef Manure	0.35 – 0.38
Dairy manure	0.17 – 0.24
Swine (pig) manure	0.38
Poultry manure	0.49

Source: Echiegu (1989 and 1992)

The maximum specific growth rate μ_m is a function of temperature and can be determined from the relationship developed by Lo *et al.* (1981) or that of Hashimoto (1981) respectively:

$$\mu_m = \left\{\begin{array}{ll} 0.0186\,T - 0.325, & 30^oC \le T < 45^oC \\ 0.0048\,T + 0.298, & 45^oC \le T < 60^oC \\ -0.0200\,T + 1.770, & 60^oC \le T \le 60^oC \end{array}\right\} \tag{29}$$

$$\mu_m = 0.013\,T - 0.129, \; 20^oC \le T \le 60^oC \tag{30}$$

The dimensionless kinetic parameter, *K*, is a function of the influent VS concentration and the waste type. For swine and beef manure, the following relationships can be used (equations (31) and (32), respectively) where S_o is the influent VS concentration (kg/m^3).

$$K = 0.6 + 0.0206\, e^{0.051\, S_o} \tag{31}$$

$$K = 0.8 + 0.0016\, e^{0.06\, S_o} \tag{32}$$

Also for poultry manure, the biogas production can be computed from a regression equation developed by Converse *et. al.* (1981), i.e.:

$$\gamma_g = 0.028\bar{v}_1 - 1.139 \tag{33}$$

Having computed the methane production rate from equations (27), (28) or (33) the CO_2 production rate can be computed by assuming that CO_2 forms 40 % of the total gas production with methane forming the rest. Thus:

$$\gamma_{CO_2} = {}^{2}/_{3}\,\gamma_{CH_4} = 0.67\,\gamma_{CH_4} \qquad (34)$$

4.2 Total Energy Output

Methane has a calorific value of 35.8 MJ/m^3, at standard condition (Benefield and Randall, 1980). The total gross energy production, ξ_o is therefore given by:

$$\xi_o = 35.8\,\gamma_{CH_4} \qquad (35)$$

Alternatively since CH_4 – the only energy component of the biogas – constitute about 60 % of the total gas, ξ_o can be estimated from:

$$\xi_o = 35.8 \times 0.6 \times 24\,\gamma_g = 515.5\,\gamma_g \qquad (36)$$

5. DISCUSSIONS AND CONCLUSIONS

A number of researchers have determined the relative proportions of the various energy components for the operation of biogas reactors. In the simulation model which assumed a retention period of 5 days, an influent VS concentration of 80 g VS/L, a methane yield of 3.96 m^3 CH_4 per m^3 of reactor volume per day, and ambient temperature of 10^{o}C and an operating temperature of 55^{o}C, Chen and Hashimoto,(1981) concluded that heating energy constitutes the largest component (37 to 39 %). Also, of the total energy requirements, the energy required to raise the influent slurry temperature to the reactor operating temperature comprises 87.4 to 93.9%. This suggests the necessity for recovery of the effluent heat for pre-heating the influent slurry. Energy for mixing constitutes the next major energy requirement, amounting to about 7.3% of the total energy output of the reactor. This energy component can be reduced through intermittent mixing. The least energy is consumed in pumping according to the simulation. Furthermore, Chen and Hashimoto (1981) showed that the highest net energy output is obtained when the retention time is less than 12 days using the above simulation parameters. Comparing mesophilic (35 ^{o}C) and thermophilic (55 ^{o}C), they concluded that mesophilic operation results in higher net energy output at linger retention time (> 25 days).

Singh and Schulte (1984) estimated energy requirements for temperature ranging from 20 to 35 ^{o}C, retention time ranging from 10 to 60 days and influent total solids concentration ranging from 3 to 12 %. They concluded that the worst operating condition occur at 20 ^{o}C, retention time of 10 days and influent total solids concentration of 3 %. Under this operating condition, the total energy requirement was estimated to be 140.6 % of the gross energy output of the reactor, i.e. more energy was expended in the reactor than the energy output from the generated biogas.

Schulte *et. al.* (1979) indicated that heating energy constitutes about 14.7 % of the total annual gross energy production with the energy for influent heating constituting up to 91.8 % of the heating energy requirements. The estimate was based on the operating temperature of 35 ^{o}C and ambient temperature which ranged from -15.0 to 18.5 ^{o}C.

The heating energy requirement has been shown to be a function of the colour of the reactor surface. Echiegu, *et. al.* (1990) have shown that black painted surfaces resulted in the least supplemental energy requirement while shinny surfaces results in the most.

These results were based on estimates made for the temperate regions where the ambient temperature is usually low. Hence, the conclusion that the heating energy required constitutes the highest proportion of energy requirement. In the tropical environment where the ambient temperature is close to mesophilic, perhaps the heating energy requirement may not be significant, unless of course, the reactor is being operated at thermophilic range. It will be instructive to carry out a simulation based on tropical conditions.

Although, the above relationships are given for biogas reactors, they can be applied with necessary modifications for the determination of energy balances for any liquid storage. The relationships have been shown to work very well in an actual design and simulation of a bioreactor Echiegu et al, 1990).

List of Symbols

$(S_o - S)$ = COD reduction (g/L),
$\bar{v}_h$ = slurry flow rate (L/h)
$\bar{v}_a$ = recirculation air flow rate (m^3/s),
$\bar{v}_s$ = volumetric flow rate of substrate (m^3/s),
$\bar{v}_g$ = specific volume flow rate of re-circulation gas (m^3/min per m^3 of reactor volume),
C_{ps} = heat capacity of the slurry (J/kg ^oC),
M_{sw} = saturation moisture content (g/m^3 of biogas).
Q_{ca} = heat losses from the reactor walls above the ground (W)
Q_{cb}, = heat losses from the reactor walls below the ground (W)
Q_{cf} = heat loss from the base of the reactor
Q_{comp} = compression power requirements (W),
Q_{ct} = heat loss from the top of the reactor
S_o = influent VS concentration (g/L),
T_s = average temperature of the influent slurry (^oC).
α_s & α_t = surface absorptivity (for solar radiation) of the side and top of the reactor, respectively
β_o = ultimate methane yield (L/g VS added as the retention time, tend to infinity),
$\gamma_{T_{CH_4}}$ = total methane production (m^3/d)
γ_{CH_4} = methane production rate (L/h),
γ_{CO_2} = CO_2 production rate (L/h)
γ_T = total daily biogas production rate (m^3/d)
γ_g = biogas production rate, (m^3/h).
γ_o = litres of methane produced per gram COD at STP (0.35 L/g COD),
μ_c = viscosity of the slurry (centipoises)
μ_m = maximum specific growth rate (h^{-1}).
ξ_i = energy input (MJ/d)
ξ_o = total gross energy production,
ρ_s = slurry density (kg/m^3),
ρ_s = slurry density (m^3/kg),
A_i = area of surface *i* of the reactor perpendicular to the direction of heat of heat flow (m^2),
CO_2 & CH_4= refers to parameters for carbon dioxide and methane, respectively
C_p = specific heat capacity (J/kg ^oC),
C_{pw} = heat capacity of water (4.2 J/g ^oC).
F_g = surface to ground view factor (0.5 for horizontal surface).
F_s = surface to sky view factor (0.5 for vertical surface)
H_d = submerged depth of diffusers (m),
H_s = height of liquid slurry in the reactor (m),
i = the surface under consideration (above or below the ground, top or bottom)
I_b,I_d,& I = hourly beam, diffuse and total solar radiation on a horizontal surface,
K = kinetic parameter
L_w = heat of vaporization of water (2260 J/g),

m = mixed liquor suspended solid concentration (kg/m^3)
M_{sw} = saturation moisture content,
M_w = mass rate of moisture removal (g/h)
n = is the number of sides.
Q_c = conduction heat loss through the walls of the reactor (W),
Q_h = heat energy to be supplied (W),
Q_i = thermal energy required to heat the influent slurry (W),
Q_m = mechanical heat gain due to mixing (W),
Q_p = power requirements (W),
Q_{rx} = heat of reaction for methane fermentation (W),
Q_s = heat gain from solar radiation (W),
Q_w = the latent and sensible heat losses due to moisture content of the biogas (W).
Q_{wL} & Q_{ws} = latent and sensible heat losses (W) due to the moisture content of the biogas, respectively,
Q_γ = heat loss due to biogas removal (W).
R = rating of the electric motor used in the mixing used in the mixing process (kW).
R_b = ratio of beam radiation on the vertical surface to that on the horizontal surface,
S_o = influent VS concentration (kg/m^3).
t = the hours of operation of the compressor in a day (h)
T_{ai} = ambient temperature of the medium surrounding the given surface (^oC),
T_r = reactor operating temperature (^oC),
TS = percentage total solid content of the waste
U_i = overall heat transfer coefficient of surface i of the reactor($W/m^2.^oC$).
V = volume of the reactor (m^3)
ΔP = pressure drop (pumping head in Pa).
ΔS = ultimate COD removal rate (g/L) and equals $V(S_o – S)$,
β = orientation of the surface (-ve due east)
γ = rate of gas production (m^3/h),
δ = angle of declination,
η = efficiency of the heat source in percentage (%).
θ = hydraulic retention time (s).
λ = ground reflectance (albedo, usually 0.2 for graced surface),
ρ = density (kg/m^3),
ω = hour angle (-ve for hours before noon).
ϕ = latitude (+ve for northern hemisphere and vice versa),

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ENGINEERING PROPERTIES OF RAW AND COMPOSTED COIR PITH

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ABSTRACT

The interactions taking place in mulch/manure handling and land application equipment involve the physical and flow properties of the product as well as the dynamics of the machinery elements. The interactions between the machine and the product as well as the important product properties to be considered are dependent upon the type of applicator used. Bulk density and moisture content for all the solid products are essential for the design and analysis of material handling systems, transportation equipment and spreaders. The physical properties of solid organic byproducts like coir pith *viz.*, moisture content, bulk density, normal stress, shear stress, friction coefficient are necessary in the development of conveying systems of applicator. The raw coir pith available from coir industries is in loose form with high moisture content and at different particle sizes. The moisture content and particle size play an important role in the flowability of coir pith.

The properties of raw and composted coir pith were measured at recommended levels of 10, 15, 20 and 25% moisture content (w.b.). The raw and composted coir pith respectively holds 3.1 and 1.8 times of water on weight basis. The raw coir pith holds 43% more water on weight basis than composted coir pith. The shear stress Vs normal stress relation of raw and composted coir pith was linear and hence it followed the behaviour of granular materials. The cohesion increased with moisture content for raw coir pith. The cohesion values for composted coir pith are higher than that of raw coir pith due to the chemical composition. The effect of moisture on cohesion does not show a definite pattern within 10 to 25% moisture content. The angle of internal friction for raw coir pith is more than composted coir pith. The bulk density at low moisture content increased linearly with increase in pressure and the effect of moisture content on bulk density is less at low moisture content for raw and composted coir pith. But at higher moisture content the bulk density increased nonlinearly with pressure upto 5 KPa and then increased linearly. The bulk density was also significantly higher at higher moisture content.

KEYWORDS: Coir pith, shear stress, coefficient of friction, pressure density relationship.

1. INTRODUCTION

The abundant availability of coir pith as a waste is the main disposal problems for the coir fibre industries. Coir pith with a range of interesting properties finds various applications. The unique property of coir pith is to hold additional moisture which would help to improve upon the moisture and nutrient availability of root zone. Since coir pith is highly resistant against biological degradation, the subsoil mulching can have long term effect, compared to surface incorporation. Application of coir pith as subsoil mulch could prevent recompaction of subsoil and also improve the soil structure. Shear strength in reference to biological materials is a term used to describe the maximum strength at which point significant plastic deformation or yielding occurs due to an applied shear stress.

There is no definitive "shear strength" of biological materials as it depends on a number of factors affecting the biological materials at any given time and on the frame of reference, in particular the rate at which the shearing occurs. Lawton and Marchant (1980) designed and fabricated a shear box to measure the coefficient of friction of agricultural seeds. The effect of seed moisture content on coefficient of internal friction of wheat, barley, oats, tick beans, and field beans was tested using the designed shear box. It was reported that material moisture content had a significant effect on the coefficients of internal friction of all the tested seeds; the coefficient increased with increase in moisture content. However, the rate of increment was higher for the moisture range of 15 to 25% (w.b.). Zhang *et al*. (1994) measured the coefficient of friction of wheat on corrugated galvanized steel and smooth galvanized steel using a direct shear box. Three different levels of moisture contents and four levels of normal pressures were considered. Results showed that increase in normal pressure (9.73 to 70.53 kPa) with the moisture content 11.9 to 17.7% (w.b.) decreased the coefficient of friction of wheat on a corrugated steel surface.

Glancey and Hoffman (1996) investigated trends in the measured properties to develop general guidelines for the design and analysis of material handling systems, transportation equipment and spreaders. They concluded that wet bulk density was dependent on moisture content for all the solid products evaluated and that knowledge of moisture content was therefore more important than the type or source of material. The static friction characteristics suggested that there was little practical difference between the different products.

Another trend identified by them and indicated that all unscreened products contained large clumps. This presented potential design problems in developing conveying systems to handle unscreened materials. Thirion *et al*. (1998) measured manure properties including normal stress, shear stress, bulk density, friction coefficient, straw content and dry matter content. The reported efforts were targeting the measurement of manure properties from a machinery testing and development viewpoint. They also reported that the values of normal stress between 0.14 and 1.60 MPa, as measured by a penetrometer. Neethi and Subramanian (2006) investigated the physical properties of coir pith and concluded that the bulk density of coir pith increased with an increase in moisture content and decreased with an increase in particle size.

The main aim of this study was to measure the engineering properties of raw and composted coir pith. These properties are useful in developing technologies for wider applications of coir pith.

2. MATERIALS AND METHODS

The interactions taking place in mulch/manure handling and land application equipment involve the physical and flow properties of the product as well as the dynamics of the machinery elements. The interactions between the machine and the product as well as the important product properties to be considered are dependent upon the type of applicator used. Bulk density and moisture content for all the solid products are essential for the design and analysis of material handling systems, transportation equipment and spreaders. The physical properties of solid organic byproducts like coir pith *viz.*, moisture content, bulk density, normal stress, shear stress, friction coefficient are necessary in the development of conveying systems of applicator. The raw coir pith available from coir industries is in loose form with high moisture content and at different particle sizes. The moisture content and particle size play an important role in the flowability of coir pith.

2.1 Moisture Content of Coir Pith

The moisture content of the raw and composted coir pith selected for the investigation was determined (AOCC, 1976) by drying the coir pith samples of 5-10 g, placed in containers of 20-25 mm depth at 130 ± 1^{0}C in a ventilated hot-air oven for 2-3 h till the samples attained constant mass. The recommended moisture content of bioorganic fertilizer for land application is 15-25% w.b. (FCO, 2006). Hence the coir pith samples of 10, 15, 20 and 25% moisture content for use in the experiments were prepared by drying and adding required quantity of water.

2.2 Shear Strength of Coir Pith

The measurement of shear strength of coir pith is to evaluate two parameters 'C' and 'φ' where 'C' is the cohesive strength of the coir pith and 'φ' is the angle of internal friction. The shear strength of raw and composted coir pith at selected levels of 10, 15, 20 and 25% moisture content (w.b.) was measured. The value of angle of internal friction is equal to the tangent angle of coefficient of friction for the material. The design of bins and hoppers for gravity flow and the coefficient of friction between granular materials are needed as designing parameters (Wilhoit *et al*., 1994; Glancey and Hoffman, 1996; Thirion *et al*., 1998; Pezzi and Rondelli 2002). Its value is determined by the following expression.

$$\text{Shear stress } (\tau) = c + \sigma \tan \varphi \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

Where, φ = Angle of internal friction, deg, c = Cohesive strength, Kg, σ = Normal stress, Pa, τ = Shear stress, Pa.

A direct shear test apparatus was fabricated to measure the shear strength of coir pith under varying normal loads. Direct shear test apparatus consists of two wooden boxes of size 300 x 200 x 100 mm. This method is commonly used for determination of coefficient of friction of coarse, powdered and grain particles (Lawton and Marchant., 1980; Thompson and Ross, 1983; Viswanathan *et al.*, 1990; Zhang *et al*., 1994; Sreenarayanan *et al.*, 1998; Neethi and Subramaniayn, 2006). The bottom box with open top is fixed on a wooden table. The top box is a hollow frame work which is placed over the bottom box. Both the boxes were filled with raw and composted coir pith. On the top surface of the filled coir pith, a mild steel plate (300 x 200 x 3 mm) is placed. The load cell with indicator is connected to the top wooden box through a hook. The Novatech load cell used to measure the shearing force has the following components *viz.*, the load cell, transducer read out and battery charger. The load cell (Type F256) is an axial diaphragm type with an active sensing section being the recessed face at the base of the top stud. The load is applied through the top stud on the active diaphragm and this face is not directly connected against any surface because of occurrence of damage. The sensed load will be read with the help of read out supplied along with the unit. The TR 200 transducer read out is a microprocessor based portable instrument to read load cell with full bridge output between 0.6 and 7.5 mV V^{-1} for a full-scale display of 19999.

The top box is pulled manually till the maximum shear force of the coir pith is observed. The procedure was repeated by varying the quantity of weight added on the mild steel plate till maximum shear failure indicated by the load cell indicator is recorded. The experiment was repeated for selected levels of moisture content (10, 15, 20 and 25%, w.b.) of raw and composted coir pith. Experiments were replicated thrice and the mean value was computed. Measurement of shear strength of coir pith by using direct shear apparatus is shown in Figure 1 and 2.

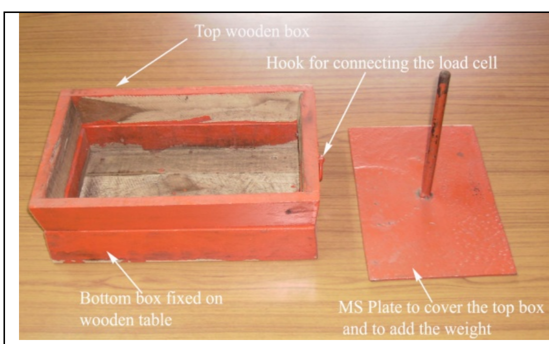


Figure 1. Direct shear apparatus for measuring the shear strength of coir pith

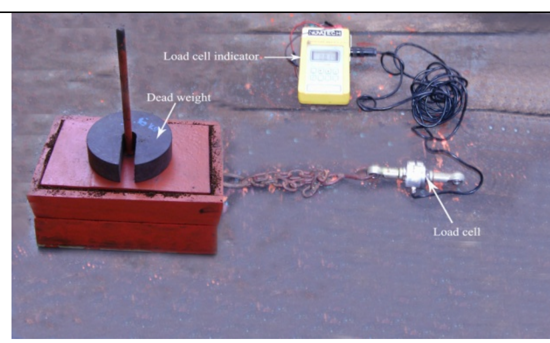


Figure 2. Operational view of shear apparatus for measuring the shear strength of coir pith

2.3 Bulk Density of Coir Pith

Bulk density is not an intrinsic property of a material; it can change depending on how the material is handled (Glancey and Hoffman, 1996; Thirion *et al*., 1998; Pezzi and Rondelli, 2002). The measurement of pressure density relationship of raw coir pith and composted coir pith was carried out.

An experiment was conducted to measure the bulk density of the raw and composted coir pith at recommended levels of moisture content of 15, 20 and 25% (Viswanathan and Gothandapani, 1999; Agnew *et al*., 2003). It consists of perforated PVC pipe of diameter 200 mm and 363 mm height. The perforations were made on the periphery of the pipe to evacuate the air during filling. This cylinder is placed over a flat surface and filled with coir pith. A plate is placed on top of the filled coir pith and weight is added over the top of the cylinder on mild steel sheet of diameter 180 mm and 2 mm thick to prevent the spillover of coir pith. The experiment is started by placing a known weight of one kg load and the change in depth of coir pith in the cylinder is measured using a scale. An additional weight (at increments of 1 kg) is added till there was no deformation by coir pith which indicates that coir pith has attained maximum compaction. The experiment was conducted for different quantity of raw and composted coir pith. Experiments were replicated three times and the mean value was used. The experimental set up for the measurement of pressure-density relationship for coir pith is shown in Figure 3 and 4.

Figure 3. Instrument for measuring the pressure - volume relationship of coir pith

Figure 4. Operational view of apparatus for measuring the pressure - volume relationship of coir pith

3. RESULTS AND DISCUSSION

3.1 Shear Strength of Coir Pith

The measurement of shear strength of coir pith is to evaluate shear strength parameters ‘C’ and ‘φ’ where ‘C’ is the cohesive strength of the raw and composted coir pith and ‘φ’ is the angle of internal friction (Table 1). The shear strength of raw and composted coir pith at recommended levels of 10, 15, 20 and 25% moisture content (w.b.) was measured as explained in section 2.2. The shear stress Vs normal stress for raw and composted coir pith at recommended levels of moisture content is shown in Fig. 5 and 6 respectively. It is clear that the cohesion increased with moisture content for raw coir pith. This is similar to the behaviour of cohesive frictional soils. The angle of internal friction did not change significantly over the range of 10 to 25% moisture content. Hence the flow behaviour of raw coir pith will not be influenced by moisture content when the moisture content is in the range of 10 to 25%.

Table 1. Cohesive strength and angle of internal friction of raw and composted coir pith

S/No.	Mulch materials	Moisture content, %	Cohesive strength, KPa (C)	Angle of internal friction, deg (φ)
i	Raw coir pith	10	0.66	69.32
		15	0.69	67.92
		20	0.71	66.75
		25	0.74	67.58
ii	Composted coir pith	10	1.30	50.47
		15	1.43	52.02
		20	1.34	49.05
		25	0.87	68.77

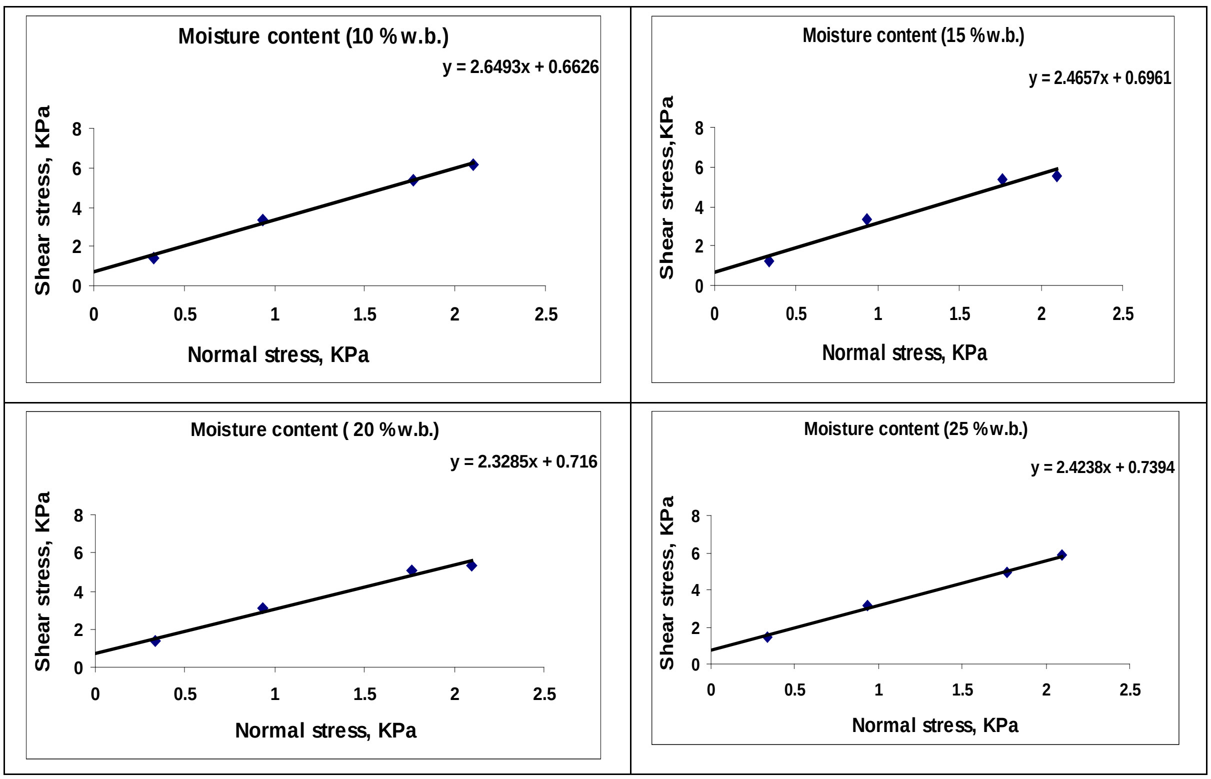
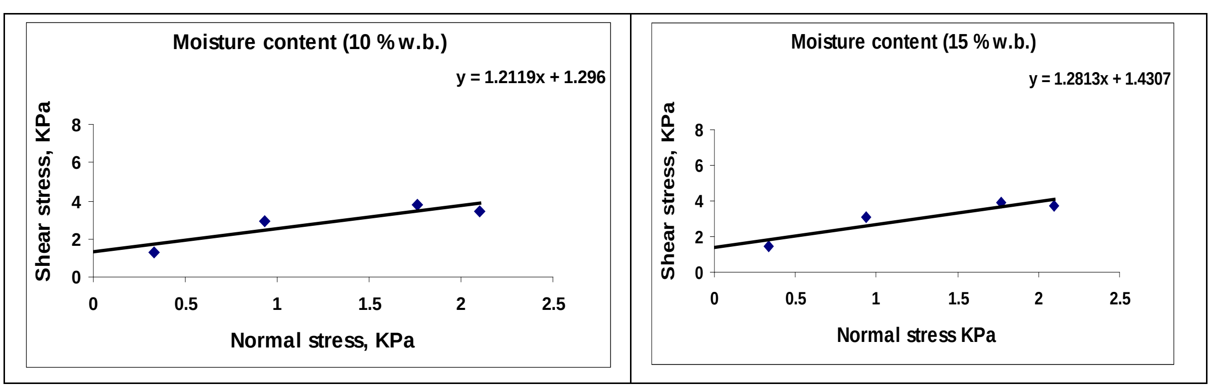


Fig 5. Shear stress Vs normal stress for raw coir pith at recommended moisture contents (10-25 %)



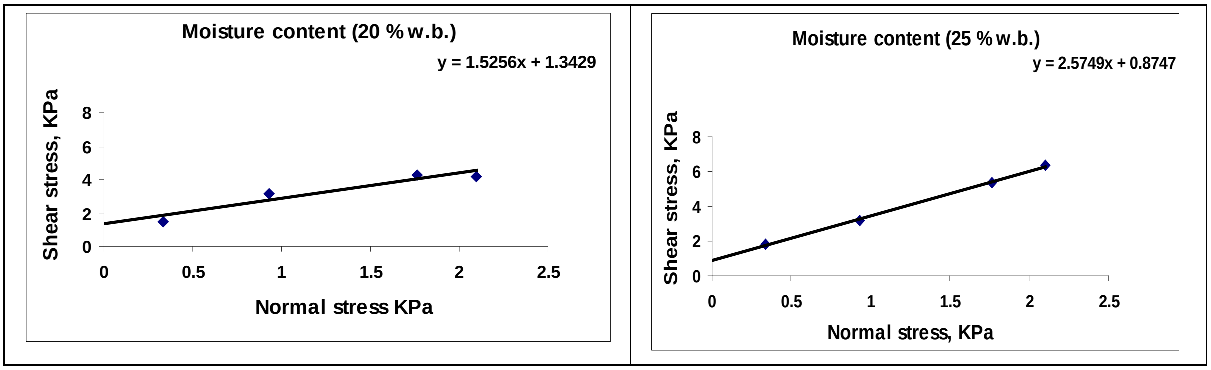


Fig 6. Shear stress Vs normal stress for composted coir pith at recommended moisture contents (10-25 %)

The cohesion values for composted coir pith were higher than that of raw coir pith due to the change in chemical composition of the material. The effect of moisture on cohesion did not show a definite pattern within 10 to 25% moisture content. However the angle of internal friction increased from 52 to 68° with increase in moisture content. This clearly indicated that the flowability of composted coir pith at high moisture content will be significantly different from that at low moisture content. The angle of internal friction for raw coir pith was more than composted coir pith which signified that raw coir pith will be more difficult to meter than composted coir pith.

3.2 Pressure Density Relationship

The pressure density relationship of raw and composted coir pith was investigated for the recommended range of moisture content of 15 to 25% (w.b.) and shown in Fig. 7 and 8 respectively.

It is inferred that the bulk density at low moisture content increased linearly with increase in pressure and the effect of moisture content on bulk density was less at low moisture content for raw and composted coir pith. But at higher moisture content the bulk density increased nonlinearly with pressure up to a pressure of 5 KPa, then increased linearly.

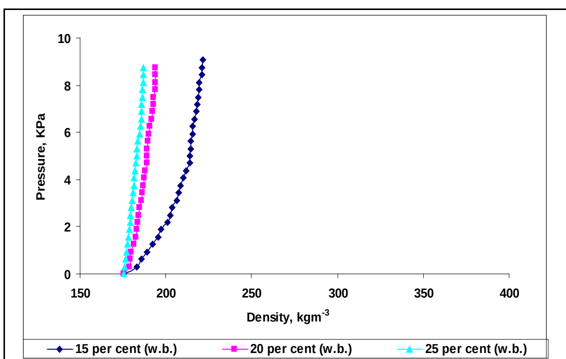


Fig 7. Pressure density relationship for raw coir pith at recommended levels of moisture content

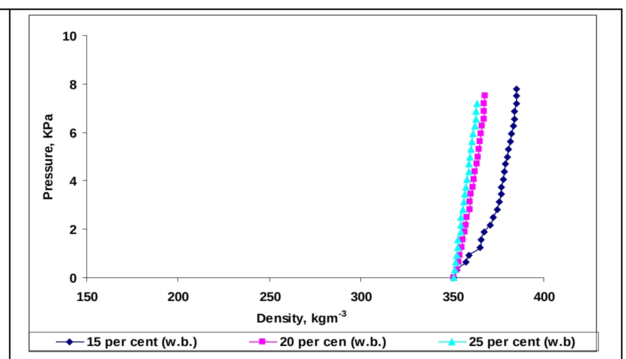


Fig 8. Pressure density relationship for composted coir pith at recommended levels of moisture content

The bulk density was also significantly higher at higher moisture content. The metering of coir pith was done on volumetric basis; however the influence of coir pith depends upon the quantity to be applied (w.b.).

4. CONCLUSIONS

The moisture content and particle size play an important role in the flowability of coir pith. The properties of raw and composted coir pith were measured at recommended levels of 10, 15, 20 and 25% moisture content (w.b.). The raw and composted coir pith respectively holds 3.1 and 1.8 times of water on weight basis. The raw coir pith holds 43 per cent more water on weight basis than composted coir pith. The shear stress Vs normal stress relation of raw and composted coir pith was linear and hence it followed the behaviour of granular materials. The cohesion increased with moisture content for raw coir pith. The cohesion values for composted coir pith are higher than that of raw coir pith due to the chemical composition. The effect of moisture on cohesion does not show a definite pattern within 10 to 25% moisture content. The angle of internal friction for raw coir pith is more than composted coir pith. The bulk density at low moisture content increased linearly with increase in pressure and the effect of moisture content on bulk density is less at low moisture content for raw and composted coir pith. But at higher moisture content the bulk density increased nonlinearly with pressure upto 5 KPa and then increased linearly. The bulk density was also significantly higher at higher moisture content.

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OPTIMIZATION OF DRY MAIZE MILLING - A RESPONSE SURFACE APPROACH

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ABSTRACT

In Nigeria, at cottage level, size reduction operations are widely done using plate mill. Effects of machine speed, moisture content and feed inlet opening on efficiency of milling using plate mill were determined using response surface methodology. Independent variables were moisture contents (12.46, 12, 14, 16, 19.36 % w.b), speed of shaft rotation (382.9, 432, 504, 576, 625.9 rpm) and feeding rate openings (3456.8, 3900, 4550, 5200, 5643.17 mm^2). Responses were grits, meal and flour fractions which ranged from 48.36% to 75.94%, 21.23% to 48.28% and 1.08% to 4.26%, respectively. Effect of the moisture content, speed of rotation and feed opening significantly influenced milling efficiency ($p<0.05$). Optimising grit fraction gave 79.63% grits, 19.75% meals and 1.03% flour. While meal fraction optimisation gave 54.03% grits, 44.89% meals, and 1.97% flour. Flour production optimisation resulted in 64.82% grits, 30.43% meals, and 4.77% flour.

KEYWORDS: Maize, size reduction, plate mill, fractions, response surface methodology, optimization.

1. INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop produced in Nigeria. It is the third most important in the world and ranked the second most important cereal crop in Nigeria (Enwere, 1998). The carbohydrate levels of maize grains are very high and the protein quality of common maize is similar to that of rice and wheat with lysine as the most limiting amino acids (FAO, 1992). Maize is reasonably fair in sulphur containing – amino acids (methionine and cystine) and vitamin A precursor, beta-carotene (Obiakor, 2001).

The meaning of the term milling varies with the crop and may include the processes of cleaning, grading, separating, mixing, polishing, de-husking and size reduction. In food processing, solid appears in many forms as large irregular pieces or finely divided powders. The particles may be hard and abrasive, soft, brittle, dusty or sticky and plastic. According to the forms of solids, means are to be found to manipulate them into products and possibly to improve their handling characteristics. The type of materials, moisture content of feed, material feed rate and condition of mill, product size requirement and nature of abrasive surfaces are factors that determine the milling operation (Singh and Singh, 1981). Grits, meal and flour are products of dry milling of maize. Products with mean particle size of 2.81 mm, 1.0 mm and 0.2 mm are classified as grits, meal and flour respectively (Kent, 1983). Maize grits are used traditionally for porridge, maize-flakes and as brewing adjunct. Meal is used for table consumption while the flour is used in baking.

Modelling is the use of mathematical equations to simulate the operation of a system. Researchers have applied mathematical models to predict properties of food products during crop processing and storage. Such studies include application of response surface to study product characteristics of extruded rice-cowpea-groundnut blends (Asare *et al.*, 2004), prediction of hulling efficiency of green gram (Sanjay and Agrawal, 2005). Others are Nwabueze (2006) who developed models to predict water absorption and solubility indices of extruded African breadfruit (*Treculia African*) blends, Sibel and Fahretin (2008) used response surface methodology to investigate the effects of extrusion conditions on extruded snacks and Akinoso *et al.* (2009) developed a predictive model for palm- kernel oil yield.

In order to have an efficient process, it is necessary to have a clear insight into the mechanisms of dry milling of maize and an understanding of the important process variables. Prediction of product properties and quality can then be obtained in terms of process parameters. Studies to generate models and data that can serve as useful tool in adequate selection of processes and equipment for efficient milling of maize at different processing parameters are necessary. The information will benefit design engineers, maize processors and researchers. Thus, the objective of this work was to study the effect of machine speed, moisture content and feed inlet opening on efficiency of dry milling of maize (*Zea mays* L*)* using plate mill.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Initial moisture content of maize was determined using ASABE (2008) standard. Three samples each weighing 20 g was placed in an oven set at 130^{o}C for 6 hours. The samples were cooled in a glass jar containing silica gel as desiccant. The dried samples were weighed using a digital compact balance model (AND 6100i Digital Weighing Balance, A&D Co. Ltd. Japan). The difference in weight before and after drying was taken to be moisture loss. Ratio of moisture loss to weight of wet material in percentage was recorded as moisture content wet basis.

2.2 Experimental Design

Central composite rotatable design of response surface methodology was employed as reported by Montgomery (2005). The variables and levels were fixed based on information from literature and trial experiments (Goyal *et al.,* 2010). The independent variables used for the study were moisture contents (10.64, 12, 14, 16, 17.36 % w.b), speed of shaft rotation (189.08, 288, 432, 576, 673.92 rpm) and feeding rate openings (1716, 2600, 3900, 5200, 6084 mm^2) while the response was product fractions. Twenty experimental combinations were generated (Table 1).

Table 1. Design matrix and responses as influenced by treatments

		Variables		Responses		
Treatments	X_1	X_2	X_3	Y_1	Y_2	Y_3
1	12	504	4550	68.16	29.85	1.99
2	12	504	5200	68.55	29.82	1.63
3	12	576	4550	75.94	21.23	2.83
4	12	576	5200	74.44	22.76	2.80
5	16	504	4550	59.81	38.70	1.49
6	16	504	5200	66.84	31.51	1.65
7	16	576	4550	68.28	30.00	1.72
8	16	576	5200	70.06	28.65	1.29
9	19.36	432	3900	69.54	27.71	2.76
10	12.64	432	3900	75.03	21.65	2.72
11	14	625.09	3900	56.40	39.34	4.26
12	14	382.9	3900	48.36	48.28	3.36
13	14	432	5643.17	74.15	24.77	1.08
14	14	432	3456.83	70.54	27.45	2.01
15	14	432	3900	68.99	28.76	2.25
16	14	432	3900	71.24	27.24	1.52
17	14	432	3900	65.74	32.78	1.48
18	14	432	3900	69.74	29.40	1.53
19	14	432	3900	69.04	23.90	2.38
20	14	432	3900	73.06	26.07	1.57

Where X_1 is moisture content in wet basis (%), X_2 is speed of shaft rotation (rpm), X_3 feed inlet opening (mm^2), Y_1 is grit (%), Y_2 is meal (%) and Y_3 is flour (%)

2.3 Moisture Content Variation

The desired moisture content levels were achieved by adding calculated volume of distilled water as obtained from Equation 1. Each sample was sealed in a separate polyethylene bag for 12 hours at ambient temperature (29 ± 2^{o}C) to equilibrate.

$$Q = {A(b-a)}/{(100-b)} \qquad (1)$$ (Akinoso et al, 2006)

Where A is initial mass of the sample (kg), a is initial moisture content of the sample (% wet basis), b is final (desired) moisture content of sample (% wb) and Q is mass of water to be added (kg).

2.4 Speed and Feed Inlet Opening Variation

The desired speed was achieved by using variable speed electric motor (SVF model, Guang Dong M & C Electric Power Co. Ltd, Guangzhou, China) while feeding rate was controlled by using a sliding gate arrangement as described by Sanjay and Agrawal (2005). The discharge end of the hopper measuring (65 x 100 mm) was divided into 5 entry levels 4373, 2600, 3900, 5200 and 8746 mm^2.

2.5 Milling Efficiency

Conditioned samples (1 kg each) were milled using attrition mill model 415-SF-24-DD (Andritz Sprout, Inc., Graz, Austria) at different experimental combination (Table 1). Particle size distribution of products obtained at one pass of feeding was determined by AOAC 965.22 method using WQS model vibrator (Precision & Scientific Instrument Co. Ltd, Shanghai, China) (AOAC, 2005). Retained fraction on each sieve was weighed using a sensitive weighing balance (AND EK-6100i Digital Compact Balance, A&D Co. Ltd. Japan). This was classified as reported by Kent (1983) into grits (those that passed through 2.81 mm sieve), meal (those that passed through 1.00 mm sieve), and flour (those that passed through 0.211 mm sieve). The milling efficiency was determined using Equation 2.

$$Milling\ Efficiency = \frac{W_1}{W_2} \times 100 \qquad (2)$$

Where W_1 is weight of product fraction (g) and W_2 is total weight of milled products (g)

2.6 Statistical Analysis

All the experimental procedures were repeated in triplicate. The mean values were recorded. These were subjected to regression analysis and analysis of variance. Level of significance was fixed at 5%. Mathematical models were generated by using Design -Expert 8.0 version (Stat Ease Inc. Minneapolis, USA). Adequacy of the models was tested by coefficient of determination R^2 and by lack of fit test.

2.7 Optimisation

In optimising milling operation, primary products was maximised while minors were minimized. The following constraints were used; grit maximized, meal and flour minimized; meal maximized, grit and flour minimized; flour maximized, grit and meal minimized. Appropriate combinations of moisture content, speed of shaft rotation and feed opening that produce best results were obtained using a commercial statistical package (Design-Expert, Stat ease Inc., Minneapolis, USA). To validate the optimal parameters, maize was milled at these conditions. The result was compared with predicted values and percentage error calculated.

3. RESULTS AND DISCUSSION

3.1 Grits Fraction

Visual illustrations of effects of moisture content, speed of rotation and feed opening on percentage of grits fraction are shown as Figures 1 to 3. Grits fraction ranged from 48.36% to 75.94%. Sanjay and Agrawal (2005) also reported high milling efficiency (73.72%) for green gram using roller mill at 10% moisture content. Milling efficiencies were generally high for grit when compared with meal and flour. According to NAMA (2010), the primary objective in dry maize milling is to obtain the maximum yield of grits. ANOVA showed significant influence of treatments on grits fraction at $p < 0.05$. Mathematical expression of the relationship is presented as equation 3. High coefficient of determination (R^2) justifies the suitability of the model. All the model terms were significant. In addition, the model satisfies lack of fit test at 5% level of significance.

$$\begin{aligned} Grit = {} & +69.63 - 1.99X_1 - 57.36X_2 + 1.67X_3 + 3.58{X_1}^2 - 6.71{X_2}^2 + 2.51{X_3}^2 - 0.25X_1X_2 \\ & + 1.24X_3C - 0.89X_2X_3 - 0.77{X_1}^3 + 6.68{X_2}^3 - 0.71{X_3}^3 + 53.85X_1 \\ & - 0.42X_1X_2X_3 \qquad (3) \end{aligned}$$

$$p - value = 0.0105, \qquad R^2 \quad 0.96$$

Where X_1 is moisture content (%wb), X_2 is speed (rpm) and X_3 is feed opening mm^2

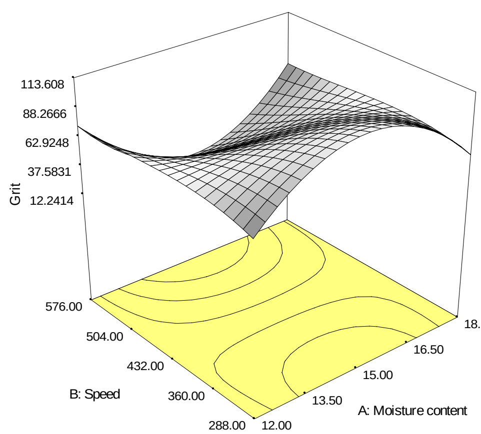

Figure 1. Effect of speed and moisture content on grit fraction

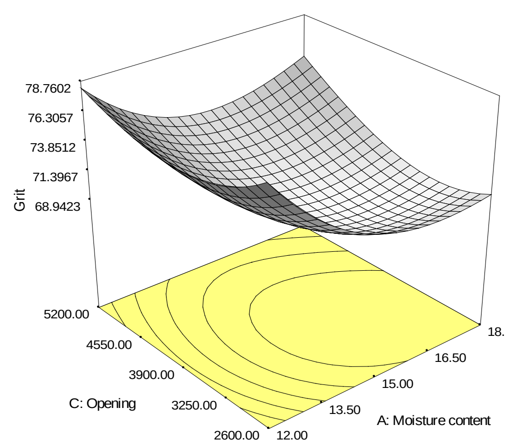

Figure 2. Effect of feed opening and moisture content on grit fraction

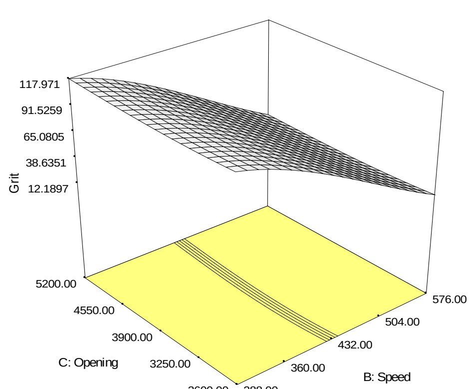

Figure 3. Effect of feed opening and speed on grit fraction

3.2 Meal Fraction

The meal fraction obtained varied from 21.23% to 48.28%. Kent (1983) reported average dry milling yield of coarse meal and fine meal of 20% and 10%, respectively. Response surface plot of the relationship are shown as Figures 4 to 6. Equation (4) shows the model generated for predicting effect of moisture content, speed of rotation and feed inlet opening on meal fraction. The model satisfies lack of fit test. The coefficient of determination (R^2) of 0.94 suggests that the model can be applied with about 80% confidence.

$$\begin{aligned} Meal \; = {} & +28.03 + 2.27X_1 + 54.65X_2 - 1.21X_3 - 4.10{X_1}^2 + 6.28{X_2}^2 - 1.14{X_3}^2 + 0.52X_1X_2 \\ & - 1.26X_1X_3 + 0.92X_2X_3 + 0.88{X_1}^3 - 6.36{X_2}^3 + 0.33{X_3}^3 - 51.69{X_1}^2X_2 \\ & + 0.53X_1X_2X_3 \qquad (4) \end{aligned}$$

$$p - value = \; 0.031, \qquad R^2 \quad 0.94$$

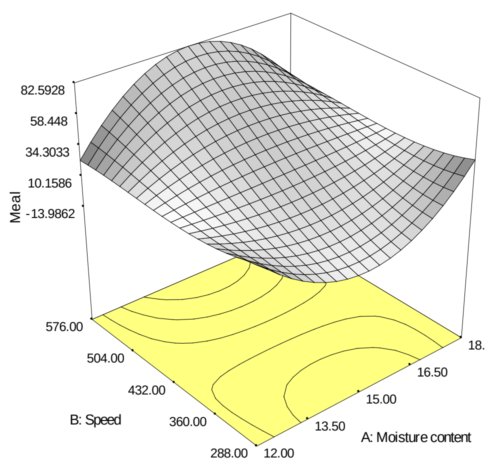

Figure 4. Effect of speed and moisture content on meal fraction

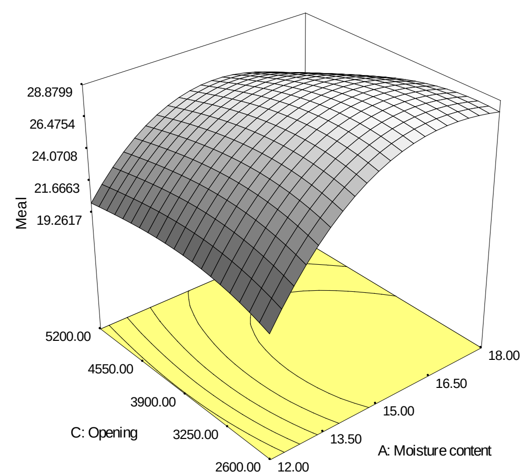

Figure 5. Effect of feed opening and moisture content on meal fraction

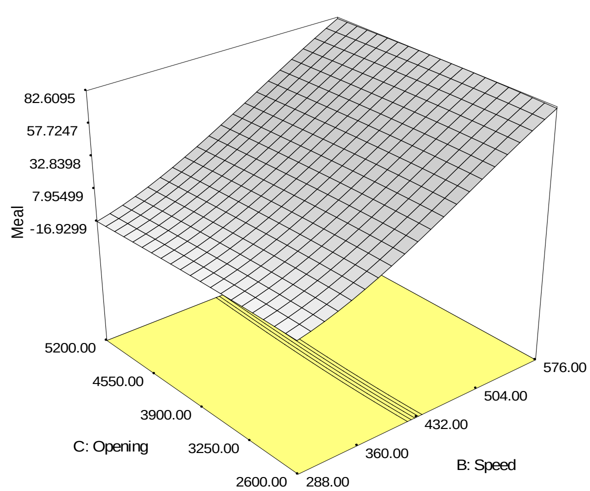

Figure 6. Effect of feed opening and speed on meal fraction

3.3 Flour Fraction

Figures 7 to 9 are plots of treatment against flour fraction. Percentage of flour proportion in the samples ranged from 1.08% to 4.26%. Curt and Eric (2009) reported 4.71 to 8.31% as range of flour fraction from dry milling of maize using plate mill while Kent (1983) reported 5 %. The relationship between moisture content, speed of rotation and feed inlet opening is expressed as Equation (5). The effects of the variables are significant on flour fraction ($p < 0.05$).

$$\begin{aligned} Flour = &+1.79 - 0.32X_1 + 4.85X_2 + 0.25X_3 + 0.42{X_1}^2 - 1.39{X_2}^2 + 1.11{X_3}^2 - 0.27X_1X_2 \\ &+ 0.015X_1X_3 - 0.032X_2X_3 - 0.069{X_1}^3 + 0.052{X_2}^{34\cdot} - 0.33{X_3}^3 - 4.67{X_1}^2X_2 \\ &- 0.12X_1X_2X_3 \qquad (5) \end{aligned}$$

$$p - value = 0.046, \qquad R^2 \quad 0.93$$

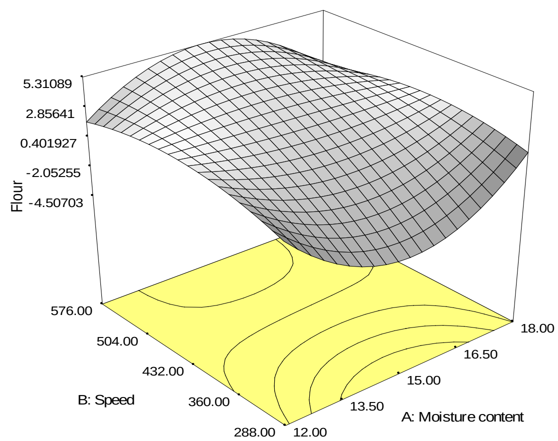

Figure 7. Effect of speed and moisture content on flour fraction

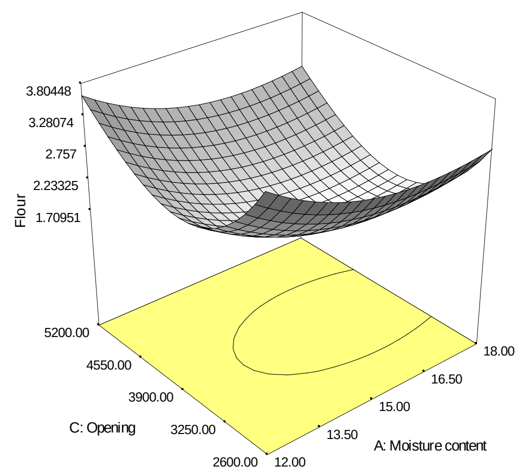

Figure 8. Effect of feed opening and moisture content on flour fraction

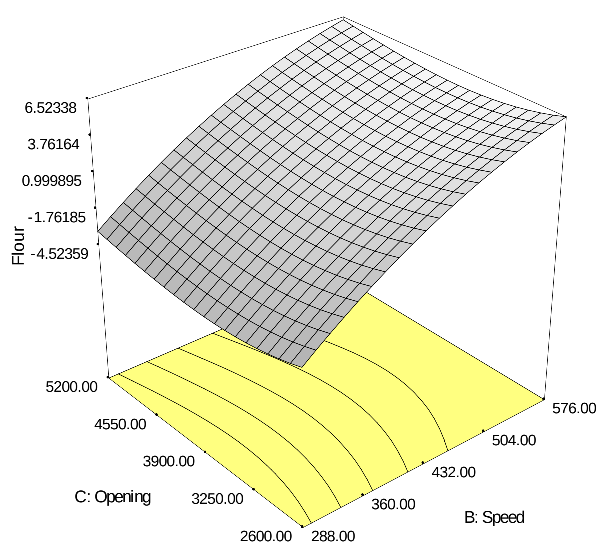

Figure 9. Effect of feed opening and speed on flour fraction

3.4 Optimization of Processing Conditions

The numerical optimization finds a point that maximizes the desirability function. Table 2 summarizes optimization of processing conditions for maize grits, meals and flour and their desirability. Desirability is reliability factor that ranges from zero to one. Zero is worst while one is best. Optimising grit fraction gave 79.63% grits, 19.75% meals and 1.03% flour. While meal fraction optimisation gave 54.03% grits, 44.89% meals, and 1.97% for flour. Flour production optimisation produced 64.82% grits, 30.43% meals, and 4.77% flour. Curt and Eric (2009) reported mean yield of 67.27%, 24.64% and 5.69% for grit, meal and flour fractions, respectively when using plate mill for maize size reduction. Validation of predicted optimal moisture content, worm shaft speed and feed inlet opening gave 77.21% grit, 20.62% meal and 2.17% flour. This gave errors of 3.03, 4.04 and 2.5% for grit, meal and flour respectively.

Table 2: Optimum processing parameters for maize grits, meals and flour

Variables			Responses			
Moisture content (%wb)	Speed (rpm)	Inlet opening (mm^2)	Grit (%)	Meal (%)	Flour (%)	Desirability
17.9	546.9	6426.6	79.6	19.7	1.0	1
18.0	864.0	5790.53	54.0	44.9	1.9	0.794
12.97	864.0	3611.8	64.8	30.4	4.8	0.649

4. CONCLUSIONS

Based on the results of the study, it was concluded that fractions of grit, meal and flour in the product were functions of moisture content of maize, speed of worm shaft rotation and feed inlet opening. The plate mill is more appropriate if the primary aim of the size reduction is production of grit. However, it is possible to get up 44.9% meal fraction from maize using the mill.

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SOME PHYSICAL PROPERTIES OF *CHRYSOBALANUS ATACORENSIS* RELEVANT TO ITS PROCESSING

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ABSTRACT

The physical properties of *Chrysobalanus atacorensis* seeds relevant to the design of systems for its processing were investigated. The properties determined were size, shape, coefficient of sliding friction, angle of repose, density, volume, and percentage porosity, major, intermediate and minor dimensions. Techniques employed in the experiments includes micrometer screw gauge, cussons inclined apparatus and water displacement method. The result obtained for the various dimensions studied were: 14.81mm ±0.86, 13.95mm ± 1.2 for major, intermediate and minor diameters respectively. Mean value of sphericity, surface area, bulk volume, solid volume, bulk density and solid density were: 95%, 618.64mm^2, 315.75cm^3,160cm^3, 0.58g/cm^3 and 1.15g/cm^3 respectively. Angle of response ws 25.7^0 and porosity was 49.36%. The mean low values obtained for angle of repose of the seeds on different structural surfaces indicates the easy flowing capacity of the seeds.

KEYWORDS: *Chrysobalanus atacorensis*, physical properties, processing, dimension, density, friction, angle of response.

1. INTRODUCTION

Chrysobalanus atacorensis belongs to the family *Rosaceae*. It is a small tree with leaves that are oblong elliptic, acuminate and *Cuneate* at the base (Hutchinson and Dalziel, 1963). The flowers are hermaphrodites, *actinomorphic*, and arranged in cymes. Petals are present, fruits are ribbed and pubescent when young (*Hutchinson and Dalziel*, 1963).

This tree is indigenous to the south-south region of Nigeria, particularly Akwa Ibom State. The most basic known use of the dried seeds of *C. atacorensis* is as spice in foods, beverages and as meat tenderizer (Bassey et al., 2011). These seeds have strong, peppery, unique and distinguishing flavor. It is believed that the seeds of *C. atacorensis* stimulate salivation, promote digestion, and improve palatability and appeal of dull foods (Bassey et al., 2011). The picture of C. atacorensis tree and seeds is presented in Fig.1 and Fig.2 for clarification.

Fig. 1: *C. atacorensis* Tree

Fig. 2: *Chrysobalanus atacorensis* seeds

A study by Bassey et al. (2011) revealed the nutritional properties of *C. atacorensis* to include: protein 15.74%, fibre 7.33%, ash 2%, carbohydrate 62.9% and calcium 32 mg/kg of dried seeds. The high calcium content is indicative of its complementary role in calcium deficient diets. Calcium is necessary to cure Osteoporosis characterized by low bone mass (Abrams *et al.*, 2000). The harvesting and handling of *Chrysobalanus atacorensis* seeds are usually carried out by human labor. The use of finger nails to dehull the dried seeds of *C. atacorensis* is not only unhygienic but poses a potential danger to the processor's cuticle as well as serve as a medium of transmitting pathogenic bacteria to the final consumer. Also the manual grating of the seeds of *C. atacorensis* to powder form is arduous and time consuming.

However, as the degree of mechanization in the handling of agricultural products has risen in the past decades. It is essential to have knowledge of physical and mechanical properties of agricultural products in order to design equipments for handling, storing and processing these products (Mohsenin, 1970). Other researchers such as: Dutta *et al*. (1988), Cooper *et al*. (1990), Fraser *et al.* (1978) and Oje *et al*. (1997) amongst others have worked on the engineering properties of different agricultural products.

Therefore, the aim of this study is to determine the engineering properties of *C. atacorensis* necessary for designing mechanized systems for its post-harvest processing. These seeds are mostly used in the powdered form, and there has been no reported engineering research on this seed prior to this study.

2. MATERIALS AND METHODS

Several dried seeds of *C. atacorensis* were obtained from Akpan Andem market, Uyo, Akwa Ibom State, Nigeria. These seeds were dehulled manually, 100 seeds were randomly selected to from the sample for analysis to avoid bias and experimental error. The samples were labeled for easy identification, the engineering properties of the sample were determined using experimental procedures/methods described as follows:

2.1 Size

The three principal dimensions namely major, minor and intermediate diameter, were determined using micrometer screw gauge. This instrument was carefully handled in order to avoid exerting undue pressure on the seed while taking the readings. Also error due to parallax was avoided by reading the micrometer screw gauge in upright position.

2.2 Shape (Roundness and Sphericity)

Sphericity: The mean value of the major, minor and intermediate of the sample was used in calculating the *sphericity* of the seed, as specified in equation 1.

$$\Phi = \frac{(abc)^{1/3}}{a} \quad \ldots 1,$$

Where ϕ = *sphericity*, a = major diameter, b = intermediate diameter,
c = minor diameter *(Mohsenin* 1970).

Roundness: this was determined from equation 2 proposed by *Alonge 2008.*

Roundness = r/R - - - - (2)

Where r = intermediate diameter & R = major diameter.

2.3 Surface Area

The estimated surface area was determined by analogy with a sphere of same geometric mean diameter as described in equation 3 (Olajide & Ade-Omo waye 1999: Sacilik et.al 2003).

$S = Dg^{2}$ - - - - (3), Where s = estimated surface area, Dg = geometric mean.

Volume (Bulk and Solid Volume)

Bulk volume: The height of the sample in a $100cm^3$ beaker and the internal diameter of the beaker measured with venier caliper was used to determine the bulk volume of the sample. As described in equation (4)

$Vb = \pi\ (di/2)2h$……………… (4)

Where Vb = Bulk volume, di = internal diameter of beaker and h = height of sample in beaker.

2.4 Solid Volume

The solid volume (Vs) was obtained from water displacement method by reading and calculating the difference in volumes of water in a calibrated cylinder before and after the introduction of the sample as described by Mohsenin (1970).

2.5 Density (Bulk & Solid Densities)

This was determined by applying bulk and solid volumes in appropriate density equations.

2.6 Angle of Repose/Coefficient of Sliding Friction

The sample seeds were split into 10 groups, each group containing 10 seeds. These seeds groups were placed on cussons inclined apparatus that has a calibrated scale attached to it. The apparatus was tilted gently until all the seeds fall-off. The corresponding angle was read and recorded as Θ.

This angle was used in calculating for coefficient of sliding friction as described in equation 5;

$\mu = \tan \Theta$ - - - - - (5)

where Θ = angle of repose, μ = coefficient of sliding friction (Mohsenin, 1970, Carson et.al 1986)

2.7 Specific Gravity

The specific gravity which is defined a
s the ration of the mass of the product to the mass of an equal volume of water at 40°C, was determined using equation 6.

$$SG = \frac{mass\ of\ air\ X\ \ specific\ gravity\ of\ water}{mass\ of\ displaced\ water} \text{ - - - - - - - (6)}$$

2.8 Percentage Porosity

The percentage porosity was determined based on the relationship established for porosity by (Mohsenin, 1984).

$P_f = (1-Db/Ds) \times 100$ …………….. (7)

Where P_f = percentage porosity, Db = bulk, Density, & Ds = solid density.

2.9 Mass

The mass of the selected sample seeds was determined using sensitive electronic weighing balance read to the accuracy of 0.001g. The value obtained was subsequently applied in solid density determination.

3. RESULTS AND DISCUSSION

The summary of the results obtained for each parameter studied is presented in Table 1.

3.1 Size Determination

The values of the three principal dimensions: major, minor and intermediate axes are summarized in Table 1. The seeds height ranges from 17.30mm to 13.20mm with a mean value of 14.81mm and a standard deviation of ± 0.86mm for the major axes of the 100 seeds sample. The minor axes height ranges from 16.25mm to 11.61mm with mean of 13.38mm and a standard deviation of ± 0.87mm. The intermediate axes height ranges from 17.44mm to 10.35mm with mean of 13.95mm and a standard deviation of ± 1.20mm. The intermediate axes had the widest spread of values as indicated in the higher standard deviation value. This implies that the intermediate axes had wide variability compared to both major and minor axes of the seed.

3.2 Shape Determination

The sphericity of *C. atacorensis* varied from 0.98mm to 0.88mm with a mean value of 0.95mm (95%) and a standard deviation of 0.05mm. The value 0.95mm or 95% (i.e. percentage sphericity) indicates that the seed is spherical. The roundness of *C. atacorensis* varied from 1.01mm to 0.78mm with a mean value of 0.94mm (i.e. 94% - percentage roundness).

3.3 Surface Area

The estimated surface area of *C. atacorensis* ranges from 620.22mm^2 to 617.54mm^2 with a standard deviation of 0.05mm^2 and a mean value of 618.64mm^2 as shown in Table 1. The knowledge of the surface area of an object is essential in estimating the amount/quantity of packaging material and rate of heating, freezing, cooling and drying as heat transfer is proportional to surface area.

3.4 Volume

The bulk and solid volumes of *C. atacorensis* determined were 315.75 cm3 and 160.00 cm3 respectively.

3.5 Density

The means of bulk and solid densities determined were 0.58 g/cm^3 and 1.15g/cm^3 with a standard deviation of 0.003 and 0.06 respectively. The difference in the bulk and solid densities indicates that the seeds have interstitial air spaces. The densities of food materials as well as processed products dictate the characteristic amount and strength of its packaging material.

3.6 Coefficient of Sliding Friction

These were determined on three surfaces namely: plywood, galvanized metal and aluminium. The whole process was replicated 10 times. The means values as shown in Table 1 were thus: plywood – 0.525, Galvanized metal – 0.458, Aluminium – 0.462, and a standard deviation of 0.09, 0.08 and 0.12 respectively. From the results obtained, it can be inferred that the coefficient of sliding friction was maximum for plywood and minimum for galvanized metal. This agrees with the results obtained for spherical grains by Alonge (2008).

3.7 Angle of Repose

The angle of repose values determined from the experiment ranges from 27.7° to 24.6° with a mean value of 25.7° for the ten groups of the seeds, and the trials made. This lower angle of repose represents easier flow ability. The flow capacity of agricultural products is also influenced by size, shape, moisture content and the orientation of the seed particles.

3.8 Specific Gravity

The mean value of specific gravity obtained for *c. atacorensis* from equation (8) described in material and method was 1.10 with a standard deviation of 0.07.

3.9 Geometric Mean

The geometric mean determined from computing the major, minor and intermediate diameters was 14.03mm with a standard deviation of 0.67mm.

3.10 Percentage Porosity

Porosity defined as the percentage of volume of inter-grain space of the total volume of grain in bulk depends on shape, dimensions and roughness of the grain surface (Barbosa-canovas, 2006). The percentage porosity determined for the sample was 49.36%. Beds with low porosity are more resistant to fluid flow.

3.11 Mass

The mean mass of the 100-seeds sample determined was 184.51g with a standard deviation of 0.05g.

Table 1: Summary of some Physical Properties of *Chrystobalanus atacorensis*

S/N	Property/unit of measurement	No. of Trials	Mean value	Standard deviation	Maximum value	Minimum value
1	Major diameter (mm)	100	14.81	0.86	17.30	13.20
2	Intermediate diameter (mm)	100	13.95	1.20	17.44	10.35
3	Minor diameter (mm)	100	13.38	0.87	16.25	11.61
4	Geometric mean (mm)	100	14.03	0.67	16.99	11.66
5	Sphericity (mm)	100	0.95	0.005	0.98	0.88
6	Roundness (mm)	100	0.94	0.12	1.01	0.78
7	Est. surface area (mm^2)	6	618.64	0.05	620.22	617.54
8	Volume (cm^3)	6	160.00	0.03	160.01	159.96
9	Mass(g)	6	184.51	0.05	184.55	184.20
10	Bulk density (g/cm^3)	6	0.584	0.03	0.588	0.582
11	Solid density (g/cm^3)	6	1.150	0.06	1.16	1.12
12	Porosity (%)	6	49.36	0.72	50.40	48.65
13	Specific gravity	6	1.10	0.07	1.14	1.00
14	Angle of repose (°)	30	25.70	1.05	27.70	24.60
15	Coefficient of sliding friction:					
	Plywood	10	0.525	0.09	0.675	0.384
	Galvanized metal	10	0.458	0.08	0.577	0.364
	Aluminium	10	0.462	0.12	0.649	0.268

4. CONCLUSION

The investigation revealed that *C. atacorensis* seeds were heavier than water. This established fact may be used in separating the seeds from other agricultural materials that are lighter than water. The three principal dimensions of the sample seeds varied widely with the intermediate dimension having the highest spread. This confirms the irregular nature of most agricultural materials. Hence, the physical properties studied will be of immense importance in designing systems necessary for the mechanization of *C. atacorensis* processing operations considering its nutritional as well as medicinal values. However, the mechanical and thermal properties of *C. atacorensis* still remain a virgin area for prospective researchers.

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PERFORMANCE EVALUATION OF NCAM KEROSENE-FIRED BATCH DRYER

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ABSTRACT

The performance evaluation of NCAM developed kerosene-fired batch dryer was carried out at the Engineering and Scientific Services Department of the National Centre for Agricultural Mechanization (NCAM), Ilorin using three different crops namely: rice, cassava and maize obtained from the Centre's research farm. Crop parameters and machine variables such as moisture content, thickness of agricultural material, drying rate, fuel consumption, and drying time were measured and recorded. For the entire test carried out using the three different crops, it was discovered using NCAM's kerosene-fired batch dryer recorded fuel consumption rates of 2 l/h of kerosene and 0.33 l/h of diesel during drying of paddy rice, 2.77 l/h of kerosene and 0.38 l/h of diesel during drying of round cassava chips, 2.75 l/hr of kerosene and 0.37 l/h of diesel during drying of threadlike cassava chips and 1.89 l/h of kerosene and 0.44 l/h of diesel during drying of maize on cob. The NCAM kerosene-fired batch dryer is found most economical for the drying of paddy rice as a result of drying conveniently parboiled paddy rice to a safe storage/milling moisture content of 14% $_{w.b}$ within 60 minutes of drying using 2 litres of kerosene and 0.33 litres of diesel. The drying rate at which NCAM's kerosene-fired batch dryer dries crops is much faster when compared to the sun drying method. The drying of cassava chips (threadlike shape) was found to be faster than the drying of cassava chips (round shape) due to its smaller surface area. Because of the sooth content contained in the dried cassava chips, there is need for the modification of the dryer by incorporating a heat exchanger to reduce or eliminate fumes on the chips.

KEYWORDS: Batch, dryer, kerosene, diesel, temperature, drying.

1. INTRODUCTION

When heated air is used as a drying medium, the primary factor influencing the rate of drying is the drying temperature (Yunfei and Morey, 1987). It was reported, that drying is independent of air velocity in the range of 0.15 to 0.81 m/s, but depends sharply on the drying temperature of the air from 21.1 to 76.7^{o}C (Sun et al 1994).

Drying is essential for normal preservation of perishable foods and some crops, this problem can be minimized by cold storage or processing into more stable products. Cassava roots stored at temperature and relative humidity (RH) of 13^{0}C and 85 - 90%, respectively, can last for a maximum of 2 months and can as well last between 5 to 6 months when stored at temperature and relative humidity (RH) of 0 - 2^{o}C and 85 - 90%, respectively, (NRI, 1994).

In most cases, cold storage is not economically feasible hence processing remains the best alternative towards improving availability of crops during off-season periods. In cassava processing the most common processing methods are direct sun drying of peeled roots for days into a storable product (Mlingi 1995). Quick drying using mechanical dryers is advantageous in the sense that the risk of contamination and mould growth are minimized.

FAO 1987 reported that moisture content was the most important factor of deterioration; hence, use of drying to prevent deterioration is a very important process in post harvest operation.

In a study by Pathak et al (1991) the effect of drying temperature on thin layer drying of crops was high, followed by initial moisture content, air velocity and relative humidity as the least factor.

In an attempt to improve the standard of living of peasant farmers in the country, the evaluation of the NCAM developed kerosene-fired batch dryer is necessary to provide an alternative means of preserving our farm produce after harvest.

The objective of this research was to carry out performance test on NCAM developed kerosene-fired batch dryer. The specific objectives are to: -

i) determine the dryer suitability for drying cassava chips, paddy rice, and maize on cob using thin layer drying;
ii) determine the rate of moisture removal from the stated crops;
iii) determine the drying rate of the stated crops; and
iv) Establish the operational indices for the dryer.

2. THE BATCH DRYER

2.1 Description of the Batch Dryer

The batch dryer was developed by NCAM. It consists of an axial fan blower unit, 4.5 kW diesel engine, belt-pulley transmission system, burner unit which comprises of the burner and the kerosene metering device, the plenum and the drying tray. The drying tray is made of a 2 mm diameter stainless screen. The batch dryer has an overall length of 2501 mm, width of 1165 mm and height of 810 mm. It was mainly constructed of 1.5mm galvanized sheet and 50mm by 50mm angle iron. Figure 1 shows the pictorial view of the dryer.

Figure 1. Pictorial view of NCAM kerosene-fired batch dryer

2.2 Working Principle of the Batch Dryer

For the purpose of this experiment the working principle of the batch dryer followed the following steps described below.

i) Turn on the kerosene supply knob, to wet the wick in the burner;
ii) Light the burner;

iii) Start the engine to set the axial flow fan working. The fan sucks air across the burner, thereby picking up heat to the plenum layer for the drying operation to begin; and

In order to monitor the temperature of the drying air just before entering the drying tray through the plenum layer and the temperature of the moist air immediately after drying, a K-type thermocouple probe was fixed at 4 different locations above the drying tray marked T_1, T_2, T_3 and T_4 and 2 other locations inside the plenum marked T_5 and T_6. Figure 2 is the pictorial view showing the locations of the thermocouple probes within the plenum layer and just above the drying trays.

Figure 2: Pictorial view of the dryer showing the various positions of thermocouple

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Cassava Chips

Freshly harvested cassava roots (Manihot spp) were obtained from the Farm Management Unit (FMU) of the Centre. They were peeled, washed and chipped. For the purpose of this experiment, two different types of cassava chips were used, namely: round shape cassava chips and thread like shape cassava chip. These two types of cassava chips were obtained using two different types of NCAM developed chipping machines. One of these cassava chipping machines was designed in such a way that it produces cassava chips having an average thickness of 0.92 cm with its length varying between 30 – 50 mm depending on the size of the cassava roots. While the other type of NCAM developed cassava chipping machine available was used to produce cassava chips with the thread like shape. The different shapes of cassava chips obtained were as a result of the two different types of chipping discs incorporated into the cassava chipping machines.

During this experiment, the initial weight used for conducting the experiment for both round shape and thread like shape cassava chips were 43 kg and 60 kg, respectively.

3.1.2 Paddy Rice

Paddy rice used for this evaluation was Faro 56 purchased from the National Cereals Research Institute, Baddegi, Niger State, having an initial moisture content of 10% $_{w.b}$. The paddy was parboiled using the NCAM farm level paddy parboiler. The average moisture content value of the parboiled paddy before drying was 27% $_{w.b}$.

35 kg of parboiled paddy rice was used for the drying experiment with NCAM batch dryer while 5 kg of parboiled paddy rice was used for the sun-drying method.

3.1.3 Maize

Fresh maize on cob used for the evaluation was purchased from an irrigated farm in Ejiba, Kogi State having an initial moisture content of 35% $_{w.b}$. The maize on cob used for the experiment was measured. A total weight of 65.3 kg maize on cob was used for this thin layer drying experiment.

3.2 Methods

3.2.1 Drying Procedure

Before starting the drying experiment, the dryer's burner was first of all fired together with the suction blower (axial flow fan) switched on via 4.5kW diesel (Viking prime mover) thus allowing it to run for a period of 30 minutes so as to stabilize the heated air in the dryer. Temperature was taken at six different points simultaneously using k-type thermocouples connected to digital milti-meters. The relative humidity and the ambient air temperature were recorded with the hygrometers and digital thermometer respectively while the speeds of the prime mover and blower were obtained using an analog tachometer.

The machine variables and crop parameter measured were moist air temperature, drying air temperature and moisture content respectively, at an interval of 30 minutes.

The time required for all the operation was recorded using an analogue stop watch. Moisture contents were determined at intervals using an analogue quick moisture analyzer and confirmed by using the oven drying method. While weights of samples were determined using a sensitive electronic weighing balance.

The fuel consumption for the diesel engine (prime mover) and the burner were both measured using graduated cylinders.

3.2.2 Test Parameters

Kajuna et al 2001 gave the expression for obtaining the amount of bone dry matter based on the initial moisture content of the sample using the equation expressed below:

$$MC_{db} = \frac{100\ (\%MC_{wb})}{100 - (\%MC_{wb})} \text{....................} 1$$

$$\text{but } MC_{db} = \frac{M_w}{M_{dm}} x\ 100\% \text{..............................} 2$$

$$M_w = \frac{MC_{db}\ x\ M_{dm}}{100} \text{....................................} 3$$

$$M_{dm} = Ms - M_w \text{..} 4$$

Where: MC_{wb} = moisture content wet basis, MC_{db} = moisture content dry basis, M_s = mass of sample, M_w = mass of water, M_{dm} = mass of bone dry matter .

This equation was also found useful for obtaining the amount of moisture removed, moisture present in the sample, average moisture content dry basis (d.b) and the drying rate from the data collected during the experiment. All these parameters are related together using the mathematical expression given below to calculate the drying rate. This can be expressed mathematically as:

$$R = \frac{Mw}{To\ \frac{(Mbd)}{100}} \ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where, R = drying rate in gm of water per minute per 100 gm of bone dry material, Mw = Amount of moisture removed; Mbd = Total bone dry weight of sample in gm; To = Time taken to dry.

4. RESULTS AND DISCUSSIONS

Results obtained for the temperature readings taken at the six spotted locations of the dryer for paddy rice drying using NCAM batch dryer is presented in Table 1. The average temperature readings for the moist air and drying air were used in plotting the graph presented in Figure 3. Figure 3 shows the graph of average temperature versus drying time for paddy rice. It can be deduced from Figure 3 that the temperature of the drying air increases steadily from 26^{0}C to a maximum of 94.5^{0}C within the first 50 minutes which implies that the dryer can attain its maximum drying air temperature of 94.5^{0}C within 50 minutes. It took the drying air temperature additional 20 minutes to move from 94.5^{0}C to 51.5^{0}C which is considered to be within the range of safe drying air temperature for paddy rice.

Table 1: Temperature distribution at six spotted locations of NCAM batch dryer during paddy rice drying

Time (Minutes)	T_1 (^{O}C)	T_2 (^{O}C)	T_3 (^{O}C)	T_4 (^{O}C)	t_5 (^{O}C)	t_6 (^{O}C)	Ta (^{O}C)	Tb (^{O}C)
0	25	29	27	22	27	25	25.75	26.00
10	21	24	32	21	42	40	24.50	41.00
20	22	25	36	21	46	39	26.00	42.50
30	26	25	31	29	54	48	27.75	51.00
40	36	34	37	37	85	78	36.00	81.50
50	37	43	36	35	100	89	37.75	94.50
60	40	46	42	34	80	72	40.50	76.00
70	32	35	37	40	56	47	36.00	51.50

Legend:-
T_1:- temperature at point 1 on the top layer of the dryer
T_2 :- temperature at point 2 on the top layer of the dryer
$T_{3:-}$ temperature at point 3 on the top layer of the dryer
$T_{4:}$ - temperature at point 4 on the top layer of the dryer
$T_{5:}$ - temperature at point 5 under the dryer
$T_{6:}$ - temperature at point 6 under the dryer
Ta – average moist air temperature: $(\underline{T_1 + T_2 + T_3 + T_4})$ 4
Tb- average drying air temperature: $(\underline{T_5 + T_6})$ 2

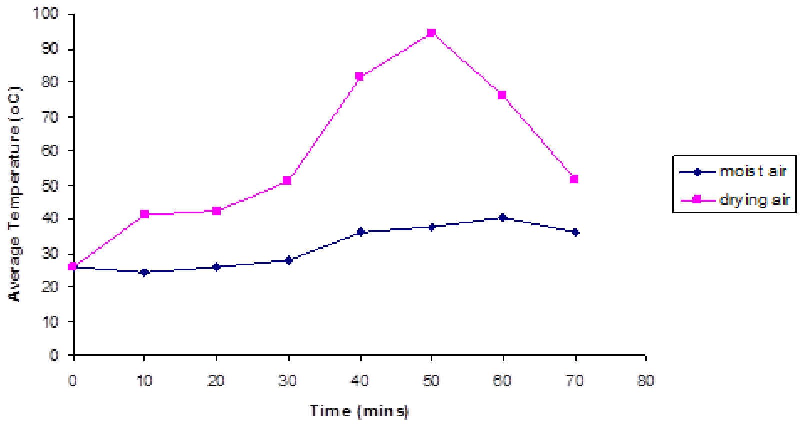

Fig. 3. Average temperature versus drying time for paddy rice

Results obtained for the moisture content readings taken at different time interval for paddy rice drying using NCAM batch dryer and sun-drying method are both presented in Table 2. Results obtained in Table 2 were used in plotting the graph presented in Figure 4. Figure 4 shows the graph of moisture content versus drying time for paddy rice. From Figures 3 and 4, one will notice that the rate of moisture removal was high within the first 30 minutes of drying using NCAM batch dryer. This might be attributed to the high initial drying air temperature that drives out moisture from the surface of the grains at this initial time. The moisture removed gradually increases over a period of time. As drying continues, the paddy rice attains a safe storage/milling moisture content of 14.33% within 60 minutes of drying. In comparing the drying rate of paddy rice using NCAM batch dryer and sun drying methods, it was observed that after 90 minutes of drying using NCAM batch dryer, 6.21 kg of moisture was removed corresponding to 0.269 kg of water/minute, (see Table 3). In the case of sun drying method, it took only 0.56 kg of moisture to be removed after 90 minutes of drying which corresponds to 0.17 kg of water/minute, (see Table 4). Thus drying rate is faster with NCAM batch dryer compared with the sun drying method for drying of paddy rice.

Table 2: Moisture content readings obtained during drying of paddy rice

Drying Method in Use	Moisture Content value (%) in (Wet Basis)			
	Initial	30 minutes	60 minutes	90 minutes
Mechanical drying using NCAM Batch dryer	26.8	17.37	14.33	11.8
Sun-drying	26.8	22.77	19.15	17.5

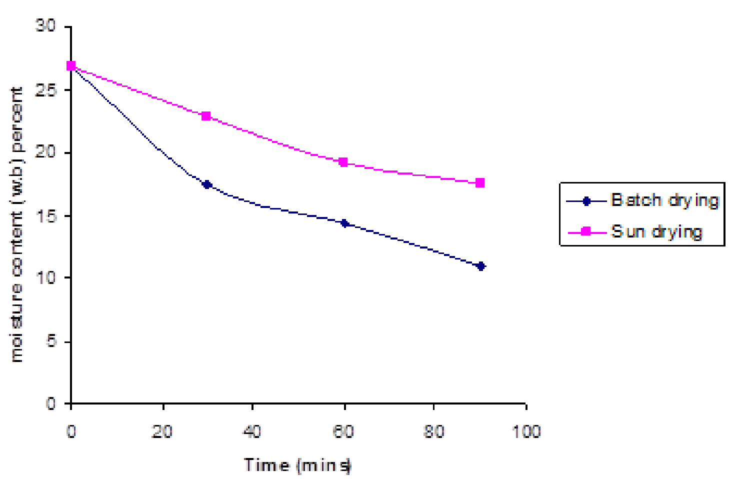

Fig 4. Moisture content versus drying time for drying paddy rice

Table 3. Drying characteristics of the paddy in the dryer

S/No.	Drying time (min)	Moisture removed (kg)	Moisture present in the sample (kg)	Moisture content (d.b) percent	Average moisture content (d.b) percent	Drying rate, R (g of water/min 100g of b.d materials)
1	0	0.00	9.38	36.61		
2	30	3.99	5.39	21.02	28.815	0.519
3	60	5.09	4.29	16.73	18.875	0.331
4	90	6.21	3.17	12.36	14.545	0.269

Table 4. Drying characteristics of paddy during sun drying

S/No.	Drying time (min)	Moisture removed (kg)	Moisture present in the sample (kg)	Moisture content (d.b) percent	Average moisture content (d.b) percent	Drying rate, R (g of water/min 100g of b.d materials)
1	0	0.00	1.34	36.61		
2	30	0.26	1.08	29.48	33.045	0.237
3	60	0.47	0.87	23.69	26.585	0.214
4	90	0.56	0.78	21.21	22.45	0.17

Results obtained for the temperature readings taken at the six spotted locations of the dryer for cassava chips drying using NCAM batch dryer is presented in Table 5. The average temperature readings for the moist air and drying air were used in plotting the graph presented in Figure 5. Figure 5 shows the graph of average temperature versus drying time for cassava chips. It can be deduced from Figure 5 that the temperature of the drying air increased steadily from 27^{0}C to a maximum of 84.5^{0}C within the first 90 minutes, while the moist air temperature was at a maximum of 57.5^{0}C within 90 minutes of drying cassava chips. This implies that for drying of cassava chips, it takes the dryer 90 minutes to attain a maximum drying air temperature of 84.5^{0}C. This may be attributed to the high moisture content nature of the cassava chips as well as the tendency of moisture to drip from the chips into the plenum thereby reducing the temperature of the moist air for some time.

Table 5. Temperature distribution at six spotted locations of NCAM batch dryer during cassava chips Drying

Time (minutes)	T_1 (^{O}C)	T_2 (^{O}C)	T_3 (^{O}C)	T_4 (^{O}C)	T_5 (^{O}C)	T_6 (^{O}C)	Ta (^{0}C)	
0	26	26	25	26	26	26	25.75	26.00
10	28	36	30	39	61	69	33.25	65.00
20	27	35	29	37	50	55	32.00	52.50
30	30	33	34	43	56	63	35.00	59.50
40	40	35	39	47	55	62	40.25	58.50
50	27	29	31	37	41	45	31.00	43.00
60	52	37	43	53	66	79	46.25	72.50
70	31	40	45	49	48	59	41.25	53.50
80	33	50	60	65	70	88	52.00	79.00
90	35	52	69	74	74	95	57.50	84.50
100	34	49	64	69	59	80	54.00	69.50
110	34	46	63	70	65	84	53.25	74.50
120	33	46	62	69	33	80	52.50	56.50
130	33	44	59	69	33	76	51.25	54.50

Legend:-

T_1:- temperature at point 1 on the top layer of the dryer
T_2 :- temperature at point 2 on the top layer of the dryer
$T_{3:-}$ temperature at point 3 on the top layer of the dryer
$T_{4:}$ - temperature at point 4 on the top layer of the dryer
$T_{5:}$ - temperature at point 5 under the dryer
$T_{6:}$ - temperature at point 6 under the dryer
Ta – average moist air temperature: $(\underline{T_1 + T_2 + T_3 + T_4})$ 4
Tb- average drying air temperature: $(\underline{T_5 + T_6})$ 2

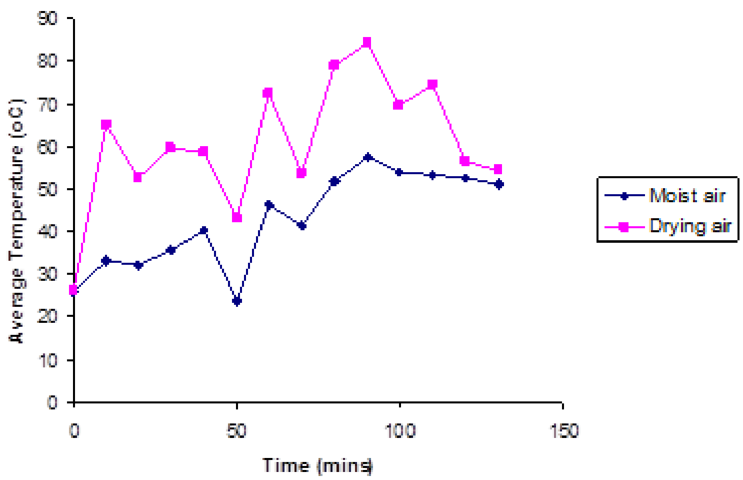

Fig. 5. Average Temperature versus drying time for cassava chips

Results obtained for the moisture content readings taken at different time interval for drying both thread like and round shaped cassava chips are presented in Tables 6 and 7 respectively. Both Tables were used in plotting the graph presented in Figure 6. Figure 6 shows the graph of moisture content versus drying time for cassava chips. It can be deduced from Figure 6 that the moisture content of the thread like cassava chips decrease from the initial moisture content of 66% w.b to 12% $_{\text{w.b}}$ within 114 minutes of drying, while for the round shaped cassava chips it reduces from an initial moisture content of 73% $_{\text{w.b}}$ to 22% $_{\text{w.b}}$ within 120 minutes of drying. This shows that the thicker the thickness of cassava chips, the longer time it takes to dry. It was also observed that within the first 60 minutes of drying, the outer layer of the chips looks drier than the inner part. Further drying of the cassava chips for 40 minutes at a lower temperature allows for migration of moisture from region of higher concentrations (inner part) to region of lower concentration (the outer part), thus it can then be deduced that fast drying using higher temperature results in fast removal of moisture from the outer surface of the chips. However, to reduce the time of drying, it is better to start drying with a very high drying air temperature within the first one hour is encouraged because of the fast rate at which moisture is been removed.

Table 6: Moisture content readings obtained during drying of thread-like shaped cassava chips

Moisture Content value (%) in (Wet Basis)				
Initial	24 minutes	54 minutes	84 minutes	114 Minutes
65.92	47.93	40.6	38.95	11.73

Table 7: Moisture content readings obtained during drying of irregular shaped cassava chips

Moisture Content value (%) in (Wet Basis)				
Initial	30 minutes	60 minutes	90 minutes	120 Minutes
73.2	58.5	53.8	52.8	21.8

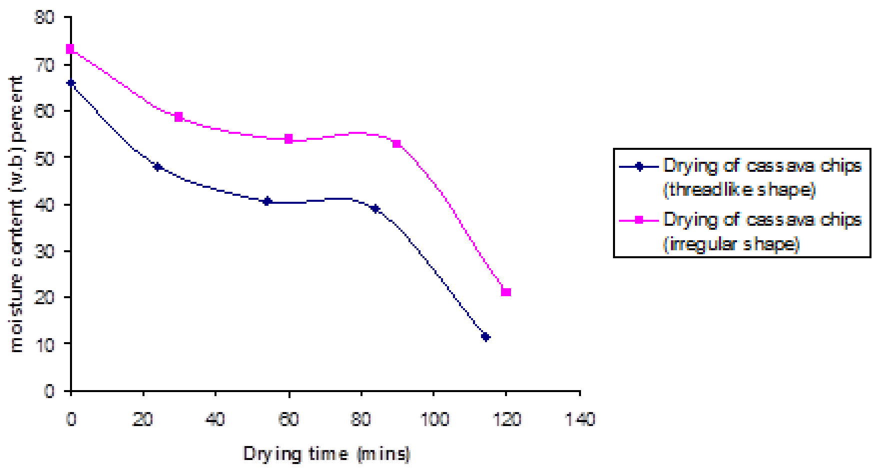

Figure 6. Moisture content versus drying time (batch drying of cassava chips)

Results obtained for the temperature readings taken at the six spotted locations of the dryer for maize on cob drying using NCAM batch dryer is presented in Table 8. The average temperature readings for the moist air and drying air were used in plotting the graph presented in Figure 7. Figure 7 shows the graph of average temperature versus drying time for maize on cobs. It can be deduced from Figure 7 that the temperature of the drying air attained a maximum of 79^0C after 110 minutes of continuous firing of the dryer. This implies that when drying maize on cob using the NCAM batch dryer, the maximum drying air temperature that can be attained within a period of 110 minutes is 79^0C.

Table 8. Temperature distribution at six spotted locations of NCAM batch dryer during maize on obs drying

Time (minutes)	T_1 (^{0}C)	T_2 (^{0}C)	T_3 (^{0}C)	T_4 (^{0}C)	T_5 (^{0}C)	T_6 (^{0}C)	Ta (^{0}C)	Tb (^{0}C)
0	25	30	34	31	43	61	30.00	52.00
10	30	45	45	45	45	58	41.25	51.50
20	27	43	45	44	40	52	39.75	46.00
30	27	42	43	43	40	49	38.75	44.50
40	30	46	49	48	43	55	43.25	49.00
50	28	43	46	46	40	52	40.75	46.00
60	30	42	46	46	42	59	41.00	50.50
70	36	52	56	58	59	72	50.50	65.50
80	30	48	50	50	43	54	44.50	48.50
90	34	56	64	64	65	81	54.50	73.00
100	34	54	66	69	69	81	55.75	75.00
110	39	52	66	70	72	86	56.75	79.00
120	39	49	65	68	67	82	55.25	74.50
130	35	45	53	56	50	59	47.25	54.50
140	34	40	51	50	48	58	43.75	53.00
150	32	40	49	47	41	50	42.00	45.50
160	32	38	44	43	41	49	39.25	45.00
170	36	45	58	52	60	71	47.75	65.50
180	32	46	57	50	52	66	46.25	59.00
190	36	45	55	50	54	64	46.50	59.00
200	33	44	54	50	53	62	45.25	57.50
210	33	46	55	49	49	60	45.75	54.50
220	33	44	50	45	44	52	43.00	48.00
230	34	44	54	49	51	61	45.25	56.00
240	32	40	46	45	36	43	40.75	39.50

Legend:-
T_1:- temperature at point 1 on the top layer of the dryer
T_2 :- temperature at point 2 on the top layer of the dryer
$T_{3:-}$ temperature at point 3 on the top layer of the dryer
$T_{4:}$ - temperature at point 4 on the top layer of the dryer
$T_{5:}$ - temperature at point 5 under the dryer
$T_{6:}$ - temperature at point 6 under the dryer
Ta – average moist air temperature: ($\underline{T_1 + T_2 + T_3 + T_4}$) 4
Tb- average drying air temperature: ($\underline{T_5 + T_6}$) 2

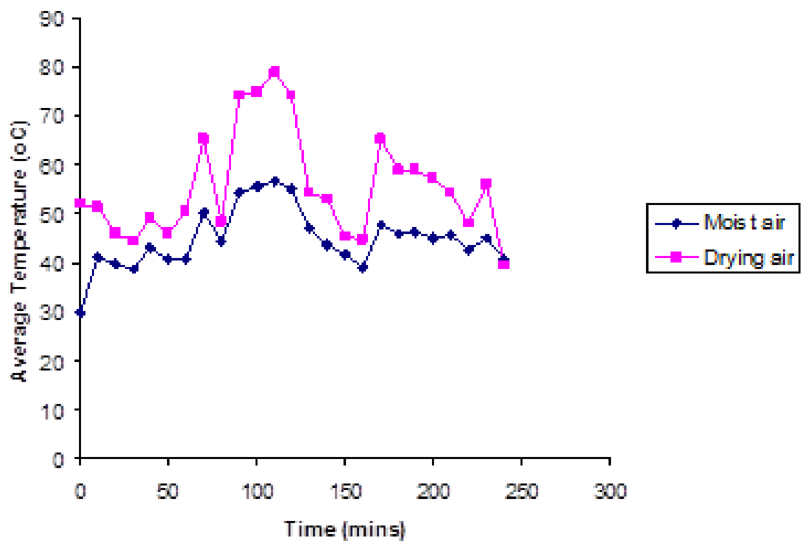

Figure 7. Average Temperature versus drying time for maize on cobs

Results obtained for the moisture content readings taken at different time interval for NCAM batch dryer and sun-drying method is presented in Table 9. The readings presented in Table 9 were used in plotting the graph presented in Figure 8. Figure 8 shows the shows the graph of moisture content versus drying time for single layer drying of maize on cob. It can be deduced from Figure 8 that for both drying methods used (mechanical drying and sun drying), there was fluctuation in the values of the moisture content obtained for maize on cob which might be attributed to the movement of moisture from inside the cobs to the grains. As the moisture from the grain surface reduces, there is every tendency for moisture to migrate from region of higher concentration (i.e. within the cobs) to region of lower concentration (i.e. within the grains) after a specific period of time.

Table 9: Moisture content readings obtained during drying of maize on cob

Drying Method in Use	Moisture Content value (%) (on Wet Basis)								
	Initial	30 min	60 min	90 min	120 min	150 min	180 min	210 min	240 min
Mechanical drying using NCAM batch dryer	35.00	27.90	25.60	27.45	32.25	30.00	30.60	28.90	31.40
Sun-drying	35.00	16.90	29.00	31.20	29.00	30.00	28.40	28.90	28.50

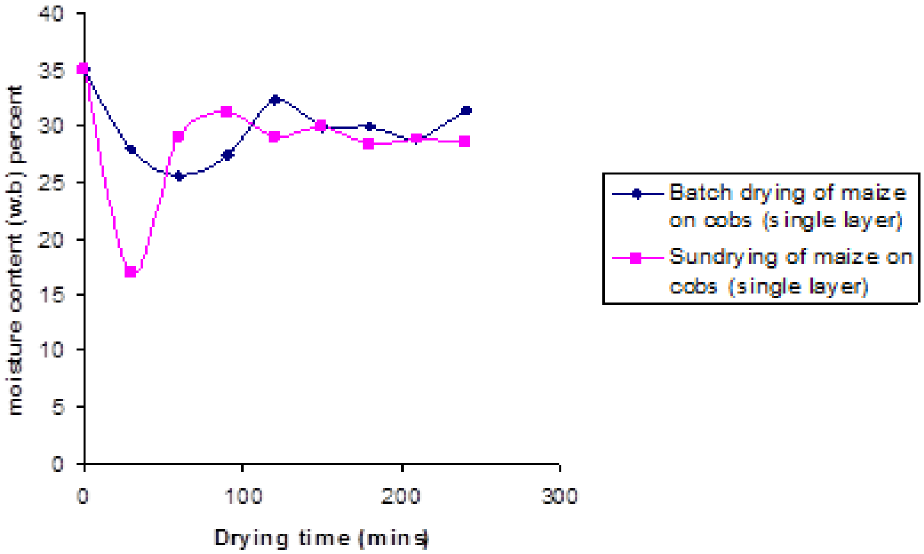

Fig. 8. Moisture content versus drying time for drying maize on cobs

5. CONCLUSIONS

The performance evaluation carried out on NCAM developed kerosene-fired batch dryer brought about the following concluding statements:

i) The NCAM kerosene fired batch dryer is most economical for the drying of paddy rice as it conveniently dries parboiled paddy rice to a safe storage/milling moisture content of 14% within 60 minutes of drying using 2 litres of kerosene to generate heat and 0.33 litres of diesel to run the axial fan (blower). Therefore, it is highly recommended for drying paddy rice.
ii) The maximum average temperature of the drying air attained within the dryer is 94.5^0C.
iii) As expected, the drying rate at which the NCAM kerosene-fired batch dryer dries crops is much faster when compared with the use of the sun drying method.
iv) The batch dryer was able to dry round shaped cassava chips from an average thickness of 0.92cm to 0.62cm and initial moisture content of 73% w.b to 22.0% $_{w.b}$ respectively within 120 minutes of drying using a total value of 5.53 litres of kerosene and 0.75 litres of diesel.
v) The batch dryer was able to dry thread like shaped cassava chips from initial moisture content of 66% w.b to 12.0% $_{w.b}$ within 114 minutes of drying using a total value of 5.23 litres of kerosene and 0.71 litres of diesel.
vi) The NCAM kerosene-fired batch dryer conveniently dried cassava chips. However it was observed that the dried cassava chips were contaminated by sooth/fumes from the burner. As a result of this, there is need to incorporate a heat exchanger to eliminate fumes from the chips.
vii) In the drying of maize on cob, the batch dryer used a total value of 7.55 litres of kerosene and 1.75 litres of diesel within 4 hours of drying. Based on the result obtained in Table 9, drying maize on cob is not suitable for this dryer.

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MODIFICATION AND PERFORMANCE EVALUATION OF A PALM KERNEL SEED OIL SCREW PRESS TO A CASTOR SEED OIL SCREW PRESS

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ABSTRACT

The need for modifications came-up as a result of the inability existing screw press in the Agric Engineering Department workshop to express the oil in castor seed. A detailed test was carried out using the existing screw press which was actually designed to extract oil from palm kernel nuts. The test revealed the required modifications needed to get the machine to extract oil from castor seed. The Palm Kernel oil extractor was modified, re-fabricated and tested. Design related physical properties of the castor seed were determined prior to equipment design. The effects of shaft speed, seed feeding rate and temperature of the seeds on the performance of the screw press was investigated. The results obtained showed that shaft/screw speed and feeding rate had significant effect on the oil output of the machine. Shaft speed, feeding rate and the temperature of the seed at introduction have significant effect on the output of meal all at 5% significance level. The highest oil extraction efficiency and output were obtained at a screw speed of 140rpm and feeding rate of 50kg/hr, giving an efficiency value of 64%. The impact of temperature was not high on the oil output due to the fact that friction within the cylindrical chamber developed heat that enhanced the process. The study showed that the higher the speed of the screw beyond 140rpm, the lower the oil output. This was evident in the result obtained at screw speeds 150rpm and 160rpm, the oil output went low while the meal output increased. The resultant drop in oil output due to increase in shaft speed beyond 140rpm brought about a drop in efficiency of the machine from 64% to 59% respectively. The machine operated at this high shaft/screw speed i.e. 150rpm to 160rpm resulted in the increase in meal output of the system. The meal output increased from 30% to 40%. From the results obtained, shaft/screw speed rate of 140rpm, feeding rate of 50kg/hr and temperature of 40^0 gave excellent oil extraction result. The temperature of the seed during feeding had no statistical significant effect on the oil extraction efficiency of the machine.

KEYWORDS: Castor seed, screw shaft, castor oil, extraction.

1. INTRODUCTION

Extraction of oil from vegetative materials is as old as man though the efficiency of the process differs from one specific material to the other. In the Stone Age the extraction was done by beating the vegetative material until the cells binding force gives way thus releasing the oil to flow. With advancement in science and technology, more efficient and profitable methods were developed.

Generally extraction of oil from oil seeds can basically be divided into two steps and these are Maceration and Extraction steps. Maceration is breaking of the seed cell for release of the oil contained in its tissue F.A.O. (2006). Extraction is the forceful squeezing of oil from the seed oil bearing tissues. There are basically two methods of oil extraction from seeds/vegetative materials and these are Traditional Method and Modern Method. Modern Method is sub-divided into Mechanical and Chemical methods.

The cells of oilseed embryo contains oil in an extremely fine emulsion (Asedu, 1990), which when broken or bruised, become injured causing tiny drops of free oil to ooze out and collect on the surface.

In an extraction process, the rate of oil recovery, extraction efficiency and quality of the oil are dependent on the pre-extraction treatments. For an efficient oil extraction that will bring out a high quality castor oil, the steps required to be taken are stated in Fig. 1.

PRE-EXTRACTION

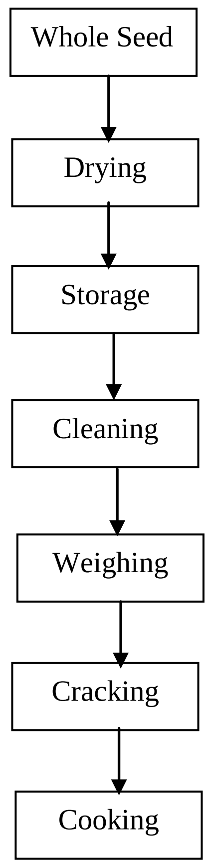

Fig. 1. Recovery Technique Chart
Source: (Robbelen et al, 1989)

To extract oil from oil seed traditionally, the seeds are dried to 10% moisture content; at this MC level oil expression will be at a high efficiency/ rate. At higher moisture content, extraction will be difficult and oil quality will be poor. The seed is then crushed using mortar and pestle. The crushing dislodges the oil from the seed tissue, thus requiring minimal effort to remove oil from the smashed by product that results Bachmann, (2001). The oil is then separated by pouring the smashed by product in hot water, this melts the oil from the smashed tissues, dislodging the binding force that holds the oil to the tissues and allows it to flow easily. Based on the floatation principle of oil in water, the oil is separated from the meal.

Mechanical extraction of oil from oil seed is done with the use of either oil press or oil expeller. The mechanical process here has to do with interaction of the screw and the seed in the extraction chamber. The result of friction and pressure brings about the extraction of oil from the seed. From literature, the rate of oil recovery, extraction efficiencies and qualities of the resulting oil are affected by moisture content, quality of the seed and the type and level of pre-extraction treatments applied to the seed prior to extraction Macfarlane *et al*., (1989).

Chemical process of extraction is a laboratory method of extracting oil from oil seeds using a chemical called Hexane and an apparatus called Soxhlet Extractor. The castor beans undergo crushing, just like in the other methods explained above. The crushing is to weaken the cell walls and to release the oil. It is then introduced into a Soxhlet Extractor and Hexane is used to strike a reaction to remove the oil.

The castor oil has a very high economic value hence its high demand in the international market (Tierramerica, 2008). Castor oil has an advantageous physicochemical characteristic compared with other existing oil and these are Iodine value - 82, Saponification value- 177, Acid value- 2.7 and hydroxyl value- 180. (Mensah and Ochran, 2005). The castor oil has a unique hydroxyl fatty acids that is hard to find in any other seed; this acid is an essential by- product in making high quality lubricants for heavy equipment and jet engines as well as other products ranging from paints, cosmetics, anti-fungal, bullet proofs e.t.c.(Atique-ur-Rehman and Mohammed, 2007). Although, there are other seeds from which hydroxyl fatty acids can also be produced, cultivation of castor seed is easier than others (USDA, 2001). Also castor oil comes out ready for use after extraction without need for processing (Fellows, 1996).

The castor oil market has been on a vicious cycle of shortfall and surplus, depending on yields, weather, domestic consumption and economic conditions in the producing countries. Although the price has fluctuated between \$500/ton and \$1500/ton, the price of castor oil remains higher than any other vegetable oil *(Cherry, 2001).*

Table 1. Production pattern of castor in popular producing countries between 1996 and 1999.

Table 1. World castor seed production data in tonnes

Countries/Years	1996-1997	1997-1998	1998-1999	Harvest period
USSR	3	3	4	July - Sept
Brazil	45	128	45	May - Sept
Paraguay	9	9	10	May - Sept
China	220	180	210	Sept - Jan
India	770	700	800	Nov - Mar
Pakistan	3	8	7	Dec - May
Thailand	18	18	15	Dec - May
Others	40	50	50	Nov - Jan
World prodtn	1100 tons	1100 tons	1200 tons	(thousands of tons)
Average of wld Seed prdtn	0.85	0.87	0.88	0.87
Oil produced (42%)	462 tons	462 tons	504 tons	476 tons

Source: Cherry (2001)

There is therefore the need to continue to develop technologies for oil expansion from castor seeds in order to make Nigeria to become one of the significant producers of castor seeds and castor oil. The objective of this study was to modify and evaluate the performance of a palm kernel oil press for castor seed oil extraction.

2. MATERIALS AND METHOD

2.1 Preliminary Evaluation of an Existing Palm Kernel Oil Screw Press

An existing palm kernel oil screw press in the Agricultural Engineering Department workshop of Ahmadu Bello University, Zaria was appraised in order to determine its ability to extract oil from castor seed. The machine which is functionally made-up of the following components;

Extraction chamber- where the seed is exposed to a high pressure.

Pressure screw- located within the pressure chamber, designed with pitch that reduces from one end to the other through the length of the screw (Fig 2).

The feature of the screw which is basically observed to be designed/constructed to ensure that adequate pressure is applied in the extraction chamber.

The oil being extracted is collected via a trough located below the cylinder.

The extraction chamber is fitted with adjustment bolts at the ends for control of the pressure within the extraction chamber as the need maybe.

Fig. 2: Picture of the machine.

The machine was tested with castor seed and the results gotten are shown in below Table 2.

Table 2: Test of the palm kernel oil expeller.

S/no.	Weight of seed input (gm)	Weight of oil output (gm)	Weight of meal output (gm)	Seed losses (gm)	Meal losses (gm)
1.	3.3	0	2.0	0.9	0.4
2.	2.5	0	1.3	0.84	0.36
3.	2.0	0	1.2	0.48	0.32
4.	1.8	0	1.1	0.46	0.25
5.	1.8	0	1.0	0.56	0.24
6.	1.8	0	1.0	0.56	0.24
Total	13.2	0	7.6	3.8	1.81

This result showed the inability of the machine to extract oil from castor seed, thus the need for modification of the machine.

2.2 Design Considerations

i. The machine operational speed was determined from literature to be 55-70rpm range (Ajao et al., 2009). This was used as a reference considering the fact that groundnut and castor seeds are soft.

ii. The machine was designed with pulley as a means of speed reduction mechanism in place of a gear box and powered by a diesel engine. This is to make it affordable to the processors.

$N_1 D_1 = N_2 D_2$ …………………… (1) (Smith and Wilkes, 1976)

iii. The heating temperatures were chosen based on literature recommended range for which the value and quality of the oil will be highest i.e. 40^oC – 60^0C (Ndunda, 2005).
iv. The screw pitch was re-designed to enhance pressure development and reduce clogging by reducing the screw pitch from the feed point to the discharge point.
v. The length of screw was extended so as to get appreciable oil recovery in the expression process. (Olaoye, 1999).

Power transmission is by the use of belt drive. Picture of the modified machine is shown in Fig 3 below.


Fig. 3: Picture of the Modified Machine

2.3 Design Calculations

Screw
Screw size selection were based on the code for solid shafts having axial loads
The diameter of the screw was determined thus (Hall et al., 1982):

$$d = \frac{16}{\pi S_s} \left\{ (K_b M_b)^2 + (K_t M_t)^2 \right\}^{\frac{1}{2}} \text{...} 2$$

Where:
d = the diameter of the shaft (mm)
Ss = allowable shear stress, Pa
$K_b.K_t$ = the combined shock and fatigue factors applied to bending and tensional moments, respectively.
M_b, M_t= Bending moment and torsional moment, respectively, Nm
Belt tensions: belt tension was determined based on the following relationship:
$M_t = (T_1 – T_2) R$………………………………………………………3 (Hall et al, 1982)
M_t = Transmitted torque Nm
T_1, T_2 = Tight side tension and slack side tension respectively (Newton)
R = Radius of the pulley, mm

Belt length: Belt lengths and sizes was determined based on the following relationships:

$L_p = 2c + 1.57(D + d) + (D - d)^2 / 4c$..4 (Bainer et al., 1955)

Where
c = the center distance, mm
D, d = effective or pitch diameter (mm) of the larger and smaller pulleys, respectively.

Transmission ratio: for speed determination:
$N_1 D_1 = N_2 D_2$ ………………………………………………………..5 (Smith and Wilkes, 1976)
N_1= speed of driving pulley, rpm
N_2 = speed of driven pulley, rpm
D_1 = effective diameter of driving pulley, mm
D_2 = effective diameter of driven pulley, mm

2.4 Performance Evaluation

The Performance of the fabricated machine was determined based on its oil yield extraction efficiency. The following equations were used,

1. $$OY = \frac{w^1 - w^2}{w^1} \times 100 ---------------------(6)$$

2. $$EF = \frac{w^1 - w^2}{Xw^1} \times 100 ---------------------(7)$$

Where:

w^1	=	Weight of sample before expression (g)
w^2	=	Weight of cake after expression (g)
OY	=	Oil yield (%)
EF	=	Extraction Efficiency (%)
X	=	Oil content of castor seed (65%)

(Ojifinni, 2004).

2. $$W = \frac{CW_0}{P^2 t^6 V} -- (8)$$

Where: W = oil yield gram/min

C= constant for the kind of seed

W_o= constant of the seed

P = pressure (MPa)

t = pressing time (hr)

V = kinematics viscosity of oil at press temperature (m/s) (37.8m/s)

Z= exponent of kinematics viscosity (1/6-1/2)

From the table of value of components castor seed has the following values: - $Z = \frac{1}{6}$, $C \times 10^3 = 51.3$ i.e. C = 0.0513, and W_o= 64.2

(Reddy and Bohle, 1993)

3. RESULTS AND DISCUSSION

3.1 Results

The results of the performance test carried out on the Castor Seed Oil screw press are shown on Table 3 while the analysis of variance (ANOVA) of the result are shown on tables 4-7.

Table 3. Performance Test Result of the Castor Seed Oil Screw press

S/N	Losses (Diff btw weight of seed and weight of oil	Weight of oil extracted (gm)	Losses of the machine %.	Efficiency of Machine %	Throughput of the machine (Ct)	Oil yield capacity (OY)	Temp at loading H	Shaft speed rpm P	Feeding time (MINS)
1	0.5	0.9	64.29	35.71	1.08	29.04	40	140	3
2	0.67	0.23	25.56	34.44	0.55	18.59	40	140	1.5
3	2.31	0.99	30.00	70.00	0.71	13.55	40	140	5
4	2.16	0.84	28.00	72.00	0.60	13.55	40	140	5
5	2.13	0.87	29.00	71.00	0.78	70.37	50	120	4
6	1.99	0.91	31.38	68.62	0.82	70.37	50	120	4
7	2.19	0.81	27.00	73.00	0.68	33.50	50	140	4.3
8	2.52	0.98	28.00	72.00	0.74	17.31	50	140	4.8
9	2.3	0.9	28.13	71.88	0.81	51.70	60	140	4
10	2.52	0.88	25.88	74.12	0.74	33.50	60	140	4.3
11	2.38	1.02	30.00	70.00	0.85	33.50	60	140	4.3
12	2.38	1.02	30.00	70.00	0.87	38.58	60	140	4.2
13	2.13	0.87	29.00	71.00	0.78	51.70	50	140	4
14	2.38	0.92	27.88	72.12	0.77	33.50	50	140	4.3
15	2.03	0.87	30.00	70.00	0.78	51.70	50	140	4
16	2.38	1.02	30.00	70.00	0.82	34.71	60	120	4.5
17	2.48	1.02	29.14	70.86	0.82	34.71	60	120	4.5
18	2.34	0.96	29.09	70.91	0.80	45.59	60	120	4.3
19	2.38	1.02	30.00	70.00	0.85	25.64	40	160	4.3
20	2.03	0.87	30.00	70.00	0.78	39.58	40	160	4
21	2.1	0.9	30.00	70.00	0.83	46.07	40	160	3.9
22	2.17	0.93	30.00	70.00	0.86	46.07	40	160	3.9
23	2.52	1.08	30.00	70.00	0.97	45.03	60	150	4
24	1.97	0.93	32.07	67.93	0.84	45.03	60	150	4

25	1.99	0.81	28.93	71.07	0.75	52.42	60	150	3.9
26	2.13	0.87	29.00	71.00	0.78	45.03	60	150	4
27	2.41	0.99	29.12	70.88	0.87	38.83	50	150	4.1
28	2.41	1.09	31.14	68.86	0.91	29.18	50	150	4.3
29	2.52	1.18	31.89	68.11	0.94	22.21	50	150	4.5
30	2.38	1.12	32.00	68.00	0.96	33.60	50	150	4.2
31	2.92	1.58	35.11	64.89	1.07	83.23	50	150	5.3
32	2.56	1.44	36.00	64.00	1.02	10.48	50	150	5.1
33	3.2	1.8	36.00	64.00	1.10	43.74	40	150	5.9
34	2.88	1.62	36.00	64.00	1.06	66.65	40	150	5.5
35	2.75	1.55	36.05	63.95	1.12	11.80	40	150	5
36	2.73	1.57	36.51	63.49	1.11	10.48	40	150	5.1
37	2.48	1.52	38.00	62.00	1.07	10.48	40	150	5.1
38	2.36	1.44	37.89	62.11	1.13	22.35	50	140	4.6
39	2.24	1.26	36.00	64.00	1.05	33.50	50	140	4.3
40	2.17	1.33	38.00	62.00	1.11	33.50	50	140	4.3
41	2.27	1.23	35.14	64.86	1.05	38.58	50	140	4.2
42	2.24	1.26	36.00	64.00	1.05	25.64	60	160	4.3
43	2.21	1.29	36.86	63.14	1.11	29.53	60	160	4.2
44	2.13	1.37	39.14	60.86	1.17	29.53	60	160	4.2
45	2.2	1.3	37.14	62.86	1.11	29.53	60	160	4.2
46	2.1	0.9	30.00	70.00	0.81	39.58	60	160	4
47	1.95	1.05	35.00	65.00	0.95	70.37	60	120	4
48	1.93	1.07	35.67	64.33	0.99	81.91	60	120	3.9
49	1.95	1.05	35.00	65.00	0.97	819.17	60	120	3.9
50	1.4	1.6	53.33	46.67	1.44	703.73	60	120	4
51	1.3	1.7	56.67	43.33	1.53	703.73	60	120	4
52	1.4	1.6	53.33	46.67	1.44	703.73	60	120	4
53	1.65	0.85	34.00	66.00	0.85	1324.19	60	120	3.6
54	1.67	0.83	33.20	66.80	0.81	1123.45	60	120	3.7
55	1.49	0.81	35.22	64.78	0.91	2684.50	60	120	3.2
56	1.61	0.79	32.92	67.08	0.89	2684.50	40	120	3.2
57	1.59	0.81	33.75	66.25	0.88	2231.93	40	120	3.3
58	1.53	0.77	33.48	66.52	0.87	2684.50	40	120	3.2
59	1.5	0.7	31.82	68.18	0.79	2684.50	40	120	3.2
60	1.3	0.7	35.00	65.00	0.81	3247.83	40	120	3.1
61	1.47	0.73	33.18	66.82	0.80	2231.93	40	120	3.3
62	1.61	0.79	32.92	67.08	0.86	2231.93	40	120	3.3

63	1.52	0.78	33.91	66.09	0.85	1255.46	50	160	3.3
64	1.55	0.95	38.00	62.00	0.98	882.02	50	160	3.5
65	1.41	0.79	35.91	64.09	0.89	1510.03	50	160	3.2
66	1.41	0.79	35.91	64.09	0.89	1510.03	50	160	3.2
67	1.54	0.86	35.83	64.17	0.94	1255.46	50	160	3.3
68	1.36	0.74	35.24	64.76	0.89	2224.12	50	160	3
69	1.6	0.9	36.00	64.00	0.93	1568.03	50	120	3.5
70	1.41	0.79	35.91	64.09	0.89	2684.50	50	120	3.2
71	1.54	0.86	35.83	64.17	0.91	1865.91	50	120	3.4
72	1.66	0.94	36.15	63.85	0.97	1568.03	50	120	3.5
73	1.47	0.83	36.09	63.91	0.93	2684.50	50	120	3.2
74	1.62	0.88	35.20	64.80	0.88	1324.19	40	120	3.6
75	1.64	0.86	34.40	65.60	0.88	1568.03	40	120	3.5
76	1.63	0.87	34.80	65.20	0.87	1324.19	40	120	3.6
77	1.63	0.87	34.80	65.20	0.87	1324.19	40	120	3.6
78	1.62	0.88	35.20	64.80	0.88	972.87	50	140	3.6
79	1.26	0.74	37.00	63.00	0.86	2386.16	50	140	3.1
80	1.28	0.72	36.00	64.00	0.84	2386.16	50	140	3.1
81	1.5	0.7	31.82	68.18	0.81	2386.16	50	140	3.1
82	1.42	0.78	35.45	64.55	0.91	2386.16	50	140	3.1
83	1.41	0.79	35.91	64.09	0.89	1972.29	50	140	3.2
84	1.28	0.72	36.00	64.00	0.86	2224.12	60	160	3
85	1.29	0.71	35.50	64.50	0.85	2224.12	60	160	3
86	1.53	0.77	33.48	66.52	0.87	1510.03	60	160	3.2
87	1.44	0.76	34.55	65.45	0.88	1826.91	60	160	3.1

3.2 Effect of Temperature and Speed of the Shaft on the Efficiency of the Machine

In Table 4, effect of Temperature of the seed and Speed of the shaft on the efficiency of the machine was determined. The interaction of temperature and speed was also determined.

From the Table of the analysis of ANOVA, Temperature is not significant while Speed of the machine shaft is significant at $p<0.05$. The interaction of Temperature and Speed has a significant effect on the machine efficiency. Futher test revealed on Table 4 that the best speed for an efficient extraction of oil by the machine is 150rpm, $p<0.05$. The reason why temperature is not significant can be linked to the fact that the machine itself generates heat in the cause of operation. This being as a result of the friction effect.

Table 4. Effect of Temperature & Speed on Efficiency of the Machine

Source of Variation	Degree of freedom	Sum of squares	Mean square	$F_{cal.}$	$F_{tab.}$
Temperature	2	0.034	0.017	0.354**	3.11
Speed	3	1.386	0.462	9.625*	2.72
Temperature*Speed	6	1.904	0.317	6.60*	2.21
Error	75	3.599	0.048		
Total	86	6.923			

* = Significant at p<0.05 ** = Not Significant at p<0.05

Table 5. Means at various Speed levels for Feeding Time (minutes), Weight of the Whole Seed, Weight of the Oil Extracted & Weight of Meal

Speed	**Feeding Time (minutes)**	**Weight of the Whole Seed**	**Weight of the Oil Extracted**	**Weight of Meal**
120	3.64^a	2.64^a	0.95^a	1.14^a
140	3.88^a	2.83^a	0.92^a	1.48^b
150	4.67^b	3.80^b	1.28^b	1.99^c
160	3.62^a	2.72^a	0.93^a	1.07^a

Mean speeds with different letters along the same column are statistically different from each other at p < 0.05.

3.3 Effect of Temperature & Feeding rate on the efficiency of the machine

In Table: 6. below the Analysis of Variance for the effect of Temperature and Feeding rate on the efficiency of the machine was determined. It was found that temperature is still not significant while feeding rate is significant at p<0.05. The interaction of Temperature and Feeding rate is not significant on the efficiency of the machine at p< 0.05.

Table 6. Effect of Temperature & Feeding Rate on the Efficiency of the Machine

Source of Variation	Degree of freedom	Sum of squares	Mean square	$F_{cal.}$	$F_{tab.}$
Temperature	2	0.121	0.060	0.760**	3.11
Feeding rate	2	0.507	0.254	3.215*	3.11
Temperature*Feeding rate	4	0.152	0.038	0.481**	2.49
Error	78	6.143	0.079		
Total	86	6.923			

* = *Significant* at p<0.05, ** = *Not Significant* at p<0.05

In Table 7, further test to determine the best feeding rate to achieve result i.e. which of the levels of feeding rate (50, 70, 90) is significantly different from the other; reviled 50kg/hr at p<0.05.

Table 7: Means at various Feeding rates for Feeding Time (minutes), Weight of the Whole Seed, Weight of the Oil Extracted & Weight of Meal

Feeding rate	Feeding Time (minutes)	Weight of the Whole Seed	Weight of the Oil Extracted	Weight of Meal
50	3.68^a	2.68^a	0.92^a	1.23^a
70	4.11^b	3.15^b	1.07^a	1.58^b
90	3.87^{ab}	2.93^{ab}	1.00^a	1.27^a

Mean speeds with different letters along the same column are statistically different from each other at p < 0.05.

3.4 Effect of Speed of shaft & Feeding rate on the efficiency of the machine

In Table 8, the effect of shaft speed and feeding rate on machine efficiency was determined. And it was found that speed of shaft is significant and so is feeding rate. The interaction of speed and feeding rate was also found to be significant; all these are evidence from the table below. The calculated F = 4.500 while the table value F = 3.11 is lower. This higher value of calculated F in all the factors being onsidered than their table values shows significance of the factor.

Table:8 Effect of Speed & Feeding rate on efficiency of the machine

Source of Variation	Degree of freedom	Sum of squares	Mean square	$F_{cal.}$	$F_{tab.}$
Speed	3	0.882	0.294	5.654*	2.72
Feeding rate	2	0.467	0.234	4.500*	3.11
Speed*Feeding rate	6	1.675	0.279	5.365*	2.21
Error	75	3.899	0.052		
Total	86	6.923			

* = *Significant* at $p<0.05$

At least one of the levels of speed (120, 140, 150, 160) and feeding rates (50, 70, 90) is significantly different from the other; a further test to show where the significant difference occur could be seen in Table 5 above and Table 9 below. Also, there was a significant interaction effect between Speeds and Feeding rates, indicating that the four (4) different levels of Speed are not the same at the different three (3) levels of Speed.

Table: 9. Means at various Feeding rates for Feeding Time (minutes), Weight of the Whole Seed, Weight of the Oil Extracted & Weight of Meal

Feeding rate	Feeding Time (minutes)	Weight of the Whole Seed	Weight of the Oil Extracted	Weight of Meal
50	3.68^{a}	2.68^{a}	0.92^{a}	1.23^{a}
70	4.11^{b}	3.15^{b}	1.07^{a}	1.58^{b}
90	3.87^{ab}	2.93^{ab}	1.00^{a}	1.27^{a}

Mean speeds with different letters along the same column are statistically different from each other at $p < 0.05$.

4. CLONCLUSION

A low cost castor oil extractor which is a modified version of an existing palm kernel oil extractor is certified to express oil from castor seed. The machine has the efficiency of 64% at a feeding rate of 50kg/hr and shaft speed of 140rpm

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SOIL INFILTRATION CHARACTERISTICS AND GROWTH OF FLUTED PUMPKIN UNDER IRRIGATION WITH LEACHATE FROM MUNICIPAL SOLID WASTE

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ABSTRACT

A simple mixture of municipal solid waste (MSW) leachate and ravine spring water (constituting grey water) was characterized and used for dry-season irrigation of fluted pumpkin (*Telfairia occidentalis*) on the riparian soil adjacent Uyo urban drainage stream. Effects of grey and clear water applications were compared on the growth, yield and seed quality performances of sample crop cultivated by small-scale urban vegetable growers and on physico-chemical properties and the infiltration capacity (hydraulic effect) of riparian soil irrigated with the water. Infiltration and crop growth data were statistically analyzed by percentage mean difference, paired sample t-test and Spearman correlations as well as geometric mean and sodium absorption ratio (SAR) parameters. For crop growth and yield, grey water irrigation conferred significant ($p < .05$) and superior performance than clear water, particularly the vine and leave number were 12% and 17%, respectively, more than the values for clear water application which, however, gained advantage in pod girth and seed number . Also, yield was higher in terms of seed size and mass of samples under grey water than under clear water irrigation. Quality of seeds was greater than leaves of *Telfairia occidentalis* under MSW leachate-mixed water irrigation. The percentage composition of surrogate parameters in pumpkin leaves and seeds characteristics showed no distinctive advantage between irrigating with either of the two water qualities except for crude fat and nitrogen-free extract which grey water gave higher qualities. For dry matter and ash content, clear water irrigation gave superior leave quality. Leachate-water irrigation impacted on texture, increasing silt by 370% and dispersing clay by 40% of control value, thereby moving silt/clay ratio from < ½ before to ½ after treatment. Infiltration rate of the sandy riparian soil was reduced from 49 mm/hr under clear water irrigation to 25 mm/hr under grey water irrigation, which was a significant reduction of 50% under grey water quality. Different dilutions of leachate, as organic fertilizer, for irrigation application should be studied for environmental sustainability.

KEYWORDS: Municipal solid waste, leachate irrigation, water quality, infiltration capacity, crop yield.

1. INTRODUCTION

Waste water and composted mixed urban waste have been used by urban and peri-urban farmers under the pressure of urbanization and urban expansion to provide food, income and other forms of individual and household well-being (Shackleton et al., 2009). They utilized valley bottoms, river-side areas and resource or utility lands such as municipal waste areas, flood control and drainage right-of-way or plots close to grey water sources in urban utility, wild and corridor spaces to extend the growing season to provide all-year-round supply of vegetables to households and markets (Shackleton et al., 2009). It also forms a reservoir of natural resources to maintain hydrological functions in the supply of water and discharge of waste.

Organic fertilizer - based agricultural production is a rapidly emerging technology and relies on techniques such as waste composting and leachate irrigation which partly solve the waste disposal problems through the conversion of bio-degradable waste into organic compost (He et al, 2001; USEPA, 2002) and the alternative routing of leachate disposal to irrigated farming (Sawyer et al, 2005). The use of leachate irrigation is being allowed to continue in the UK for a number of low profile systems (IPPTS Associates, 2011). On application to soil, these methods ensure the availability of natural fertilizers for crop absorption and growth, and satisfy the developing policy of converting waste-to-wealth. In such cases, the generated leachate infiltrating into the soil enables high quality crops production because the rate of application of its constituent nutrients is more natural in application (as liquid infiltration) and is cheaper than the costlier direct (solid) deposition of chemical fertilizer (Enwezor et al., 1990). It also rehabilitates and sustains the fertility of marginal soils used for cropping, such as soils which are degraded by intensive crop production by subsistent farmers whose knowledge of soil management is rather poor. This advantage is expected to benefit the often-flooded and runoff-leached acid soils of the riparian wetland, such as this study site which adjoins the banks of Uyo urban drainage river into which the Municipal Solid Waste (MSW) leachate effluent drains. Such leached sandy soils, on their own, do not support high crop productivity (Bhattacharya and Michael, 2003). Farmers utilize the leachate-polluted water to irrigate their dry season crops and sustain livelihood.

However, the bio-wastes from urban areas contained some toxic chemicals, like heavy metals, which may cause chemical and heavy metals contamination (Kjeldsen et al, 2002; Suresh, 2008; Sekabira et al., 2010; Essien, 2012), which must be avoided so that the emerging benefits to the urban green growers may be sustained. A few studies which tested the effects of wastewater use in India indicated the presence of measureable levels of pathogens on vegetables irrigated with grey water but which were usually below levels that posed a risk to human health except dermatological problems due to some farmers standing in wastewater (Bradford et al., 2003; Ambrose-Oji, 2009). Previous study of the physico-chemical properties of this leachate-polluted stream water (grey water) showed it to be within tolerable limits of irrigation water standards used for crop production (Ayers and Westcot, 1985; Essien, 2010a, b). However, the concentration of some heavy metals like lead (Pb) and Iron (Fe) needed to be watched because of their temporal and dry season variation (Essien, 2012), and it is known that where such metals exist, geo-accumulation, surface crusting and concretions may occur on the receiving soil surface and could be higher over time especially due to repeated flooding. Such occurrences may affect the macro-porosity of the soil, hence the hydraulic properties.

Leachate contain suspended solid and a range of organic and inorganic materials which are washed out of the waste fill or dumpsite and these materials may in-fill the sandy soil macro- pores (IPPTS Associates, 2011). Any in-filling of the voids in sandy soils by such organic materials, just as soil amendment, reduces infiltration rate lower than the rate for normal sandy texture and that is beneficial to water conservation in dry season when there is generally ineffective or no rainfall (Essien and Saadou, 2012; Essien and Sangodoyin, 2009). Equally, the packing of the pore spaces in sands by settleable organic solids allows time for roots to absorb nutrients from the soluble and suspended solids of the leachate, which is expected to replenish the nutrients loss in the frequently flood-leached acid sands of the riparian wetlands to the advantage of crop growth. The tentative storage or runoff delay encouraged by in-filling of voids reduces percolation of flow (Bhattacharya and Michael, 2003), thereby reducing the prospect of nutrient leaching by the irrigating stream water in the dry season. These will affect crop growth, thus making it necessary to investigate its effect on the hydraulic properties (especially infiltration capacity) of and crop growth on the riparian soil irrigated with it.

Therefore, the objectives of this study were to: (1) investigate changes in the soil texture of the riparian soil under dry-season irrigation with the leachate-mixed stream water; (2) investigate the infiltration properties of the riparian wetland soil under the application of leachate-mixed stream water in dry season irrigation, and (3) determine the effect of applying the MSW leachate-mixed water on crop (fluted pumpkin) production on the riparian soil.

2. MATERIALS AND METHODS

The study area was Ikot-Ituen, one of the villages in Uyo situated between latitudes 5 º 17^1 and 5º 27^{1}N and longitudes 7º 27^1 and 7º 58^{1}E in Akwa Ibom State, Nigeria (Wikipedia, 2013). The natural soil at Ikot Ituen is sandy loam (SLUK-AK, 1989); and is located between Ekpri-Nsukara and University of Uyo (Main Campus), on the upslope below which lies the downstream of Uyo urban drainage river.

2.1 Planting of Experimental Crop

The experimental plant was fluted-pumpkin (*Telfairia occidentalis* Hook F) which is a staple vegetable in southern Nigeria and has many nutritional properties (Wikipedia, 2010; Christian, 2007). The experimental plot was 50 m^2, with two replicate blocks separated by two footpaths of 1.0 m each. Each block had 3 rows planted with three seeds of fluted pumpkin per hole at a spacing of 2 m x 2 m. Weeding took place twice at two weeks interval after plant emergence.

2.2 Infiltration Test

Infiltration capacity (maximum infiltration rate at t = 0) and basic or constant infiltration rate at infinite elapsed time (i.e. t = α) were determined using double-ring cylinder infiltrometer with each ring being 3 mm thick, 40 cm diameter for outer ring and 25 cm for inner ring diameter; and both were 30 cm high. The concentric rings were driven with a pallet into ground uniformly without tilt and unduly disturbing the soil to, at least, a depth of 15 cm (leaving 10 cm of ring height outside the ground). Falling head infiltration was used by flooding the top of the soil in both the inner ring centre and annular space to maintain original constant depth of 5 cm of water. Water was replenished as the level fell to a minimum of about 1 cm. Point gauges were fixed in the centre of the rings and the annular space between the rings. Reading of the volume or the depth of water in the inner cylinder after commencement continued at regular intervals of 1, 5, 10, 15, 20, 30, 40, 60 min, etc. up to a period of six hours or till a repeatedly constant rate of infiltration was recorded. Thus, volume of water infiltrating in time interval = depth in time interval x inner cylinder area; also, infiltration rate = depth infiltrated in time interval/time interval. This rate was plotted against increasing duration of time.

2.3 Sampling and Analysis of Soil Leachates and Plant

Soil samples at the control and treatment plots were collected separately at 5, 15 and 35 cm depths using soil auger before planting and after weeks of crop growth. Samples were bagged in black nylon bags and taken immediately to Soil Science Laboratory, University of Uyo for physical and chemical analysis. Some samples from different depths were used for oven-drying method of moisture content determination. The rest of the soil samples were spread on a waste newspaper to dry, after which they were crushed with piston and mortar, and sieved with 1 mm-sieve; thereafter the samples were stored in a well-labeled nylon bags for analysis. Also, municipal solid waste leachate was collected in 100 cl-plastic bottle for analysis of its physical and chemical properties.

For plant samples, fresh and recently matured plant leaves were harvested from the treatment plots, cleaned with 2% P-free detergent solution and washed with pure water. The leaves were chopped and oven-dried at 80ºC to a constant mass for moisture content and dry matter determination. It was kept in an air-tight container for chemical and food analysis by AOAC (1990) methods.

2.4 Determination of Chemical Elements in Soil and Plant

A standardized pH meter (H198127 model by Hanna Inc) was used in a sample solution of 1:50. The potentiometric method made use of pH meter to measure the electrical potential between a reference solution and the soil sample by means of a glass electrode (AOAC, 1990). Electrical conductivity was determined by electrical conductivity meter (DIST-3 by HANNA Inc). The electrode was immersed completely in water sample to read in the value.

Nitrate was determined by Brucine colorimetric method on 10ml of the aliquot of the soil extract (for soil sample). The absorbance was read at 470 nm with the UNICAM 8626 UV/VIS spectrometer. Calcium utilized titration against the standard EDTA to obtain fluorescent yellow end point. Other nutrients chemicals and parameters were determined by their appropriate methods: Nelson and Sommers (1996) for total carbon and organic matter; Sieve analysis and hydrometer analysis (ASTM D422) for both sand and fines (Liu and Evett, 2000; Gee and Or, 2002); APHA (1995) was used for clear and grey water sample analysis.

2.5 Methods of Irrigating

Water was applied by gravity from a tank located at 10.0 m from the side; clear water was applied two times daily, and leachate-mixed water was applied two times daily at the rate of 4 litres per every irrigation. Other data were collected on plant height, leaf area and number, mean number of fruits per plants and mean fruit weights for the treatment and control irrigation.

2.6 Statistical analysis

Statistical analysis used the SPSS version 17 package software. Percentage difference was calculated as

$$\text{Percentage difference (\% Diff)} = \frac{\text{Value in control soil} - \text{Value in treatment soil}}{\text{Value in control soil}} \times 100 \qquad (1)$$

This quantified the percentage difference in values between treatment soil and the control (background) soil. Significant difference test utilized t-statistics; and correlation of crop growth responses to the two water quality effects utilized the Pearson correlation coefficient, while (degree of macro-availability) nutrients status used the geometric mean of component nutrients concentration. Regressions were formed for possible predictions of effect on crop growth parameters.

3. RESULTS AND DISCUSSION

3.1 Soil Textural and Physical Characteristics

Generally, soil of the low-lying flood plain of Uyo urban drainage stream, in the dry season of the year, was acidic, well-drained, non-concretionary and non-mottled, low-organic carbon, loamy sand (SLUK-AK, 1989). The surface horizon was brownish black but well structured texture of loamy sand over sandy clay. Mean particle size distribution of the leachate water irrigated-soil (**LW**) or (treatment) soil was 77% sand, 16% silt and 8% clay against the control or clear water (**CW**) irrigated soil's distribution of 77% sand, 3.4% silt and 19.9% clay (Table 1), i.e. same sand proportion but silt was > 4½ times in control, while clay was 40% less in **LW** than in **CW** irrigated soil. Therefore, **LW** impacted on soil texture increasing its silt and dispersing its clay components. The riparian soil showed clay movement with depletion (dispersion) under leachate irrigation from 19.9% in the control soil to merely 8% in leachate - impacted soil, giving clay depletion of 40% of the value for control soil (Table 1). This leachate water irrigation dispersion clay in the natural soil resulted in Silt/Clay ratio < ½ for control soil and Silt/Clay ratio = ½ for grey-water irrigated soil, showing a background (control) soil with higher weatherability (increased silt and reduced clay) (Van Wambeke, 1962), and a young soil with anthropogenic activities impacting on treatment soils, which reset soil formation by dispersing and leaching clay to gain its high sodium concentration and silt/clay ratio.

3.2 Chemical or Nutrient Properties of Irrigated Soil

Chemical or nutrient properties of irrigated soils are given in Table 1. The soil fertility was low in total nitrogen (TN), exchangeable potassium and organic matter content (OMC). However, TN was lower in treatment soil than in control soil while OMC was the reverse in leachate soil. Low value of OMC (2.17%) converted to 1.08% organic carbon using conversion rate in Zachar (1982) or SMI Laboratory (2011)). Leachate, which contained large proportions of fines, and suspended and turbid solids, could have deposited them on the top soil to increase the OMC, but nitrogen compounds, being soluble, could have mixed with stream water to increase the pH of treatment soil to higher value (5.80) than the mixed water. (The leachate was alkaline (Table 2)). Apart from sodium which seemed to have been easily leached by treatment water on the sandy soil, all the nutrients, except phosphorus, were higher in the control soil which also had higher clay content than the treatment soil (Table 1). The soil, under both water applications, was acidic (5.70, 5.80) as it could have been leached of major soluble ions and was commonly deficient of major plants macro-nutrients such as calcium, magnesium, nitrogen and phosphorus, all of which had generally low values (Bhattacharya and Michael, 2003). However, the leachate-water impacted-soil had higher base metal deficiencies, especially Ca and Mg, than the clear water irrigated soil (Table 1) compared to the slightly higher sodium concentration under treatment soil. Potassium was generally deficient but more deficient under leachate – water irrigated soil than in clear - water irrigated soil.

Table 1. Textural and Chemical Properties of Riparian Soil of Uyo Urban Drainage Stream-Irrigated with Leachate-Mixed and Clear Water.

Properties	Mean Concentration Treatment Soil	Control Soil	% difference
Sand, %	77	77	0
Silt, %	16	3.4	-3.71
Clay, %	8	19.9	0.60
Silt/Clay	0.5	0.2	-
pH (1.5 H_20)	5.80	5.69	-1.90
Organic matter %	2.17	0.09	23,111
Organic Carbon, %	1.01	0.01	100
Total Nitrogen, N, mg/l	0.11	0.43	74.40
Available Phosphorus, P, mg/l	213.30	9.37	-21.76
Calcium, Ca, mg/l	0.84	2.70	68.90
Magnesium, mg, m/l	0.48	1.74	72.40
Sodium, Na, mg/l	0.06	0.02	-200.0
Potassium, K, mg/l	0.07	0.11	36.40

N/B: % difference = Eqn (1); – ve indicates aspect of grey water superiority.

3.3 Nutrient and Bio-characteristics of Leachate and Diluted Leachate

Nutrient and bio-characteristics of the organic waste leachate were analyzed as shown in Table 2. Similarly, the resultant leachate – mixed water (diluted leachate) was analyzed. On dilution with stream water, concentrations of some properties of leachate were lower than their values in leachate (Table 2). Leachate was alkaline with high proportion of NH_4^+ and low Nitrogen and base metals. The high NH_4 in the leachate arose from the conversion of Nitrogen in the original organic material (IPPTS Associates, 2011). It may impact on **LW** irrigated soil to further deplete the soils cations (Bhattacharya and Michael, 2003) and to increase acidity of the present background soil. NH_4^+ is more fixed whereas Na+, Ca^{2+} and Mg^{2+} are easily exchangeable (Kjeldson et al, 2002; Bhattacharya and Michael, 2003) and often constitutes a major long-term pollution on the leachate. NO_3 – N of 100 PPM (100 mg/l) imparted restrictive use on the leachate, being > 30 mg/l (the FAO limit) (FAO, 1985), hence, the need to mix it with stream water. The diluted leachate (i.e. leachate-mixed stream water) was acidic (Table 2).

Table 2. Characteristics of MSW Leachate and Leachate-mixed water

Leachate		Leachate-mixed stream water	
NO_3 – N	100 ppm	NO_3	0.2
NH_4 – N	770 ppm	NH_4	0.09
K	60 ppm	K	-
P	trace	P	0.51
pH	7.4 (Alkaline)	p^H	5.98
Bacteria	4×10^4 cfu/ml	Bacteria	4×10^3
Fungi	1.0×10^2 cfu/ml	Fungi	-
Rhizobia	not detected	Rhizobia	not detected

3.4 Nutrients Status

Generally, Geometric mean (G_m) of nutrient content was obtained as (Bhattacharya et al, 2003; Sekabira et al, 2010):

$$G_m = (N1 \times N2 \times N3 \ldots Nn)^{1/n} \tag{2}$$

where N_n = nutrient components 1 to n in site soil. For the combined concentrations of macro nutrients (N, P, K, Ca, Mg), geometric mean of available nutrients was 0.92 mg/kg for **LW** and 1.12 mg/kg for **CW** irrigated soils, which shows that the depth of combined nutrient availability on both soils was low. However, the G_m for the metals (K, Ca. Mg) in **LW** soil was only 0.20 mg/kg, but 0.32 mg/kg in **CW** soil, indicating base metal depletion in **LW**. Therefore, base metal macro-nutrients should be enriched using the **LW** as sodium or NH_4^+ was actively depleting the Ca^{2+} and Mg^{2+}. The base metal macro-nutrients in soils were very low; showing that enrichment did not occur because they (base metals) were being depleted. However, their concentration could pose serious soil problems if sodium hazards occurred; that condition was qualified by ESP or SAR.

Table 3: Soil solution quality under leachate-mixed (**LW**) and Clear Water (**CW**) irrigation

	LW	CW	Remarks
pH	5.8	5.7	Soils moderately acidic
SAR %	7.4	1.3%	Soils not alkaline
CEC, Meq/l	1.45	4.57	Low cation exchange capacity
ESP %	7.4	0.44	No base saturation

Sodium absorption ratio (SAR) was 7.4% for the treatment soil and 1.3% for the control soil (Table 3). Therefore, both soils were not saline but leachate-mixed irrigation increased soil pH slightly from 5.7 in control soil to 5.8 in **LW** soil (Table 1). Cation exchange capacity (CEC) for the treatment soil was 1.45 meq/kg and 4.57 meq/kg for the control soil showing that more sodium were exchanged to replace Ca in **CW** soil to obtain the low CEC and high SAR (or ESP of 7.4%) in **LW** soil compared to the slightly high CEC and Low SAR (or ESP of 0.44%) in the control soil. Thus, neither soil also showed base saturation; as such, base metal cations sites were not saturated but were actively exchanging ions. Since the soil was acidic, sandy (loose structure) and leached of the metal cations, it would require frequent application of organic fertilizer to allow crop to absorb enough nutrient for growth, especially where liquid fertilizer application rather than surface compost or mulch was used. The deficiency in base metal suggests that other base metal supplementation should be added to leachate application, as leachate was alkaline.

Leaching requirement: Leaching requirement was not computed because the salinity of the soil was not above the permissible level even with **LW** irrigation.

3.5 Initial Soil Moisture Content

Initial soil moisture content prior to treatment was 15.3% (db) or 13.2% (wb) at 15 cm depth and 15.4% (db) or 13.3% (wb) at 35 cm depth as against the 18% at field capacity for the loamy sands. This indicates homogenous distribution of soil moisture content in the profile of the loamy sand soil.

3.6 Infiltration Capacity

Figure 1 is the infiltration rate – time plot for the soil irrigated with MSW leachate-mixed stream water (**LW**) and with clear stream water (**CW**). Clear stream water was obtained at early morning when neither waste disposal nor further leachate draining took place.

Readings from the graphical plots show that constant infiltration rate for the soil irrigated with clear water was 49 mm/hr while the one with leachate-mixed water was 25 mm/hr. Clearly, infiltration rate with leachate-mixed water was one-half (≈ 50%) of the one for clear water. Thus, the use of leachate-mixed water affected irrigation application rate by reducing the rate of infiltration by almost 50% of the value of irrigating with clear water. At 25 mm/hr, the fines, suspended and settleable solids in MSW leachate mixed with stream water and infilled the macropores of loamy sand soil on application and modified (lowered) infiltration rate to that which resembled the value for sandy loam (medium textured) soil (Bhattacharya and Michael, 2003; Essien and Saadou, 2012). This holds definite advantage for irrigating the leached sandy soil in the dry season. It greatly saved irrigation water on sandy soil farming. This advantage was equally observed in the case of solid organic bio-waste soil amendment on loamy sands (Essien and Saadou, 2012).

Infiltration capacity which is the maximum instantaneous infiltration rate also indicated a significant difference between the application of water from the two sources, with clear water (**CW**) infiltration rate being (54.0 mm/hr or 5.4 cm/hr) and nearly twice faster than leachate-mixed water (**LW**) (with infiltration rate of 27.0 mm/hr or 2.7 cm/hr). The reason for this significant level under the same sandy soil texture and structure is not unconnected with the reduced water quality of the leachate-mixed stream infilling the sands macropores with the minute organic fines and suspended solids (Bhattacharya and Michael, 2003). The constant infiltration rate at infinity elapsed time was 49 mm/hr and 25 mm/hr respectively (Fig 1).

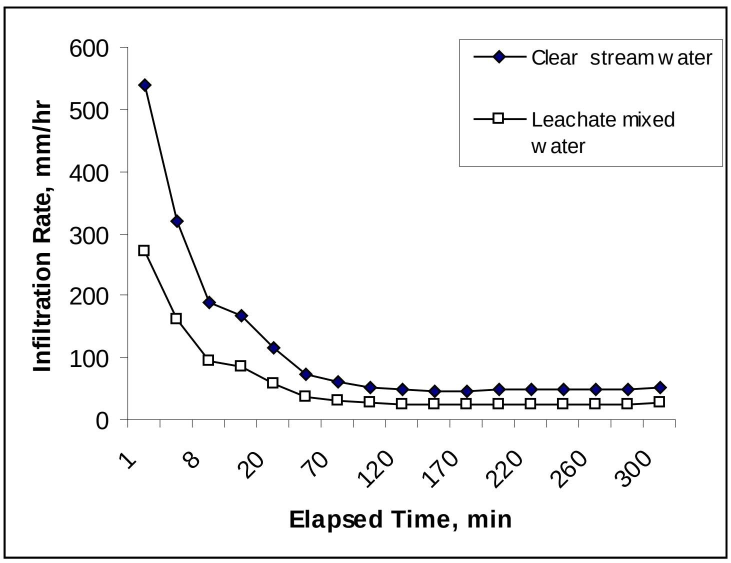

Fig. 1: Infiltration rate of the riparian soil under MSW leachate-mixed water and the clear water application.

Thus, the Hortonian infiltration equation (Horton's equation) took the forms:

1) for clear water, $f = 49 + 491e^{-2.80t}$ - (4)

2) for leachate-mixed stream, $f = 25 + 245\ e^{-2.69t}$ - (5)

Where f = infiltration rate (mm/hr), t = elapse time (mins)

3.7 Growth Response of *Telfairia occidentalis* to Waste Water Quality

The reduction of foliar growth under **LW** (Table 4) is not a clear disadvantage of its use because, even under water stress, reduction in the growth of shoots could occur without markedly affecting the growth of fruits or without reduction in the size of fruit or yield (Goodwin, 2000) (see Table 5). Tables 5 and 6 compare the effect on growth and yield. Very significant correlation existed between growth parameters under the use of **LW** and **CW** at P = 1% for cumulative leave number, leaf area and vine length except height (Table 4). Also, only cumulative leave number showed significant mean difference between **LW** and **CW** at 10%, with **LW** performing better than **CW** irrigation.

Table 4: T-test and Correlations Statistics for Growth Parameters Paired Samples under LW and CW Irrigations.

Paired Samples	*Paired Samples Correlation*		Paired Samples Test	
	Correlation %	Sign.	t	Sig (2 tailed)
Cum. Leave no: LW – CW	0.991	0.009**	3.000	0.058*
Leaf Area: LW – CW	1.000	0.000**	1.732	0.182
Height Stem: LW – CW	0.927	0.73	1.000	0.391
Length of Vine: LW – CW	1.000	0.000**	1133	0.340

N/B: where cum = cumulative, LW = leachate-mixed water, CW = clear stream water. **, * = significant @p<0.01, p=0.05.

The vegetative growth profile had a perfect growth profile correlation with time in both samples from post emergence date to 45 – 60 days growth period ($R^2 = 95.1$ to 99.9%, $P < 0.01$) (Table 4) as observed in their logarithmic growth equations below:

For cumulative Leave No.:

LW: $y = 7.072 \text{ Ln } x - 13.400$, $R^2 = 0.945$ - (6)

CW: $y = 5.977 \text{ Ln } x - 11.433$, $R^2 = 0.989$ - (7)

For Leaf Area:

LW: $y = 148.43 \text{ Ln } x - 355.17$, $R^2 = 0.999$ - (8)

CW: $y = 141.90 \text{ Ln } x - 338.49$, $R^2 = 0.998$ - (9)

For Vine Length:

LW: $y = 214.20 \text{ Ln } x - 506.00$, $R^2 = 0.949$ - (10)

CW: $y = 207.72 \text{ Ln } x - 488.24$, $R^2 = 0.951$ - (11)

For Height of Stem:

LW: $y = 8.6201 \text{ Ln } x + 51.445$, $R^2 = 0.78$ - (12)

CW: $y = 5.477 \text{ Ln } x + 60.151$, $R^2 = 0.499$ - (13)

Or, using power factor,

CW: $y = 61.375\, x^{0.0731}$, $R = 0.499$ - (14)

where x is time and y is growth parameter assessed.

The height of vine at growth stage showed low regression coefficient perhaps due to the fact that from Day 12 to Day 17 (one week) after emergence (IWAE), the height extended by 60 cm, i.e. from 20 cm (Day 12) to 80 cm (Day 17). Thereafter, the height stalled in growth at 80 cm and bent into a creeping vine length till the 50th day. The vertical elongation in height as time progressed changed to the linear growth profile in both **LW** and **CW** and tillers were produced as it grew. This is the creeping characteristic of pumpkin vine growth (by linear elongation), except if it climbs a supporting tree or stake.

3.8 Effect of MSW Leachate-Stream Irrigation on Yield Parameters

NFE values in pumpkin leaves from Grubben and Denton (2004) were: carbohydrate 7.0%, CF 1.8%, Ash 11% and CP 2.9% showing a better performance from the **LW** irrigation. Comparatively, the food value (seed quality) from **LW** irrigated pumpkin seeds performed significantly better than from **CW** irrigation (Table 6). At the end of the dry season, the MSW leachate mixed water impacted on crop productivity producing marginally higher leaf yield (2.00 t/ha) of *Telfairia occidentalis* than clear water application with (1.97 t/ha).

Data in Table 6 show that yield parameters under **LW** irrigation showed superior performance to **CW** irrigation. The vine length under **LW** irrigation was 12% longer than under **CW**; the number of leaves was 17% more, the leaf area under **LW** irrigation performed significantly ($p < .05$) better being 4% wider than the case for **CW** application. Also, apart from the insignificant differences in pod girth and seed size in favour of control water irrigation (Table 5), the actual yield performance was higher in pod length, and size and mass of *Telfairia occidentalis* seeds under MSW leachate-mixed irrigation water than those under clear water (Table 5).

The quality and quantity of irrigation water are very important factors for crop growth and yield. However, even when the quantity is assured, the quality becomes the limiting factor if the use of such polluted source of water for crop growth and yield is not assured (Ayers and Westcot, 1985). Municipal solid waste leachate is polluted water drained from biodegrading waste materials and is known to contain toxic levels of minerals, metals and bacteriological properties which endanger plants life in growth and quality, and can transfer such dangers through soil medium of its growth to consumers (humans and animals) (Marshall et al, 2007; Sharma et al, 2007; Khan et al, 2008; Adefemi et al, 2012; Essien and Douglas, 2012).

The quality of yield was also affected as shown in Table 6 for surrogate parameters in *Telfairia occidentalis* leaves and seeds. For leaves, the percentage composition of surrogate parameters in pumpkin leaves and pumpkin seeds showed no distinctive advantage over each other on quality of irrigation water except for CF and NFE, where **LW** irrigation gave higher quality and DM and ASH where **CW** irrigation gave superior leave quality (Table 6). For the quality of *Telfairia occidentalis* seeds, surrogate parameters were superior in favour of irrigation with **LW** except very marginally in CF and NFE which surprisingly were favoured in leaves by MSW leachate-mixed stream water. That means there could be a relationship somewhat between the two parameters and irrigation water quality.

The dominant superior quality in seeds due to the use of MSW leachate-mixed water is attributable to the fact that seeds store up these nutrients for better edible (health) and market value as well as germinability or productivity. Therefore, **LW** conferred superior quality to *Telfairia occidentalis* seeds than to its leaves, just like some waste water do (Goodwin, 2000).

Table 5: Effect of clear water and leachate-irrigation on yield parameters of *telfairia occidentalis* after growth on loamy sand wetland in Uyo urban.

	Yield Parameters (Average)				
Irrigation water quality	Pod girth, cm	Pod length, cm	No. of seeds	Seed size, cm	Seed mass, mg
CW	83.01	53.13	79	4.1	2.1
LW	83.52	49.85	81	4.5	2.2
% Diff	0.6	-6.2	-2.5	9.8	-4.8

N/B: negative % difference implies that CW irrigation showed better performance (Eqn 1).

Table 6: Proximate analysis of *Telfairia occidentalis* leaf and seed quality under MSW leachate-mixed and control water irrigation on loamy sand wetland in Uyo urban.

Surrogate Parameters	Leaf Characteristics under		% difference on control	Seed characteristics under		% difference on control
	CW	LW		CW	LW	
MC, %	84.76	84.56	0.23	72.89	79.21	-0.867
DM, %	15.24	13.96	8.4	23.11	29.50	-27.7
CF, %	5.20	5.90	-13.4	1.40	1.30	7.1
CFT, %	16.20	16.00	1.2	22.80	29.10	-27.6
ASH, %	4.20	3.90	0.7	3.00	3.10	-3.3
NFE, %	41.52	42.20	-6.8	49.80	49.60	0.2
CP, %	28.88	28.44	1.5	21.00	23.10	-9.5

N/B: MC = moisture content; DM = dry matter, CF = crude fat, CFT = crude fibre, ASH = ash, and CP = crude protein, NFE = nitrogen free extract, Negative (-ve) values show quality factor under LW is better than CW. Percentage MC is based on dry basis, db.

3.9 Prospect of MSW Leachate for Organic Agricultural Production

The use of animal waste, liquid fertilizer and leachate provides mineralized liquid for organic agriculture and suggests that MSW leachate of certain property range can be packaged for organic, mineralized water-based agriculture. Barring certain toxic elements that may be absorbed into the plant system, the MSW leachate can be diluted and used as slurry of organic waste for agricultural farm.

4 CONCLUSION

In Uyo municipality, MSW dumpsite situated above a ravine; and leachate from it flowed into the upstream of a line spring in the ravine with the MSW leachate (point source) pollution of the stream extending some kilometers downstream (Essien, 2012). The polluted water (**LW**) was also used for riparian farming by some urban dwellers to provide urban green areas and dry season food, particularly the staple green vegetable leaves which form a particular staple soup or food raw material generally in the urban. If the leaves and seeds absorbed and isolated polluted ions in their edible parts, pronounced health effect would be impacted on the dwellers and users. The MSW leachate is known to have imparted high heavy metal load on the stream water.

Effect of using MSW leachate-mixed water as irrigation water was assessed on riparian soil texture, composition and infiltration rate, and on growth, yield, leaves and seeds quality of *Telfairia occidentalis.*

Two effects were observed generally: (1) Where MSW leachate-mixed stream water (**LW**), as irrigation water, proved as a nutrient supplier to soil, hence showing advantage on vegetative growth of crop over control clear water (**CW**) application. Grey water conferred superior performance to vine growth and seed quality (2) Where it constituted a blockade or constriction of the sandy soil's macropores, it depressed hydraulic flow of soil water through the pores – particularly retarded the rate of infiltration below that of the control (clear water) application. Thus, grey water reduced infiltration rate of loamy sand riparian soil to 25 mm/hr, about 50% of the rate (49 mm/hr) in control soil produced by clear water irrigation. It dispersed clay and increased silt content causing a rise of Silt/Clay ratio from < ½ to ½ with **LW** irrigation. Further leachate dilution for irrigation application is recommended.

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