Some engineering of drumstick (Moringa oleifera) seeds

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ANTHROPOMETRIC CONSIDERATION OF HAND TOOLS DESIGN FOR NIGERIAN POLYTECHNIC STUDENTS

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ABSTRACT

This study presents anthropometric consideration of hand tools design for Nigerian Polytechnic Students. Nine dimensions relevant to the design of hand equipment were measured from 800 respondents within the age limit of 18 to 30 years. The result of statistical analyses showed significant differences between the dimensions of male and female students on hand length, hand breadth of metacarpal and grip diameter (inside), where those of males were larger. The comparison of the results of some hand dimensions of this study with the results of two other studies from different regions in Nigeria between two genders indicate differences among people in the regions. Mean values of most of the dimensions of Nigerians were found to be smaller when compared to four ethnic population of the world. The variations in hand dimensions should be considered and as well enlarge sample measurements to encompass students in other tertiary institutions in Nigeria.

KEYWORDS: Polytechnic students, hand tools, anthropometric dimensions, equipment.

1. INTRODUCTION

Ergonomics is the application of measurements to products, in order to improve their human use. Ergonomics often involves research into the way people interact with products and the environment around them. Anthropometric data is used to determine the size, shape and / or form of a product, making it more comfortable for human to use and easier to use. In Nigeria, majority of polytechnic students' workforce engage in different activities that involve hands. They devote many hours using hands to write, operate and construct machines, work in agricultural fields, type with computers etc, but no recognition has been given to their hand dimensions in the design of those facilities and machines being used.

Anthropometric body dimensions play a significant role in human-machine and environmental interaction. The overall working efficiency of human-machine environment and resultant discomfort has severe impact while using tools and machinery in different work conditions. Anthropometric data have wide range of applications in the design of agricultural machinery among other physical equipment and facilities. It is needed in the design of products as it varies between individuals and nations. Many western and developing countries like Indian have been making frantic efforts in establishing an anthropometric database for different population groups such as agricultural workers, industrial workers, students, military personnel, civilians, drivers among others. Ethnic diversity is always a significant factor that may affect the anthropometric data and the scopes of its applications. Pleasant (1996) suggested that the variations of body dimensions of different groups can be observed in terms of overall body size and bodily proportions.

Buchholz et al. (1992) reported that the interaction of handle size and shape with kinematics and anthropometry of hand have a great effect on hand posture and grip strength. Furthermore, (Loslever and Ranaivosoa 1993; Chandra et al. 2009; Claudon 2000) have discussed that poor ergonomic hand tools designed is well known factor contributing to biomechanical stresses and increasing the risk of cumulative trauma and carpal tunnel of syndrome disorders of users. Thus, the use of hand anthropometric data in the design of hand tools may constitute better performance of work and reduce undue stresses to the users/operators. Hand anthropometric data and its application in the design of hand fittings are generally scanty in developing countries (Gite and Yadav 1989; Nag et al. 2003;

Imrhan and Contreras 2005; Mandahawi et al. 2008; Imrhan et al. 2009; Chandra et al. 2011). Hand tools need to fit contours of hand, they need to be held securely with suitable wrist and arm posture, they may be utilizing strength and energy capabilities without over loading the body.

Das and Bhattacharya (1984) investigated the optimum design and location of a hand operated rotary device and concluded that though all body dimensions are related to each other, shoulder height and forward arm reach had direct bearing on the design parameters of the rotary device. The grip dimension of most of the hand tools such as knob, weeders, handle of wheel hoe, handle and length of cutlass among others are not properly designed and needed to be designed based on the anthropometric dimensions of the intending users otherwise the machine will be a mismatch to both the users and environment. However, in case of implements that fall within wheel hoe, which has certain working depth, necessary correction needs to be made in handle height to have comfortable holding height in working condition.

The study was carried out to generate hand anthropometric data of Nigerian Polytechnic Students to serve as a database for designing of hand tools and other human facilities that needed hand operations for Nigeria use.

2. MATERIALS AND METHODS

2.1 Subjects

Samples used in our study were conducted from January, 2012 to March, 2013 using 800 subjects (400 males and 400 females) within the age of 18 – 30 years. 200 students (male and female) were selected from each of the four polytechnics (Auchi, Ogwashi-uku, Ozoro and Bori) situated at Edo, Delta and Rivers states respectively by simple random sampling.

Nine hand anthropometric dimensions relevant to the design of hand tools were measured as described in Table1. Students were selected according to their availability and willingness to participate without reward in the form of cash or kind, because they were earlier furnished with the objectives of the study. The methods of hand anthropometric measurements were same as stated by (Davies 1980; Courtney and Ng 1984).

Table 1: Showing definition of some hand dimensions used in the Study

S/N	Dimensions	Definition
1	Functional arm reach	Horizontal distance from the shoulder to the tip of the longest finger.
2.	Hand length	The straight distance between root of the palm and tip of the middle finger.
3.	Hand breadth of metacarpal	The breadth of the palm measurement at the level of maximum bulge of the palm excluding thumb.
4.	Hand thickness	The thickness of the hand measured at the level of middle portion of the palm transversely.
5.	Maximum hand breadth	The breadth of the hand measurement at the level of maximum bulge of the palm including thumb.
6.	Hand circumference	The closed measurement that follows a hand contour at the maximum feast level, the measurement is not circular.
7.	Maximum hand circumference	The closed measurement that follows a hand conotur at the maximum feast level, the measurement is not circular.
8.	Palm length	The straight distance between root of the palm and root of the middle finger.
9.	Grip diameter	Maximum inner curvature of the hand at the touching level between tip of the middle finger and thumb.

2.2 Apparatus

Regular measurement tools were used as anthropometer for stature measurement, arm length measurement and elbow length measurement; and digital Vernier Caliper for length, breadth and depth measurement of hand, measuring tape for circumferential measurements, a wooden cone designed locally and specially to measure internal grip diameter and inner caliper for measurement of grip span.

2.3 Statistical Analysis

Mean ± SD and key percentiles were measured for each dimension. The measurements were compared between male and female genders. Data was analyzed using independent samples t – test by SPSS (Version 18.0).

3. RESULTS AND DISCUSSION

Table 2 shows the summary of the results of nine hand anthropometric data of 400 male and 400 female students of Nigerian Polytechnics in terms of means, standard deviations, fifth, fiftieth, and ninety-five percentile. The findings indicate that the mean dimensions of the subjects can be used as a reference database for designing different hand tools and fittings for the students in the area. Apart from mean, 5^{th} and 95^{th} percentile values of their body dimensions were calculated to decide various possible design limits of hand tools, handles, control panels and workplace layout to be operated by each group.

Table 2: Anthropometric Dimensions of Male and Female Nigerian Polytechnic Students

Body dimension (cm)	Male					Female				
	Mean	SD	Percentiles			Mean	SD	Percentiles		
			5^{th}	50^{th}	95^{th}			5^{th}	50^{th}	95^{th}
Functional Arm Reach	72.2	8.0	51.6	73.7	81.4	66.1	12.8	49.4	64.5	88.8
Hand Length	16.6	1.4	15.1	17.9	20.0	15.6	1.4	12.7	15.5	17.8
Hand Breadth of Metacarpal	9.6	1.5	7.6	9.3	12.7	8.8	1.2	7.3	8.9	11.1
Hand Thickness	2.9	0.25	2.5	2.7	3.1	2.8	0.21	2.4	2.8	3.0
Maximum Hand Breadth	11.3	1.9	6.0	11.3	14.2	10.8	1.9	8.1	10.5	14.2
Hand Circumference	18.1	3.4	12.3	18.9	22.8	16.9	3.2	10.2	17.8	20.3
Maximum hand circumference	24.1	1.2	22.4	24.0	25.9	23.5	1.3	21.4	23.4	s25.2
Palm Length	11.6	1.4	10.0	11.6	14.3	11.4	1.2	9.7	11.4	13.8
Grip Diameter (inside)	5.3	0.9	3.5	5.2	6.6	4.8	0.6	2.6	3.2	4.3
Grip Diameter (outside)	7.6	0.8	6.5	7.6	9.9	6.3	2.0	6.1	7.6	13.3

The results of statistical t–test comparison of hand anthropometric dimensions of the male and female data are presented in Table 3. The test results proved significant differences between the hand dimensions of male and those of their female counterparts on hand length, hand breadth of metacarpal and grip diameter (inside), where those of male were larger. The percentage of difference in hand dimensions (males and females) ranged from 1.56 % to 17.11%. Considering the data obtained (Table 3), the design of hand tools having the same dimensions for both male and female may be adopted in the area except in the design of hand tools on those dimensions that were statistically significant.

Table 3: T-Test analysis of Male and Female Anthropometric dimensions of Nigerian Polytechnic Students

Body Dimensions (cm)	Mean Male	Mean Female	N	Tcal	Df	Sig.(2-tailed)	Decision p<0.05
Functional Arm Reach	72.2	66.1	800	-1.626	799	0.120	NS
Hand Length	16.6	15.6	800	-4.413	799	0.000	S
Hand Breadth of Metacarpal	9.6	8.8	800	2.064	799	0.053	S
Elbow Hand Grip	12.8	12.6	800	0.473	799	0.641	NS
Hand Thickness	2.9	2.8	800	1.375	799	0.185	NS
Maximum Hand Breadth	11.3	10.8	800	-1.11	799	0.281	NS
Hand Circumference	18.1	16.9	800	1.00	799	0.330	NS
Maximum Hand Circumference	24.1	23.5	800	0.945	799	0.376	NS
Palm Length	11.6	11.4	800	0.82	799	0.422	NS
Grip Diameter(inside)	5.3	4.8	800	6.636	799	0.000	S
Grip Diameter(outside)	7.6	6.3	800	-1.734	799	0.099	NS

S and NS means significant and not significant respectively.

Figs. 1 and 2 show the comparison of the results of some hand dimensions of our study with the results of two other studies from different regions in Nigeria between two genders. All dimensions from each study were larger in males than females.

The results of the comparison also reveal that hand dimensions of present study (south south region) are almost lower in all dimensions for both gender, when compared to Onuoha et al. 2012(south eastern region); whereas the mean values of present study were higher than Ismaila et al. 2010 (south western region). The values of mean in each study as represented in Figs 1 and 2 showed increases in hand dimensions in middle age before declining with an increasing age. This classification revealed that there are clear difference among the three groups; and as such indicating a unique and distinct nature of hand anthropometry of Nigerian population.

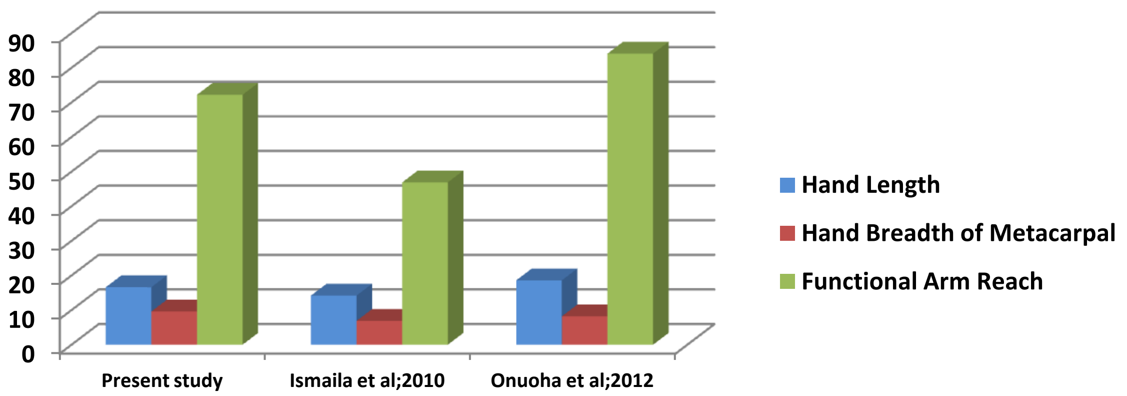

Fig.1: comparison of some hand dimension of present study with the results of two other studies in males

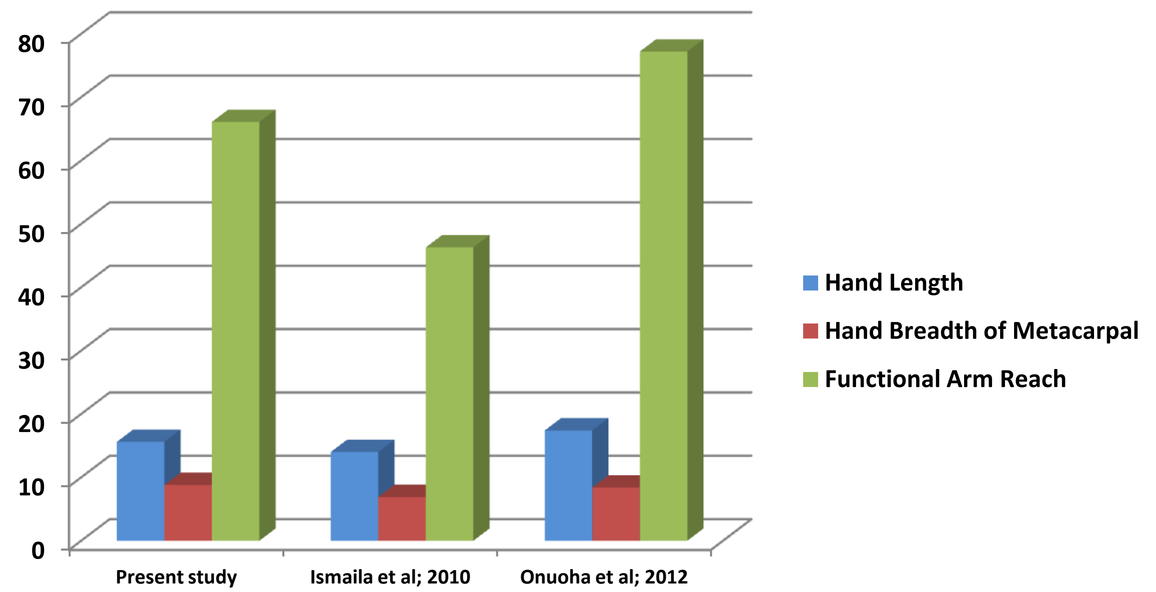

Fig.2: Cmoparison of some hand dimension of present study with the results of two other studies in females

The mean dimensions for males and females of three ethnic populations of the world were compared with the present study as presented in Table 4.

The empty data cells (DNA) are due to data being unavailable. Simple analysis was used to compare the significance of mean differences among these four ethnic populations of the world. The test results showed that there are significant differences in most of the mean dimensions.

Among the male group, present study has the lowest mean values of hand length, forward grip reach and hand thickness but has the largest mean values of hand breadth of metacarpal when compared to other ethnic populations. More so, United State of America (USA) has the largest values in all the hand dimensions except that of hand breadth of metacarpal. Similar trend were observed among female group where some variations in the mean values of Nigerian (present study) were largest for hand length and hand thickness; and lowest for hand breadth and forward grip reach respectively. Hereditary influences, economic development, social environment, type of work and labour structure all affect the ethnic differences in body shape (Lin et al. 2004). These differences should be considered for designing and buying of hand operated machines/fittings to be used by the studied subjects.

Table 4: Comparison of hand anthropometric dimensions of male and female Nigerian Polytechnic Students with other ethnic population of the world

	Male								Female							
	Present study (Nigeria)		Chinese (Karmega et al. 2011)		USA (Hsiao et al. 2005)		Indian ((Kar et al. 2003)		Present study (Nigeria)		Chinese (Karmega et al. 2011)		USA (Hsiao et al. 2005)		Indian (Kar et al 2003)	
Dimension (cm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Hand Length	17.60	1.40	18.22	1.33	19.7	1.0	17.50	0.85	15.60	1.4	17.17	1.13	18.20	0.90	16.09	0.70
Hand Breadth of Metacarpal	9.60	1.5	6.90	0.58	9.1	0.5	8.23	0.44	8.80	1.2	6.90	0.79	8.00	0.50	7.30	0.35
Forward Grip Reach	72.20	8.00	74.07	5.27	75.80	3.70	DNA	DNA	66.1	12.8	66.26	3.61	69.2	3.70	DNA	DNA
Hand Thicknes	2.90	0.25	2.95	0.33	3.00	0.20	2.81	0.28	2.8	0.21	2.36	0.26	2.50	0.20	2.58	0.18

DNA means Data not available

4. CONCLUSION AND RECOMMENDATIONS

The statistical t-test comparison of the results of hand anthropometric dimensions between males and females students showed significant differences on hand length, hand breadth of metacarpal, hand circumference and grip diameter (inside), where those of males were larger. The results of some hand dimensions of the present study was compared with the dimensions of Onuoha et al. 2012 (South eastern-Nigerian agricultural workers) and Ismaila. 2010 (South western – Nigerian passengers seated in buses) between two genders showed that all dimensions from each study were significantly larger in males than females. Hand dimensions of the present study were almost smaller for both genders when compared to Onuoha et al. 2012; whereas the mean values of the present study were larger than Ismaila et al. 2010.

The mean values of the study showed increase in hand dimensions in middle age before declining with an increasing age. These data will be useful for the engineers and scientists to decide various possible design limits of hand operated machines, hand hoes, control panel, work station, hand apparel and other hand held devices. Mean values of most of the hand anthropometric dimensions of Nigerian (present study) were found to be smaller when compared to other ethnic populations of the world.

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DEVELOPMENT OF LIQUID ANIMAL MANURE INJECTOR EQUIPMENT WITH INSTRUMENTATION FOR DRAUGHT MEASUREMENT OF TILLAGE TOOLS

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ABSTRACT

Liquid livestock manure injection equipment was developed based on the design criteria: easy adaptation, low draught force and suitability for different soil and crop residue conditions. The equipment featured two sweeps having a flat shape coulter and two shanks, coupled to 2 m wide implement frame. A 350 liters tank full of liquid manure was mounted on the frame during the experiment. The experiment was conducted with the equipment in sandy loam soil (11.52% clay, 24% silt and 64.48% sand) using convex sweeps with a forward speed of 3.49 km/h, depths of soil cut (50, 100 and 150 mm) and rake-angle of 30^o. The soil dry bulk density (1.79 Mg/m^3), moisture content (25% wb) and soil strength (10.6 kPa) were also measured during the experiment. The soil disturbance profiles increase significantly with the depth of soil cut. The draught forces were also significantly increased with injection depth. The specific draught of the convex sweep was in the range of 2.68 to 9.87 kN per tool.

KEYWORDS: Convex sweep, rake-angle, depth of soil cut, tool forward speed, draught force, liquid livestock manure.

1. INTRODUCTION

Draught force is an important parameter for measuring and evaluating implement performance for energy requirements. It has been investigated by many researchers (Oni *et al*., 1992; Onwualu and Watts, 1998; Mamman and Oni, 2005). Existing injection tools require high draught force that increases the draught force requirement and the cost of operation. Injection depth, tool rake-angle, tool travel speed and tool cutting width all influence the draught force requirement (McKyes, 1985; Rahman and Chen, 2001). Land application of liquid manure using sweep injection tool has been recognized as a cost-effective and sustainable practice for manure utilization. Comparable crop yield can be achieved when using liquid manure to replace chemical fertilizers (Chen *et al.*, 1999).

The most common injection tools used include the knife, chisel, disc, and sweep. Knife often cannot create sufficient manure holding capacity for manure application rates required by crop. The chisel type injector cuts a slot into soil and allows the manure to flow down the slot (Godwin and Spoor, 1977). In addition, they penetrate deep into soil, therefore requiring more energy and often cannot create sufficient manure holding capacity for manure application rates required by the crops (Chen and Rahman, 1999). Discs have also been used for manure injection. However, disc does not actually inject the manure, but mix and cover the injected manure with the surface soil layer (Jokela and Cote, 1994). The rolling motion of a disc helps to cut through the soil surface (Chen and Heppner, 2002) at the same time tend to compact the soil and reduce pore space, thus decreasing infiltration rate (Geohring and VanEs, 1994). Sweep type injector lifts the soil and allows the manure to flow in a wide horizontal band (laterally) at a shallow depth, and allows the soil surface to come back down over the liquid manure (Manuwa *et al*., 2012).

Sweep can be used for apply higher application rates in one pass than a knife injector, can apply in several passes. Sweep-type (winged) injection tool demonstrated the best performance for manure injection in terms of mixing soil with manure (Moseley *et al*, 1998). However, higher draught force is associated with this type of tool (Rahman and Chen, 2001), especially in clay soils.

The design of the prototype liquid manure injector was based on research work on the design of manure injection tools (Chen and Tessier, 2001; Manuwa *et al.,* 2011; Manuwa *et al.,* 2012) and also on previous studies on the evaluation of existing injection tools (Rahman and Chen, 2001; Rahman *et al*., 2001, Warner *et al*., 1991). Materials were sourced locally for affordability and ease of procurement. A medium size tractor (30- 50 kW) was considered appropriate as prime mover. The tool bars are strong and capable of varying work depth and rake angles of blade. The leading edge of the tool bar was designed to work at 45^{o} to the tool travel direction (Chen and Heppner, 2002). Sweeps were designed because they can create relatively larger cavities in soil. Sediment trap called chopper filter was put at the point where slurry was introduced into the tank to intercept anything that might damage the pump. The equipment was designed to inject manure into soil at varying depth and components replacement is a one-man job. Therefore, appropriate light weight high tensile strength steels were used.

The objectives of this paper are to report on: the development of a liquid livestock manure injector equipment; development of the instrumentation; and measurement of draught force under varying operational depth.

2. MATERIALS AND METHODS

Apart from the liquid livestock manure injector that was designed and fabricated for this study, the following materials/instruments were also used: 36 kW power tractor as prime mover for the manure injector; data logger (measure draught force); load cell; cone penetrometer with GPS to measure soil penetration resistance, measuring-tape and soil moisture meter to measure soil moisture content.

2.1 Equipment Description

The liquid manure injector equipment was designed, fabricated and assembled in the workshop of Agricultural Engineering Department of the Federal University of Technology, Akure, Ondo State, Nigeria. The liquid manure injection equipment was formed by two injection tools (sweeps) mounted on a pull type, 2 m length implement frame. A tool spacing of 60 mm was selected based on the conclusion drawn by Warner and Godwin (1988) that tool spacing smaller than 65mm was suggested for uniform crop response. The sweep was bolted to lower end of the c-shank and the c-shank was coupled to the depth adjuster. The two depth adjusters were mounted on the implement frame. Figure1 shows the main components of the liquid manure injector equipment except the tank and the equipment frame that were not shown here. The parts are; fluid-flow regulator arc (A), depth-adjusting mechanism (B), coulter bar (C), coulter (D), convex sweep (E), rake-angle regulating arc (F), furrow covering plate (G), liquid manure delivery tube (H), furrow covering plate shaft (I) and c-shank (J).

The manure delivery tube was welded to the covering plate and mounted on a 30 mm shaft (furrow covering plate shaft). Coulter was coupled to the coulter shaft and the coulter shaft attached to the front side of the depth adjuster. The pipe network installed on the frame featured a 100-mm PVC hose which do receive manure from the pump and allow it to be distributed to each of the two injection tools through flexible 50 mm PVC hoses.

Figure 1: Manure injector components

Table 1: Design specifications of the Liquid Manure Injector Equipment

Components	**Dimension (mm)**	**Components**	**Dimension (mm)**
Frame (Rectangular hollow pipe): Length Width Thickness Rectangular cross-section Mast height Lower hitch point spread	 2000 980 100 5 457 686	**Furrow covering plate**: Length Height Thickness Furrow covering plate shaft	 220 150 7 30
Sweep: Length Width Thickness	 200 224 8	**C-shank** : Diameter	 50
Manure delivery pipe: Diameter Length	 57 300	**Coulter**: Circumference Thickness	 400 8
Coulter bar: Diameter	40	**Tank capacity**	350 litres

The hoses (50 mm diameter) were fitted inside the manure-delivery-tubes which were made of 75 mm diameter galvanized pipe. The tank was mounted to the implement frame top using bolts and nuts. Four wheels were coupled to the frame with the help of 200 mm by 200 mm by 30 mm steel plate bracket. The mounting bracket was welded to the top of the wheel hub. The bracket plates were fastened to the frame using four 25 mm thickness bolts and nuts (Fig. 1). The geometric dimensions of the equipment are as shown on Table 1. The injection equipment was pulled by a 415 MF tractor during the experiment. The soil of the experimental plot was tilled at a greater depth than the maximum experimental design depth before the experiment.

2.2 Calibration of the Load Cell

The load cell was calibrated using a dead load system. The load cell (20 tons) was used in collection of draught data in the field. The characterization was done in the laboratory of Physics Department, of The Federal University of Technology, Akure, Ondo State, Nigeria on 23rd April, 2013. During the calibration, Loads were added to the cell (200 – 1200 N) and the corresponding voltages were recorded and tabulated (Data not shown). Figure 2 shows the calibration graph.

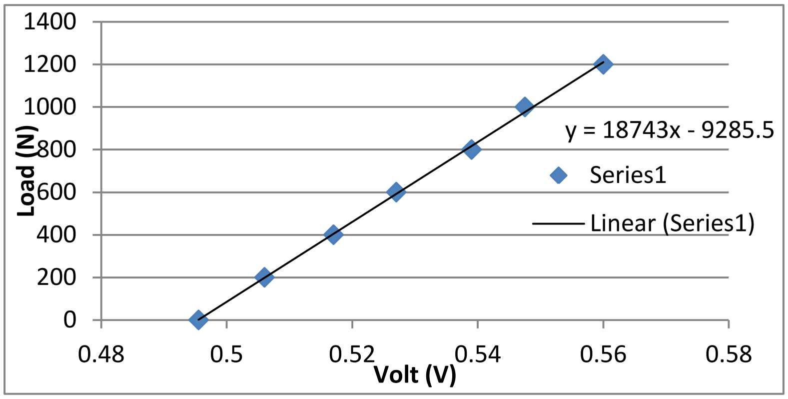

Figure 2: Load cell calibration graph

Figure 3: 20-ton Load cell

2.3 Design/Circuit of the Strain Gauge Amplifier

The load cell was used along with the strain gauge amplifier and the data lodger in the field for draught force measurement. The schematic diagram of the strain gauge amplifier is as shown in Figure 3. The Output voltage from sensor is 2.5mV (from sensor data sheet), also, sensor power input is 12V at 30mV. (Expected total output voltage). Therefore V_2 is 30mV (max) and V_1 is assumed to be insignificant i.e V_1 = 0. Expected sensor power output = 5VDC at 50mA (from data logger sheet), therefore V_{out} = 5V (Figure 4). Figure 4 and 5 show the amplifier and the data lodger respectively.

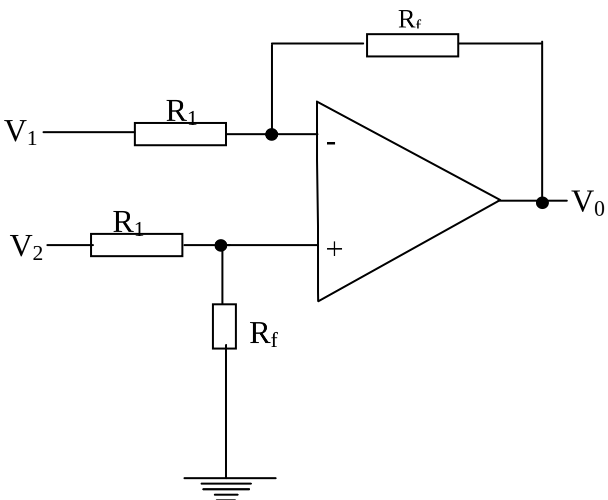

Figure 3: Schematic Circuit Diagram of the Differential Strain Gauge Amplifier (LM 358).

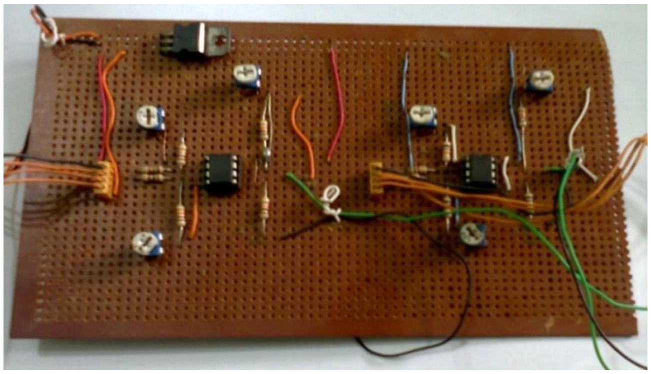

Figure 4: An Amplifier showing its component circuits

Outside part

Figure 5: Data loggers

2.4 Soil Preparation and Measurements

Field experiment was conducted at the Science and Technology Post-Basic (STEP-B) Research Farm of The Federal University of Technology, Akure, Ondo State, Nigeria. It is on longitude 7^o 15^1N and latitude 5^o 15^1 E on an elevation of 210 m. The field had a sandy loam (11.52% clay, 24% silt and 64.48% sand, by weight) with 200-mm high cereal stubble. The field was ploughed below maximum experimental depth (150 mm) before the experiment using disc plough and it was latter harrow. The soil has dry bulk density (1.79 Mg/m^3) and moisture content (25% wet basis) at the time of field experiment. Also, soil strength (10.6 kPa) was measured using a cone penetrometer (CP40II, Serial No. 130G0254, Rimik Electronic 1079 Rothvon St. Toewoumba QLD 4350, Australia) with 12.83 mm cone diameter and 30 degree angle based on ASAE standard (ASAE, 1995).

2.5 Details of Experimental Designs and Treatments

To examine the effects of the depth on draught force using a convex sweep with coulter (CS_{wc}), a completely randomized experiment (three replications) with all combinations of three injection depths (50, 100, and 150 mm) and a tool forward speeds of 3.49 km/h were used. The selected depths and speeds are commonly used by producers for manure injection. Each experimental plot has a dimension of 3 m wide and 100 m long allowing for one pass of the manure injection equipment. Rake angle of 30^o was maintained throughout the experiment. During the experiment, furrow covering plate was not mounted on the equipment.

2.6 Soil Disturbance Measurement

The machine was stopped while tine still engaging with soil and the actual depths (D) of soil cut were measured in each plot. A steel metric rule was laid on the original soil surface level across the trench. The distance measured between the ruler and the slot bottom represented the maximum furrow depth to mound height (after soil cut furrow depth (Df). maximum width of soil disturbance for two sweeps (W), maximum width of soil throw (using a sweep) (MWS), ridge to ridge distance (S), height of ridge above soil surface (H), and maximum furrow depth to mound height (F).

2.7 Draught Force Measurement

During the experiment, the equipment was operated with a 350 liters tank full of liquid manure since it was designed to apply it. It is also reasonable to assume that the weight of the liquid manure will add to the equipment draught force. Therefore, the issues of running the equipment dry as in the case of McLaughlin and Campbell. (2004) was not applied. The load cell was installed between the tractor draw-bar hitch and the implement hitch of the injection equipment. Alignment of stakes at either end of the plot provided a visual cue to the operator to start and stop the data logger.

As the injection equipment made the pass on each plot, draught force data were recorded using the ProDAS data acquisition system (Data-logger). The mean value of all readings from each plot was used for data analysis. Three runs were performed with the injection tools lifted above the ground in the field, and the average value was used as the rolling resistance of the wheels of the injector equipment. This value was subtracted when calculating the draught force for each plot.

2.8 Data Analysis

Analysis of variance (ANOVA) was performed to examine the main effects of experimental factors and their interaction. Differences between treatments were obtained using Duncan's Multiple Range tests. Statistical inferences were made at the 0.05 level of significance using SPSS 17.0.

3. RESULTS AND DISCUSSION

The picture of the liquid livestock manure injector equipment that was designed, fabricated and assembled in the Agricultural Engineering Work-shop of The Federal University of Technology, Akure, Ondo State, Nigeria is as shown in Figure 6.

Figure 6: Liquid manure injector equipment

3.1 Effect of Depth on Soil Surface Disturbance

Injector equipment operating depth was controlled by wheels on the tool bar which provided a means of reaching the same design depth (50, 100 and 150 mm). The tool caused soil crumbling and pushed the soil sideways as it moved through the soil at 50 and 100 mm depth. When cutting the soil at 150 mm depth, it was separated as two continuous soil beams (Koolen and Kuipers, 1983) along the center of the tool path. The beams were lifted up more than being moved sideways by the tool. The soil failure pattern at the two shallow depths (50 and 100 mm) can be described as "multiple failure planes", while that at 100 mm depths as "unbroken soil beams" as reported by Koolen and Kuipers (1983) for soil cutting with a blade. The general trend of soil surface disturbance produced as a result of depth at which the tool engage the soil was that the greater depth of soil cut resulted in higher values of W, MWS, Hi, and Fi (Table 2), reflecting a larger soil surface area being disturbed by the tool. The effect of depth on soil surface disturbance was statistically significant at all depth for W, MWS, Df and Fi (Table 2). The effect of depth on soil surface disturbance was not statistically significant (Chen and Heppner, 2002) on Si between the depth of 50 and 100 mm but found to be significant between 100 and 150 mm depth. Also, Hi was not statistically significant within 100 and 150 mm depth (Table 2). Greater depth caused a larger Hi, representing a rougher soil surface and greater spread (Si) of the mounds implies that soil moves more away from the center of tool path. Rahman and Chen (2001) reported similar trends for other sweep-type injection tools. Figure 7 illustrates the soil surface profile obtained during the experiment.

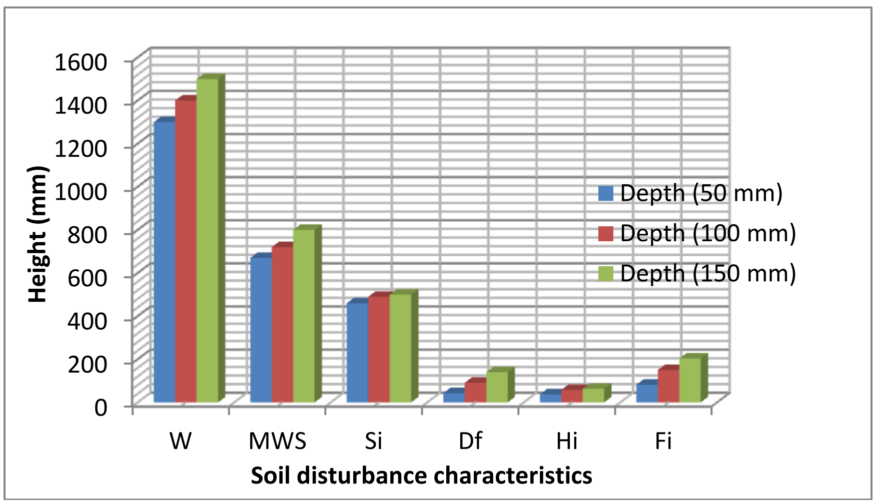

Figure 7: Soil surface disturbance characteristic/depth at 3.49 km/h speed using CS_{wc}

Table 2: Characteristics of soil surface profile produced as a result of depth of soil cut

Treatments	Soil surface disturbance					
Depth (mm)	W	MWS	S	Df	H	F
50	1311.00a	680.00c	466.00a	44.00a	39.50a	83.50a
100	1435.00b	722.00b	500.00a	93.00b	60.00b	151.50b
150	1517.50c	810.50a	513.50b	141.50c	67.50b	209.00c

*****Means in the same column that are followed by different letters are significantly different ($P<0.05$) according to Duncan multiple's range test.

3.2 Effect of Depth on Draught Force

The average draught at 50, 100 and 150 mm depth were 2.90, 7.37 and 9.87 kN/ tool respectively using a forward speed of 3.49 km/h. These values are lower or comparable with those reported elsewhere. Lague (1991) reported that injection of manure into a firm clay soil at depths not exceeding 203 mm required between 5.03 kN/ tool and 6.19 kN/tool of draught force for a winged tool operating at a speed of 0.89 m/s. The range of draught forces of a winged tool reported by McKyes *et al*. (1977) was up to 6 kN/ tool at a 150-mm injection depth and the travel speeds up to 7.92 km/h in soil textures from sand to clay loam. Other studies report injector draught forces ranging from about 0.25 kN at 15 mm depth (McLaughlin and Campbell, 2004), to 1.4 kN for a coulter followed by a 220-mm wide sweep at 150-mm depth (Rahman *et al*. 2001), and 1.6 kN for a 570-mm wide sweep at 150-mm depth (Rahman and Chen 2001). The former was at a depth of only 15 mm while the latter two studies were in loamy sand in an indoor soil bin which might explain why the draught was lower than those reported for field studies with a clay soil. The result in figure 8 indicates that draught force is a function of depth and the square of depth. The square component comes from the contribution of the adhesion and soil acceleration forces over the tool. This relationship implies that the depth increases, the slope of the line (Figure 8) describing the relationship increases (Al-Janobi and Zein Eldin, 1997).

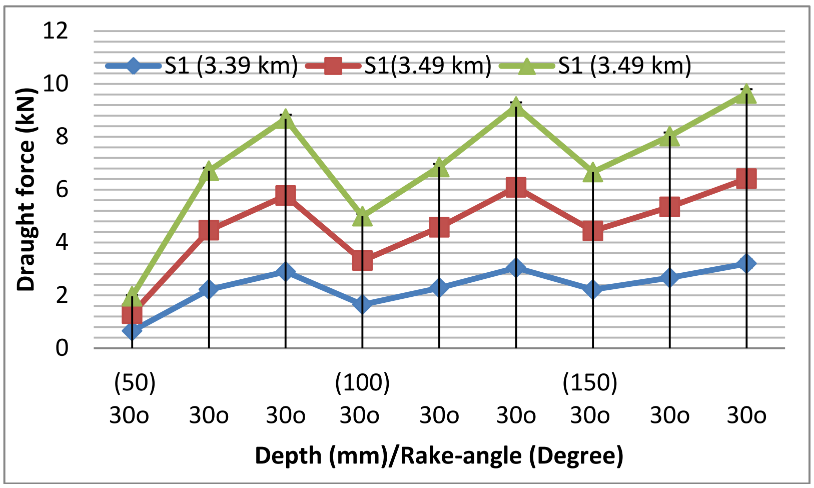

Figure 8: The relationship between depth of soil cut and draught force

It therefore implies that the draught force per unit depth of soil cut increases with depth of soil cut (50, 100 and 150 mm) which indicated increase in power requirement for the prime mover. The draught force was statistically significant with increase in injection depth (Data not shown). This implies that injection depth is important in the determination of the power required by the injection equipment.

4. CONCLUSIONS

Liquid manure injector equipment was designed. The tool used in the equipment is easy to be mounted to any frame of tillage implement via c-shank and the depth adjusting device. It can be used for various soil and field conditions. Measurements of field disturbance and draught force were undertaken. Soil disturbance increased significantly with injection depth. The convex sweep has a flat shaped coulter in its front. The draught forces of the equipment are in the range of 2.68 – 9.87 kN/tool. Its draught force significantly increased with injection depths. On the basis of this research and within the limits of the testing variables, it was concluded that the forces acting on convex sweeps under actual tillage conditions are a function of the depth Therefore injection depth should be as shallow as possible in order to reduce power requirement yet deep enough to cover manure during injection. Based on power requirement, it is suggested that the injection depth should be selected less than 100 mm to reduce draught force requirement for the tested sweep.

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The authors gratefully acknowledge the financial assistance received from the World Bank through Science and Technology Post-Basic (STEP-B) of The Federal University of Technology, Akure, Ondo State, Nigeria in providing Nasal Ranger (Olifactometer) used in testing for odour emanated during field experiment. The authors also acknowledge the assistance offered by Mr. A. Adesina and Mr. B.E. Adegoke during the fabrication and assembly of the liquid manure injector machine.

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DETERMINATION OF WEAR ELEMENTS IN TRACTOR LUBRICATING OIL: COMPARISON BETWEEN AAS AND ICP-OES TECHNIQUES

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ABSTRACT

Determination of appropriate tractor engine lubricating oil change based on hours of operation or distance travelled lead to wastage of resources/ premature failure of machine components as some tractor operators unnecessarily use to over throttle engines during clutching in order to impress others. Oil analysis has been used to assess the overall stress being encountered during operations with varied torque/speed characteristics. This study was conducted to determine the presence and level of wear elements in engine lubricating oil of tractors using inductively coupled plasma and optical emission spectroscopy (ICP&OES) technique and comparing the results with earlier results obtained using atomic absorption spectroscopy (AAS) on the same samples. The comparison between AAS and ICP&OES was based on analysis of variance (ANOVA) and Duncans Multiple range test (DMRT). The two statistical methods show significant differences between the tractors in five elements (Zinc, Chromium, Nickel, Copper and Iron) using AAS versus seven (Chromium, Nickel, Lead, Copper, Iron, Cobalt and Manganese) with ICP&OES. The ICP&OES results precisely showed that tractor number six was the most mishandled by its operator. The study recommends regular monitoring of wear elements using ICP&OES technique over AAS.

KEYWORDS: Metal wear, lubrication oil, lubricant additive, wear monitoring.

1. INTRODUCTION

The tractor engine develops power by converting the chemical energy contained in fuels into mechanical and other forms of energy. Tractor operators' behaviors play a vital role in ensuring proper maintenance and availability of machines. A consistent quality assurance program is necessary to avoid performance issues in vehicle engines and inorganic constituents in the final product can promote residue build up in the engine, cause corrosion and ultimately affect engine life (Iqbal et al., 2010). Since metallic elements in fuel are undesirable even at lower concentrations, their determination in fuel is necessary to evaluate fuel quality, to see their effect on auto engines, and to control environmental pollution.

The purpose of oil test is to measure the concentration of wear metals (machine health), oil additives (oil health) and contaminants. These parameters are determined by the concentrations of various elements from the periodic table. ICP&OES measures these elements and they fall into the various categories such as copper which is wear metal, calcium which forms part of an oil additive or silicon which is a constituent of dirt (contaminant). Note that quite a few elements can belong to more than one category as shown in Table 1.

Table 1: Categorization of elements found in engine lubrication oil analysis

Element	Category		
	Wear	Contaminant	additive
Aluminum, Al	X	X	
Boron, B		X	X
Calcium, Ca		X	X
Copper, Cu	X	X	
Chromium, Cr	X		
Iron, Fe	X	X	
Lead, Pb	X		
Magnesium, Mg		X	X
Molybdenum, Mo	X		X
Phosphorous, P		X	X
Potassium, K		X	
Silicon, Si		X	X
Sodium, Na		X	X
Tin, Sn	X		
Zinc, Zn	X		X

Source: Johnson and Spurlock, 2009

By far the biggest category is the wear metals, of which iron is the most common wearing element (Evans, 2012). Oil analysis by X-ray fluorescence spectrometry (XRF) is very fast but limited in concentration range. ICP&OES has the concentration range necessary to determine additives, wear metals and contaminates in oils (Hilligoss and Wee, 1999). A study (Hilligoss and Wee, 1999) compares the performance of ICP&OES with XRF for 5 elements (calcium, magnesium, phosphorus, sulfur and zinc) commonly determined by XRF and found that the ICP&OES results show good agreement with XRF on the high concentration elements in the oils tested.

Just as humans undergo a battery of tests to understand the state of their health, conducting oil analysis provides similar insight into the health of a machine. Subtle changes in the chemical health of the oil/lubricant and in the cleanliness of the machine's sump as well as increases in the types and concentrations of wear metals, point to solvable problems. When the analysis is conducted systematically, the relative state of the machine health can be observed. Armed with information about the machine's changing health, the machine owner can adjust operating and maintenance practices to protect the machine's long term usefulness.

As is the case with human health monitoring, there are hundreds of tests that could be recommended to deliver a particular piece of the puzzle representing overall health. A key to health management, whether human or machine, is understanding which test to use and what to look for within that test.

There are 702 discrete petroleum and lubricant tests listed in the 2009 ASTM (American society of testing and materials) catalog (Johnson and Spurlock, 2009). Some of these tests tell a broad characteristic about the test specimen, and some tell a narrow concern. In addition to the ASTM methods, there are several other standardization organizations providing test methods, including Din (German Institute for standardization), ISO (International Standards Organization), SAE (Society for Automotive Engineers), API (American Petroleum Institute and IP (Institute of Petroleum test methods). Each has standards and test methods useful for measurement of variety of lubricant properties.

Any sample that can be dissolved or digested into an aqueous solution can be analysed with ICP&OES technique (www.els.co.nz). The ICP&OES has many benefits for the analysis of oils. The samples are simply diluted, in kerosene or other suitable solvent, and aspirated directly into the ICP&OES. The ICP&OES analysis is very fast, and gives accurate, precise results (Johnson, 2010).

The analytical principle used in the ICP&OES system is optical emission spectroscopy. A liquid sample is nebulized and then vapourized within the argon plasma in same way as the Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS). Unlike the Mass Spectroscopy however, the atoms and ions contained in the plasma vapour are excited into a state of radiated light photon emission. The radiation emitted is passed to the spectrometer optics, where it is dispersed into its spectral components. From the specific wavelengths emitted by each element, the most suitable line for the application is measured by means of a charge couple device (CDD). This instrument is capable of determining the concentrations of 40 to 70 elements simultaneously to very low detection limits (ppm to ppb).

ICP&OES provides the highest and lowest levels for 29 elements which include Al, As, B, Bi, Ca, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, P, Pb, Se, Sr, Ti, Tl, V, and Zn (www.wearcheck.co.za). The ICP&OES technology allows for very low-level determination and uncertainty of many elements. Other strengths of ICP&OES technique include (ELS, 2011):

i) High sensitivity
ii) Large dynamic range from detection limit to the maximum working concentration (order of 8 compared to 2 in graphite furnace atomic absorption)
iii) Short elemental concentration determination time
iv) The ability to measure individual isotopes

The ICP&OES is most moderate in terms of cost versus performance consideration when compared to flame atomic absorption spectroscopy (AAS) and ICP&OES-MS (Sarojam, 2010) and precision of its results confirmed by ICP&OES-MS (UWLAB, 2012).

In order to determine all possible elements present or being produced in engine combustion and lubricating processes, the use of highly sensitive analytical technique is required (Iqbal et al., 2010). Hence the objective of this study was to analyse the samples earlier analysed with AAS (Ahmad et al., 2012) using ICP&OES technique and compare the two results for eight elements (Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn).

2. MATERIALS AND METHODS

2.1 Experimental Procedure

Ten tractors from Refuse Management and Sanitation Board (REMASAB) concerned with refuse collection and disposal in Kano Metropolitan area of Kano State of Nigeria were used for elemental engine oil analysis. The lubricating oil from each tractor was sampled at an interval of one week from the date of oil change until it is drained out during routine oil change. On the day of sampling, the tractor engine was warmed up in the morning before starting the day’s operation for about five minutes to ensure proper mixing of the engine oil throughout the various engine components. After warming, the engine is stopped and the area around the bottom plate nut thoroughly cleaned and gently loosened to collect about ten ml of the engine oil into plastic containers. This small quantity may not cause shortening of the oil level below the lower mark to warrant topping up. In this kind of experiment, topping up use to dilute the oil concentration and lead to wrong inference after analysis. The importance of recording oil top-ups needs to be emphasised to the operators.

This was repeated within a period of two months for all the tractors. Some tractors had two, three and even four samples taken between two consecutive oil changes**.** A replication is the interval between two consecutive oil changes. A total of sixty one samples were collected for the ten tractors within the two oil change periods. The samples were labelled in three number codes (1:1:1, 7:2:3). The first number indicating tractor, second number indicating oil change and third number indicating sample number within the oil change interval.

The above samples were earlier analysed with AAS at Soil Science laboratory of Faculty of Agriculture, Bayero University, Kano. The AAS machine (Buck 210 VGP) was warmed up for 30 minutes and the hollow cathode lamp of respective metal of interest at a time was set with wavelength of maximum absorption as directed in the manufacturer's instruction guide. The blank, calibration standards, and digested samples were aspirated separately and their absorbencies recorded. Calibration curves of the standards were plotted and regression equations obtained. The concentrations of the analytes/samples in mg/dm^3 were computed by either extrapolation from calibration curves or obtained as dependent variables in the calibration equations.

Similar analysis was done on the same samples using ICP&OES technique with a machine (PerkinElmer Optima 7300 DV) at Chemical and Environmental Engineering Department, Universiti Putra Malaysia. The results obtained were analysed using SAS procedures and ANOVA table and DMRT rankings generated for comparison with AAS results.

2.2 Specification and Operating Parameters of ICP&OES Machine

The operating conditions for the equipment used in this study are given in Table 2.

Table 2. Optima 7300 DV Operating Conditions

Plasma gas flow	15 L/min
Auxillary gas flow	0.2 L/min
Nebulizer gas flow	0.6 L/min
RF power	1450 watts
Plasma view	Axial or Radial
Read delay	90 sec
Read parameters (s)	2.0 min, 5.0 max
Peristaltic pump flow rate	1.8 mL/min
Spray chamber	Cyclonic
Nebulizer	Low flow GemCone
Injector	Alumina, 2.0 mm i.d
Sample tubing	Standard 0.76 mm i.d
Drain tubing	Standard 1.14 mm i.d.
Quartz torch	Single slot
Sample capillary	Teflon® 1 mm i.d
Replicates	3
Resolution	Normal

2.3 Measurement by ICP&OES

2.3.1 *Instrumentation*

The measurements were performed using the PerkinElmer® Optima™ 7300 DVICP&OES- OES instrument (PerkinElmer, Inc. Shelton, CT, USA) equipped with WinLab32™ forICP&OES Version 4.0 software for simultaneous measurement of all analyte wavelengths of interest. The Optima 7300 DV has been optimized to provide high speed analysis. By combining an SCD detector and an echelle optical system, the Optima 7300 DV can measure all elements simultaneously. Its wavelength flexibility allows the end users to easily add new elements as their program needs change. The measurement procedure as outlined by U. S. EPA 200.7 requirements for instruments is given in Table 3.

Table 3. U.S. EPA Method 200.7 Requirements

Check Code	Check Name	Purpose	Frequency of Check	Specified Limits
CCB	Continuing Calibration blank Checks	Check calibration validity	After calibration, after every 10 analyses and at the end of analyses	<IDL
LRB	Laboratory Reagent Blank	Checks the laboratory reagents and apparatus for possible contamination	1 per batch	<2.2 MDL
LFB	Laboratory Fortified Blank	Checks the analyte recovery of spiked blank	1 per batch	85-115% recovery
LFM	Laboratory Fortified Matrix	Checks the analyte recovery in sample matrix	10% of total samples	85-115% recovery
QCS	Quality Control Standard	Checks the accuracy of the calibration by analyzing a second source standard	Post calibration	95-105% recovery
IPC	Instrument Performance Check	Checks the accuracy and drift by analyzing a standard as a sample.	Every 10 analyses and at the end of analyses	95-105% immediately after calibration, 90-110% thereafter
SIC	Spectral Interference Check	Checks the presence of spectral interferences	Periodically	No criteria specified
CRM	Certified Reference Material	Checks the accuracy of the developed method	Immediately after calibration	Should be analysed whenever available

Source: Sarojam (2010)

The PerkinElmer S10 Autosampler was used for high throughput and automated analysis. The autosampler automates standard and sample introduction for instrument calibration and sample analysis.

2.3.2 *Initial Performance Demonstration*

An Initial Performance Solution (IPC) was run (for all analytes at the levels of their respective standards used) immediately following calibration and the recoveries were found to be within the limits of 89.5-105% specified by EPA (Table 4) with the exception of Copper which has a recovery of -64.29. This is an important parameter used to evaluate the performance of the instrument system with respect to a defined set of method criteria. Precision (%RSD) was also monitored to ensure the short term stability of emission signals.

Table 4: Analysis of Instrument performance Check Solutions.

Analyte	IPC Avg. Conc. (mg/L)	% Recovery	% RSD	Monitored wavelength (nm)
Co	0.004	100.01	0.94583333	267.7160
Cr	0.018	86.08	2.06683333	228.616
Cu	-1.635	-64.29	0.71983333	327.393
Fe	0.344	89.69	0.73183333	238.204
Mn	0.466	97.39	3.45166667	257.610
Ni	0.486	97.99	1.936	231.604
Pb	0.042	97.92	44.1398333	220.353
Zn	0.032	99.00	0.80783333	206.200

2.3.3 *Internal Standards*

All samples were spiked with 1.5 mg/L of yttrium and 2.5 mg/L of tellurium. The spiking solution was made from 1000 mg/L single element stock solutions.

2.3.4 *Calibration*

The calibration blank and standards were prepared in 1% nitric acid. Calibration was performed using a calibration blank and a single standard containing all elements at 1 mg/L. The calibration standard was prepared from a combination of single element and multi-element stock solutions, all containing elements at 1000 mg/L.

2.4 Data Processing after ICP&OES Measurement

2.4.1 *Data Handling*

All data obtained from the Optima 7300 DV was collected using the WinLab32 software loaded on a desktop PC attached to the instrument. Analytical results were computed using the WinLab32 software and exported into Microsoft Excel. The text and data tables used in this report were created using Microsoft Excel and Word.

2.4.2 *Data analysis*

Data were analysed using computer programmes (SAS 2009 version 9.2) to determine the relation between various measures made during the study.

3. RESULTS AND DISCUSSION

The summarized comparison between AAS and ICP&OES results on elemental basis is shown in Table 5 for the eight common elements found present in the ten tractors' engine lubricating oil.

Table 5: Comparison of results between AAS and ICP&OES

Element	AAS	ICP	TRACTOR(S) NO(S) WITH HIGHEST CONC. For ICP&OES RESULT
Zinc	S	NS	T6
Chromium	S	S	T6
Nickel	S	S	T6
Lead	NS	S	T6
Copper	S	S	T6
Iron	S	S	T6
Cobalt	NS	S	T6
Manganese	NS	S	T6

Key: S- Significant difference between the tractors for the element.
NS- Not significant difference between the tractors for the element

It can be seen from Table 5 that only Zinc showed significant difference under AAS but not significant with ICP&OES even though it has the second highest recovery rate of 99% (Table 4). Zinc is found in chemicals used to make antiwear, anti-oxidant, detergent and corrosion inhibitor additives. Zinc is alloyed with copper to make brass so it can be evident as a wear metal (Evans, 2012). Thus, not a major constituent of principal wearing components of the engine such as liners, pistons, rings (Figure 1) and bearings.

All other elements maintained significance between AAS and ICP&OES or an improvement in analysis sensitivity of ICP&OES over AAS. Lead, Cobalt and Manganese were not significant under AAS but showed significance under ICP&OES. Thus, the ICP&OES technique has added two more elements as criteria in augmenting the hypothesis that variation exists between tractors due to attitudinal behaviors of tractor operators.

This sensitivity has also produced the most operator attitudinal behavioral contribution to the tractors differences in elements concentrations. In the AAS results (Ahmad et al., 2012), one cannot single out the worst operator as tractor number one (T1) recorded highest element concentration in Zn, T8 (Chromium), T9 (Ni and Pb), T6 (Cu and Co) and T4 (Fe and Mn). From Table 4, tractor number 6 recorded the highest concentrations in all eight elements! Thus maintenance management strategies should include aspects of personnel behavior and attitudes in discharging duties as machinery operators are also responsible for following applicable laws, keeping logs of their activities, and making sure that their equipment is in good working condition (BLS, 2012). This has been buttressed in computerised maintenance management system (CMMS) (Tuomo Honkanen, 2004) where it was stated that the resulting maintenance systems seem to be a heterogeneous combination of methods and systems in which the integrating factor of the information and business processes is the maintenance personnel. The information in the maintenance systems goes through these human minds forming an organisational information system and creating a high reliance on the expertise of the maintenance staff.

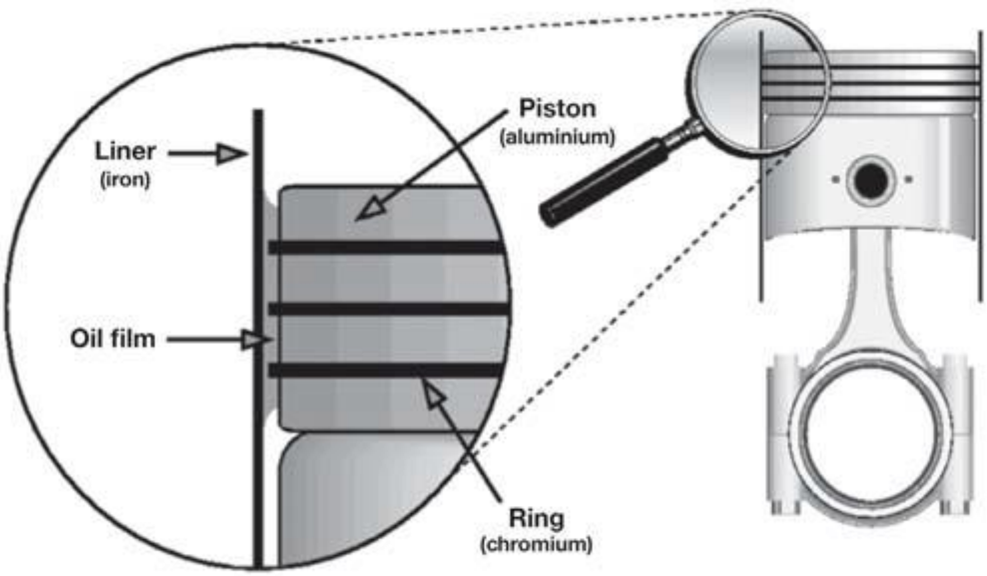

Figure 1: Piston, ring and liner wear (Source: www.wearcheck.co.za)

A study (Adekoya and Otono, 1990) has attributed the relatively higher repair costs of tractors to misuse by operators, among other factors. Also, the DMRT for ICP&OES equipment produced only two categories (A and B) (Table 6) while the AAS equipment result (Ahmad et al., 2012) had four categories (A, AB, BC and C) making clear distinction not easy.

Hours of operation by each tractor may contribute to these differences. However, if the Duncan Multiple Range Test (DMRT) for Chromium (Table 6) is looked at, tractor numbers 6, 3, 5 and 7 are having same number of samples (with seven each) which indicates been used for similar periods of time during the experiments and tractor number 1 with only four samples having the least but not significantly different from tractors number 3, 5 and 7.

Table 6: DMRT of means of ten tractors for Chromium element

Tractor	Chromium element	
No.	Mean	Ranking[a]
1	0.02825	B
2	0.03180	B
3	0.05100	B
4	0.04333	B
5	0.03743	B
6	0.09029	A
7	0.02900	B
8	0.03083	B
9	0.03533	B
10	0.04000	B

[a]Means with similar letters are not significantly different at 5% level.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This study conducted an analysis of Steyr tractor engine lubricating oil using ICP&OES technique on samples previously analysed using AAS and compared the results for eight common elements. From the study, the following conclusions can be derived:

i) That ICP&OES technique has shown its higher sensitivity and precision over the AAS.
ii) Out of eight elements analysed from the oil samples, seven showed significant differences between the tractors against five for AAS.
iii) Only Zinc element showed variance in the trend by being not significant with ICP&OES and significant under AAS
iv) ICP has clearly shown that tractor number 6 was highly mishandled by having highest concentrations in all the eight elements analysed.
v) Operator attitude may be playing significant contribution in the deterioration of machines.

4.2 Recommendations

The work presented in this study has clearly shown that full machinery/tractor management involves determining factors/elements leading to machine health, oil health, level of contamination/environmental pollution and operator behavior in discharging their duties. It is therefore recommended that:

i) Comprehensive analysis of likely elements that would lead to complete diagnosis of machinery health is conducted on regular basis.
ii) Tractor maintenance management should be extended to operator attitudinal/welfare assessment as all investment in technical infrastructure could be wasted by a psychologically depressed or irresponsible staff.

Acknowledgements

This work was conducted with the cooperation of REMASAB, Kano-Nigeria by providing its tractors as the experimental materials and financial support from UPM grant no. 9199651 in analyzing the samples using ICP&OES equipment. Authors are also grateful to Muhammad Ngabra and Joha M. B. Abdulwahab, postgraduate student and technical staff respectively in the Department of Chemical and Environmental Engineering, UPM for the tremendous assistance in running the analysis.

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DEVELOPMENT OF A FRUIT WASHING MACHINE

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ABSTRACT

A fruit washing machine was designed and fabricated taking into consideration the techno-economic status of the micro, small and medium scale fruit farmers who are the intended users of the machine. Considerations also included high washing capacity and efficiency and the desire to make the construction materials of stainless steel to ensure the quality of the washed product. Other consideration was a strong main frame as support to ensure structural stability of the machine. The machine was designed for ergonomic value, safety and ease of operation and maintenance by incorporating guards around the moving parts and components. Rollers were also incorporated in the design to ensure easy movement of the machine. The machine was tested using 50 samples of orange for the washing operation. During the testing, the belt conveying mechanism was such that the fruits were conveyed under high jet spray pressure in order to get rid of the attached foreign materials. The test result showed that the washing capacity was 0.0163 tonnes/h or 16.3 kg/h and washing efficiency was 62.5 %. Powered by a 1 hp single phase gear electric motor, the machine has a production cost of USD 300 while all the construction materials were available locally.

KEYWORDS: Washing, machine, fruits, oranges, washing capacity.

1. INTRODUCTION

Fruits are highly perishable FAO (1995), reported that over 23 % of most perishable fruits are lost during their journey through the agricultural food chain due to spoilage, physiological decay, water loss and mechanical damage. These occur during harvesting, transportation, processing and packaging. These losses have been estimated to be more than 50% in the tropics and sub tropics. Washing fresh produce (also known as surface treatment) can reduce the overall potential for microbial food safety hazards. This is an important step since most microbial contamination is on the surface of fruits. If pathogens are not removed, inactivated, or otherwise controlled, they can spread to surrounding produce, potentially contaminating a greater proportion of the produce. (FDA, 1998).

Fruits are prewashed to get rid of immediate surface dirt and pesticide residues before any leaves and stem still attached are removed. The removal of mites and other surface arthropods may be enhanced by the use of a mechanical surface cleaning system, such as high-pressure water sprays and/or rotating brushes (Walker, 1996). Hussain *et al* (1991) recommended that fruits must be cleaned after they are harvested to improve product appearance and edibility to remove residues of field-applied chemicals and to remove harmful microorganisms that would shorten the life of the product. According to Walker (1996), pressurized sprays ranging from 2240 to 5516 kPa were used to remove surface arthropods.

In recent research, Bai *et al* (2006) mentioned that use of high pressurized sprays causes damages to the fruit surface. Pressurized sprays at 560 kPa were more effective than those at 210 kPa in pest removal, but also damaged the fruit surface but sprays at 420 kPa were as effective and did not cause injury. Furthermore, increasing the pressure to 840 kPa did not significantly increase efficiency but reduced the fruits quality as it caused damages to the fruits.

Papadopoulou (1998) was of the opinion that the clarity of the water which was affected by the concentration of suspended particles was a measure of its quality. High pressures in the range 3000-8000 bars were suggested by Palou (2000) to be applied on some fruits in order to inactivate microorganisms and enzymes without the degradation in flavour and nutrients associated with traditional thermal processing. Unfortunately there are some problems associated with the use of this treatment on fresh-cut products, as it affects the integrity of porous ones as a consequence of the compression and expansion during pressurization and decompression of the air confined in the fruit matrix.

Rotary fruit washing machine features a simple design and sturdy construction. Fruits are fed into the hopper continuously and get washed by slow tumbling action of the rotary drum. After washing, the fruits come out through the other end (FAO, 1995). This machine is capable of washing fruits, vegetables and most suitable for washing fruits like mango, pears, apples, potatoes, carrots and other root vegetables but it cannot be used to clean fragile fruits like tomatoes.

The objectives of this study were to develop a fruit washing machine that can enhance the fruit quality and to determine the machine efficiency.

2. MATERIALS AND METHODS

2.1 Main Components of the Machine

As shown in Figure 1, the machine main frame is made of 40 mm x 40 mm angle iron with a thickness of 4 mm. it is the chaises of the machine on which other parts are built. Fruits are fed into the washing camber through the hopper. The hopper is in the form of a trapezium with upper dimension of 600 mm x 300 mm, base dimension of 500 mm x 300 mm and height of 150 mm, the hopper is twit at an angle of 5^0. The conveyor belt is made of balata material since they are water proof and can be easily made endless. This will convey the fruits to be washed to the washing chamber at a regulated speed. The washing chamber accommodates the sprinklers and the conveying belt.

The drain net allows the draining of the fruits of wash water. The water basin contains the drained water while the filter: filters the water being collected after washing in order to recycle it for the next washing operation. A centrifugal pump of known specification was be used for water pumping while the sprinklers sprayed water on the fruits at a regulated pressure. A weighing balance was employed to measure the weight of the fruits before and after washing while a stopwatch was used to record the time spent in washing operation. A Vernier caliper was used to measure the different dimensions (major, minor and lateral diameters) of the fruit to be washed.

2.2 Working Principles of the Machine

The machine was designed to operate in batches of about 50 oranges per batch which are fed into the washing chamber through the fruit hopper. The sprinklers spray water on the fruits while travelling through the conveyor belt at a controlled speed. This is to ensure that the fruits are are thoroughly cleaned to the required standard. The machine was powered by a 1-hp single phase geared electric motor of 200 rpm with a power transmission efficiency of 90 %.

The washing systems is aided by the sprinklers which spray water at high pressure spray across and along the conveying belt over the fruits to be washed. In operation, the fruits lie still on the surface of belt conveyor without relative motion between the product and the conveyor belt. In this way, there will generally be no damage to the fruits until the fruits arrive to the dryer sheet in which the washed fruits are discharged into a collector. The debris and unwanted particles are removed through the drain net or dissolved in the washing water. The water discharged into the water chamber after washing is recycled by pumping and filtering it into the washing chamber in order to maximize water use.

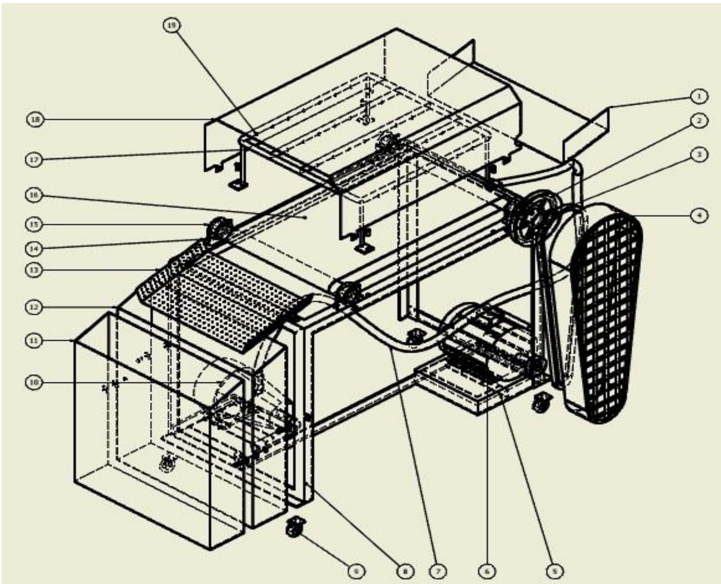

Figure 1: Exploded View of the Fruit Washing Machine: 1-Feeding Tray; 2-Pulley; 3-Belt; 4 Belt Guard; 5-Motor Seat; 6-Electric Motor; 7-Hose; 8-Frame; 9-Roller; 10-Water Pump; 11-Fruit Collector; 12-Water Tank; 13-Drain Net; 14-Shaft; 15-Bearing; 16-Conveyor Belt; 17- Pipes; 18-Washing Chamber; 19-Nozzle or Jet

2.3 Design of the Machine Components

2.3.1 Design of the Feeding Tray

The tray inclination which is considered an important design factor in feeding tray (opened hopper) design was determined using the expression given by Ashaolu, (1989). This is expressed as:

$$a = \tan^{-1} \mu \qquad \textbf{(1)}$$

where: a is angle of inclination and μ is coefficient of friction between orange and galvanized steel as proposed by Singh, (2004). Given that $\mu = 0.36$, hence, $a = 19.7^0$.

2.3.2 Design of Shaft

The shaft is the main component of the machine and is acted upon by weights of material being processed, pulley, conveyor belt and the fruits. In operation, the shaft transmits the power being generated by the gear reduction motor to the conveyor belt. Therefore, in order to safeguard against bending and torsional stresses, the diameter of the shaft was determined from the equation given by Shigley and Mitchell (2001) as:

$$d^3 = \frac{16\,T}{0.27\pi\delta_0} \qquad \textbf{(2)}$$

where: d is diameter of the shaft in m, T is torque transmitted by the shaft in Nm, δ_0 is yield stress for mild steel in N/m^2 and π is a constant. Given that T = 60 Nm and δ_0 = 200 N/mm^2, and π = 3.142, hence, d = 17.82 mm. Therefore, a mild steel rod of diameter 25 mm and length 680 mm was used for the shaft.

2.3.3 Design of Drive Mechanism

In determining the diameter of the driven pulley, the expression given by (Gupta, 2006) was used in conjunction with relevant information in standard tables.

$$\mathbf{N_1D_1 = N_2D_2} \qquad \textbf{(3)}$$

where N_1 and N_2 are the speed of the driven pulley and speed of the driving pulley respectively in rpm and D_1 and D_2 are the diameter of the driven pulley and diameter of the driving pulley respectively in mm.

According to Kempe's Engineers Yearbook and Gates Rubbert Company Manual, the minimum pitch diameter for A – type V-belting transmitting power at a speed of 1500 rpm is 2.2 in (or 55.9 mm). For this reason, a driving pulley diameter of 60 mm was chosen to be used. The calculated value of driven pulley using Equation (3) is 4500 mm (4.5 m). However, due to this large calculated driven pulley, a gear reduction box will be attached to the conveyor shaft in order to give the required speed of the conveyor 20 rpm.

Angle of Wrap

The angle of wrap was determined using the expression given by (Gupta, 2006) which was stated in the expression below as:

$$\theta_S = \pi - 2\mathrm{Sin}^{-1}\left(\frac{D-d}{3C}\right) \qquad \textbf{(4)}$$

where: θ_S is angle of wrap in radian, D is diameter of bigger pulley, d is diameter of smaller pulley and C is Centre to centre distance between both pulleys. Substituting the values of D, d and C into Equation (4) gives the angle of wrap as 2.92 radians.

2.3.4 Design of the Conveyor Belt

The conveyor belt will reduce the fruit's velocity, minimize the chance for damage. Fruit-to-fruit contact is preferred over fruit-to-metal therefore the conveyor belt is made of balata belt. The dumping sequence and fruit flow control are critical for uniform throughput and an efficient operation. The groove angle was determined using the expression given by Gupta (2006) shown in Equation (5) below as:

$$\beta = \sin^{-1}\left[\frac{(R-r)}{C}\right] \qquad \textbf{(5)}$$

where: β is groove angle, R is radius of driven pulley, r is radius of driving pulley and C is distance between the centres of the two pulleys. Given that R = 12.5 mm, r = 12.5 mm and C =

Angle of Contact:

Flat belt drives consist of a strong elastic cone surrounded by an elastomer. Drives of this type have a lot of advantages over gear drives or V-Belt drives. According to Shigley and Mitchell (2001), the contact angle is found to be

$$\theta_d = \pi - 2\sin^{-1}\left(\frac{D-d}{2C}\right) \qquad \textbf{(6)}$$

Since D = d = 12.5 mm, hence, $Q_d = \pi$ radians or 180^0.

Belt Design

The length of the belt was be determined using the equation below (Gupta, 2006):

$$L= \pi (r_1 + r_2) + 2C + \frac{(r_1+r_2)^2}{C} \quad \textbf{(7)}$$

where: L is total length of the belt in mm, r_1 and r_2 are radii of the driven pulley and driving pulley respectively in mm, C is distance between the centres of the two pulleys in mm. Substituting the values of the parameters in the equation gives L as 1478.539 mm.

2.3.5 Power Requirements and capacity of the conveyor

The power required to drive the conveyor was determined using equation (8)

$$P = (T_1\text{-}T_2)V \quad \textbf{(8)}$$

where: T_1 and T_2 are Tensions on the tight and slack sides of the belt respectively in N. With T_1 = 368.92 N and T_2 = 349.53 N; hence, P = 28.51 W.

The capacity of the conveyor was determined by the equation given by Miller *et al* (2010) as:

$$C= \frac{W \times S \times 6}{10 \times A} \quad \textbf{(9)}$$

where: C, W, S and A is the capacity (tonnes/hr.), width of conveyor in meters (m), linear speed (m/min) and area of the conveyor (m^2) respectively. Substituting W = 0.45 m, S = 0.13 m/min and A = 0.75 m^2; hence, C = 0.052 tonnes/hr.

2.4 Construction of the Machine

The machine components were fabricated based on the design specifications and were assembled together as shown by its isometric view in Figure 2. The materials of construction, their specifications and construction procedures are as shown in Table 1.

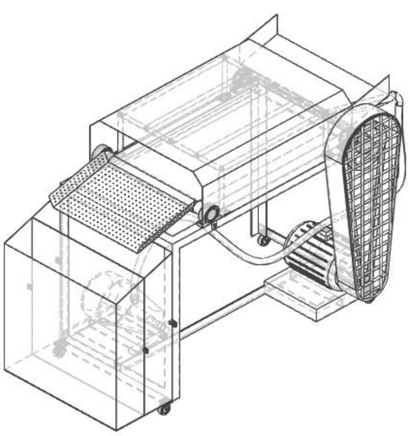

Figure 2: Isometric View of the Fruit Washing Machine

Table 1: Materials of Construction, their Specifications and Construction Procedures

S/N	Component Parts	Materials	Procedure	Quantity
1	Frame	Galvanized steel, 40 × 40 mm angle iron	600 mm × 4, 770 mm × 4 and 1060 mm × 3 was cut to form the breadth, height and length respectively of the frame. They were welded together to form a rigid frame.	3 standard length
2	Feeding Tray	1 mm galvanized steel.	The metal sheet was bent at 3 sides and screwed to the wall of the washing chamber inside	200 x 600 mm
3	Washing chamber	1.5 mm galvanized steel	The sheet was belt at 250 × 600 × 800 mm to form the height, breath and the length of the chamber.	$^{1}/_{2}$ of standard dimension
4	Pulley	Mild steel, single groove (Ø 300mm)	A pulley of 300 mm diameter was selected.	1
5	Engine Base	Galvanized steel, 40 ×40 mm angle iron	The angle iron was cut into 300mm in 5 places and welded together to form the base of the prime mover of the machine.	
6	Shaft	Mild steel	The mild steel was machined to Ø20 mm and 500 mm long. Two pairs of pillow bearing was used to support the shaft.	2

3. PERFORMANCE EVALUATAION OF THE MACHINE

3.1 The Machine

After fabrication of the component parts, the machine was assembled as shown in Figure 3. Testing was carried out in this project work to determine the suitable washing rate, washing efficiency and volume of water required to wash fruits. The gear electric motor was connected by belt mechanism to the pulley of the shaft of the conveyor belt and the water pump was connected to the sprinkler system. The machine was set into operation and, after the smooth running was maintained, fruits were introduced into the washing chamber through the feeding trays. The washing operation continued.

3.2 Washing Efficiency of the Machine

Washing efficiency of the machine was calculated by the expression given by Scott *et al* (1981) and shown in Equation (10) as:

$$WE = \frac{100\, SR}{SA}\ \% \qquad \textbf{(10)}$$

where: WE is washing efficiency in %, SR is mass of foreign materials removed by washing (mass of sample before washing - mass of sample after washing) in g/ kg and SA is mass of foreign material attached in g/kg. SA was estimated by hand washing 30 samples of fruits to full cleaning and weighing the foreign materials attached with one kg of fruits. From the test, SR and SA were found to be 100 and 160 respectively in g/kg resulting in WE being 62.5 %.

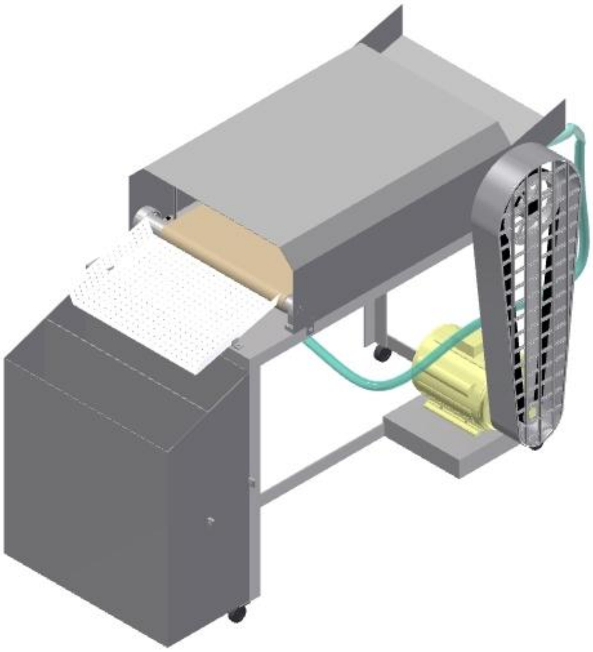

Figure 3: Pictorial View of the Fruit Washing Machine

3.3 Productivity of the Machine

The washing productivity of the machine was determined using the expression given by the equation given below as:

$$C = \frac{M \, X \, 60}{T_w} \qquad \textbf{(11)}$$

where: C is washing capacity of the machine in tonnes/h, M is mass of the washed fruit in tonnes and T_W is washing time in min. From the test, M and T_W were found to be 0.00244 tonnes and 9 min respectively resulting in C being 0.0163 tonnes/h or 16.3 kg/h.

4. CONCLUSION

The study examined the effect of pressurized sprays and conveyor belts on fruits. Washing as a unit operation in fruit processing is of high necessity and very important in any fruit process industries. From the test carried out on the machine the following salient points can be concluded that the water pressure was able to remove the foreign materials attached to fruits and also reduce the heat built up in the fruits by cooling. The steady slow speed of the geared electric motor enhances the thorough washing of the fruits. The use of water proof belt for the conveyor belt is strongly recommended as this will not absorb moisture as well as reducing the load on the conveyor belt.

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PERFORMANCE EVALUATION OF AN IMPROVED NCAM MULTI-FRUIT JUICE EXTRACTOR

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ABSTRACT

A modified fruit juice extractor based on the combination process of mastication through the screw auger and maceration through the tough belt arranged side by side on the shaft was developed. The extractor was tested using orange and pineapple and the quality of the juices produced showed that this multi-fruit extractor is suitable for small, medium and industrial juice processing business in both rural and urban communities.

KEYWORDS: Juice extract, pineapple, orange processing.

1. INTRODUCTION

Fruits juice is originally produced as a result of surplus production of fruits. Fruits are healthful, protective food; contain essential nutrients such as vitamins C, minerals, carotene and dietary fibre. (Dignan et al, 1994). Their availability depends on seasonal, climatic, geographical, environmental and social and economic factors. Fruits are difficult to keep for a considerable length of time, thus ripe fruits are utilized either as fresh or processed into juice and specialty products. Most fruits are perishable in their natural state after harvest; deterioration sets in almost immediately due to metabolic activities which continue even after harvest. (Oyeleke and Olaniyan, 2007). A study carried out on fruits indicated that the losses were up 30% during the rainy season (Tunde-Akintunde and Akintunde, 1996). It is therefore necessary to ensure effective storage and prevent unnecessary losses and wastages by processing fruit into products which will retain the important nutritional value.

Fruit juice extraction involves the process of crushing, squeezing and pressing of whole fruit to obtain the juice and reduce the bulkiness of whole fruit to liquid and pulp. Fruit extraction has been known for quite a long time ever before machines were invented. Extraction started with use of hand that was slow and tedious, the use of machine came into being as the demand for juice consumption increased (Emuleomo, 2005). Juice extraction is the process by which the liquid portion of fruit is separated from the solid portion by means of a juice extractor. Fruit juice extractor is an agricultural technological implement that involves the pressing of some fruits in order to obtain juice (Abulude et al, 2007). The method of juice extraction will differ with the structure and composition of the fruit. Broadly various machines for juice extraction include: Continuous Screw Press, Plunger – Type Press, Roller Type Press, Double Operation, Basket Press, Rack and Cloth Press, Centrifugal Juicers, Hydraulic Press Juicers etc. The early types of mechanical juice extraction included the roller press, such as the skinner (Duckworth 1968, Cruess 1958).The roller press is a drum type device and handles fruits cut into halves. In Nigeria, there are abundant under-exploited juicy fruits with high agro-industrial potentials which can be processed into juices that have plenty of scope for export. Machines used for extraction are imported into the country, because of the cost implication this has hindered the processing of juice by small scale industries. It is therefore essential to develop indigenous equipment for the processing (Adewumi, 1998).To this end, a motorised multi-fruit extractor was modified in NCAM.

The objective of this study was to carry out performance evaluation and determine the physio-chemical properties of juice extracted by NCAM multi-juice extractor.

2. MATERIALS AND METHODS

2.1 Description of the Juice Extractor

The juice extractor constructed in this research work consists of frame made of mild steel, hopper, extracting chamber, pressure plate, juice outlet and chaff outlet and the extracting chamber which consists of the external barrel that will house the sieving screen, the abrasive surface screen and the shaft which is in two form, half part of the shaft is carrying the auger for easy and quick conveyance as well as exerting compressive and shearing forces all made of stainless steel, while the latter part of the shaft is carrying tough belt arranged side by side on the shaft in order to produce soft beat. Extraction takes place by mastication through the auger and maceration through the tough belt.

2.2 Performance Evaluation Test

The machine was tested using pineapple and orange. The fruits were sliced with knife and then weighed before introducing into the hopper. The time of extraction, the weight of the extracted juice and the chaff were noted. As the shaft powered by the electric motor rotates bringing about the compressive and the shear forces. The juice drained out from the perforated screen under the housing and the pulp discharged from outlet. The machine was evaluated using these relationships (Tressler and Joslyn, 1961).

$$J_y = \frac{100W_{JE}}{W_{iJE} + W_{RW}}\% \tag{1}$$

$$J_E = \frac{100W_{JE}}{xW_{FS}}\% \tag{2}$$

$$E_L = \frac{100(W_{FS} - (W_{JE} + W_{RW}))}{W_{FS}} \tag{3}$$

Where $J_{y,}$ J_e and E_L juice yield, extraction efficiency and extraction loss respectively in %; $W_{je,}$ W_{RW} and W_{FS} are weight of juice, extracted residual waste and feed sample respectively. g and x is the juice content of the fruit decimal.

2.3 Physicochemical Analysis

2.3.1 Juice Temperature

The temperature of the juice was measured using a dry bulb thermometer. This was done immediately after extraction process because of the volatile nature of vitamin C content of the juice. (Ishiwu and Oluka, 2004).

2.3.2 Ph Determination

The pH was determined using a universal indicator. A sample of 1ml of the juice was pipetted into a test tube and a drop of the universal indicator was added and swirled vigorously. The corresponding colour on the reading of the indicator was recorded (Ishiwu and Oluka, 2004).

2.3.3 Determination of Iodine Value

The iodine value was determined by weighing 0.25g of fruit juice sample into a stoppered bottle, 12.5ml of dichrolomethane (CH_2Cl_2) and 12.5ml of Wij's solution were transferred into it. 10ml of 10% potassium iodide (10%KI) was also added and the mixture was vigorously shaken and kept in the dark for one hour (1hr) at temperature below 30^0c.

Another flask containing similar but without the fruit juice sample was prepared which served as the blank.The liberated iodine was titrated against 0.02N sodium thiosulphate (0.2N $Na_2S_2O_3$) using 1 ml of starch indicator. It was titrated from blue to colourtless end point. The iodine value was calculated using the formula.

Iodine value

$$= \frac{12.69 \; x \; N \; x \; (B - S)}{Weioght \; of \; sample}$$

Where: 12.69= Constant used to convert molar equivalent thiosulphate to grams of iodine; B= volume of thiosulphate used for blank; S = Volume of thiosulphate used for the sample; N = Normality of the thiosulphate solution (AOAC).

2.3.4 Determination of the Perioxides Value

The perioxides value was determined by properly stirring the juice sample to avoid aeration and 1gram of the juice sample was weighed into a conical flask and dissolved with acetic –chloroform solvent mixture in ratio 3:2 v/v.Then, 1ml of 40% potassium iodide (40%KL) was addede and the mixture was shaken for one minute (1min) before the addition of 75ml of water. The content of the flask was titrated with 0.01N thiosulphate solution using 0.5ml of a freshly prepared 1% starch solution as indicator which was shaken vigorously during titration. At end point (when the blue colour disappeared), the volume of thiosulphate used was noted and recorded as F.

The perioxide value was calculated using the formula:

Peroxide value $= 8000 \; X \; N \; X \; \frac{F}{W}$

Where: 8000 = Constant for expressing the value in µg of oxygen per 100g of juice; N = Normality of the thiosulphate solution; F = Volume of thiosulphate used (ml); W = Weight of the juice sample in grams.

2.3.5 Total Titratable Acidity

A 10ml sample of juice was pipetted and vigorously stirred to remove carbon (iv) oxide. The sample was titrated using 0.1N standardized sodium hydroxide (NAOH) and Phenolphthalein as an indicator. The total titratable acidity (TTA) was calculated as percentage citric acid. The total titratable acidity, TTA in %, was mathematically expressed by Ishiwu and Oluka (2004) as follows:

$$TTA = \frac{V \times 0.0070g \times 100 \times N}{1000 \times Vs} \qquad (9)$$

Where V, N and VS are mole of 0.1N NAOH used, normality and volume of juice sample used, respectively.

2.3.6 Ascorbic Acidic Content

The method of Hartley *et al.,* (1981) was used for the determination of the ascorbic content of the juice. Twenty ml sample of each juice was added to 80ml of distilled water and 10ml of 1M H2SO4. The resulting solution was titrated against 0.05M iodine solution (using 6 drops of starch mucilage as indicator). The vitamin C content was calculated thus:

$$VC100g = \text{titre value} \times F \times 100 \qquad (10)$$

Where titre value and factor are volume of iodine used and concentration (0.00886g) of acid used respectively. Each volume of iodine should be equivalent to 0.00886g of vitamin C.

2.3.7 Total Solids

Total solids were determined by the method used by Osborne and V ought (1979). An empty Petri- dish was washed, oven- dried for 15 min and cooled in a desicator for 20 min. The dried and cooled petri- dish was weighed empty and then reweighed after 10 ml of juice was put into it through a pipette. The petri-dish with its contents was oven- dried at 100℃ for 6h, cooled in the desicator and weighed. The procedure was repeated until a constant weight was obtained. The total solids ST in %, were calculated as follows:

$$ST = \frac{100W2}{W1} \qquad (11)$$

Where, W1 and W2 are weight of fresh juice and weight of dried sample, respectively in g.

3. RESULTS AND DISCUSSION

The juice yield, extraction efficiency and juice loss for orange were 66.67%, 47.52% and 25.78% respectively and for pineapple were 72.5%, 99.7% and 6.77%. This result is in agreement with the work reported by Adewumi, (1999). Fruit juice was also extracted manually as control. Both the machine extracted juice and manually extracted juice were taken to the laboratory in order to determine the effect of machine on the physicochemical properties of the juice and the laboratory result was subjected to statistical analysis, to test for the equality of the means of manual and machine extracted juice from the pineapple and the orange.

Table 1: t-Test for Equality of Means for pineapple.

	V	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% C.I	
ph value	v_1-v_2	34.293	4	.001	.28000	.00816	.25733	.30267
acid value	v_1-v_2	21.213	4	.001	.10000	.00471	.08691	.11309
iodine value	v_1-v_2	.918	4	.411	.02667	.02906	-.05401	.10735
perioxide value	v_1-v_2	-10.607	4	.001	-.05000	.00471	-.06309	-.03691
ascorbic acid	v_1-v_2	-40.305	4	.001	-.19000	.00471	-.20309	-.17691

Where v_1 is machine reading and v_2 is manual reading, V is difference between the two.

From table 1, it was observed that the significant values of the Ph. Value, the acid value, the peroxide value and the ascorbic acid value of pineapple juice extracted were less than 0.05. This indicated that there is no significant difference in the values of the physiochemical parameters of the pineapple juice extracted manually and the juice from the extractor. It is noted that the iodine value is 0.411. This is greater than 0.05 this indicated a large difference between the two treatments and this might be as a result of the difference between the time of extraction which might have given room for fermentation to take place.

Table 2: t-Test for Equality of Means of orange

	V	t	df	Sig. (2-tailed)	Mean Difference	*Std. Error Difference*	95% C.I	
ph value	v_1-v_2	1.225	4	.288	0.01000	*.00816*	-.01267	.03267
acid value	v_1-v_2	42.426	4	.001	0.20000	*.00471*	.18691	.21309
iodine value	v_1-v_2	10.247	4	.001	0.46333	*.04522*	.33779	.58887
peroxide value	v_1-v_2	-112.430	4	.001	-0.53000	*.00471*	-.54309	-.51691
ascorbic acid	v_1-v_2	-4.000	4	.016	-0.01333	*.00333*	-.02259	-.00408

Where: v_1 is machine reading; v_2 is manual reading, V is difference between the two

From Table 2, significant difference of the ph value of the orange juice is greater than 0.05 which shows that there is significant difference between the ph value of orange juice extracted manually and the orange juice from the extractor. This might be as a result of fermentation effect because the extraction process from the machine took place first before the manual process was performed. The time lag is believed to have aided fermentation on the machine extracted orange juice. Meanwhile, the significant difference the acid value, the iodine value, the peroxide value and ascorbic acid value are less than 0.05 showing there is no significant difference. This indicates that these physiochemical properties of orange juice from extractor and the manual were not altered by the method of extraction. Therefore, from the T-test carried out, the values of physiochemical properties showed that the extracted juices were of good qualities.

4. CONCLUSION

This study showed that the extraction of fruit juices through the combination process of mastication through the auger and maceration through the tough belt arranged side by side on the shaft is great improvement on fruit juice extractor. And the quality of the juices produced showed that this multi-fruit extractor is suitable for small, medium and industrial juice processing business in both rural and urban communities.

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DRYING KINETICS OF IBADAN-LOCAL TOMATO (*Lycopersicum esculentum* cv)

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ABSTRACT

There are several tomato cultivars grown in Nigeria, but their production is seasonal and availability geographical in spite of their importance in the daily dietary intake. They are usually in short supply in the dry season and effective storage in the fresh state still poses a challenge. Among these available cultivars in the southwestern Nigeria is Ibadan-Local (*Lycopersicum esculentum* CV), a variety with higher fruit yield and longer fruiting tendency which has received little or no significant attention because of the higher preference of other cultivars to it. Pre-treatment methods have been reported to improve drying characteristics of fruits and vegetables generally but there is dearth of information on drying of Ibadan-Local variety of tomato despite its high nutritional value.

Sixteen grams (16g) of Ibadan-Local variety was sorted for complete ripeness, firm and void of injury/bruises and osmotically pre-treated in a binary osmotic solution containing 45g of sugar and 15g of salt and a solution temperature of 50^{o}C previously prepared to have a solution to fruit ratio of 10:1 and the experiment was conducted in triplicate. Osmosized samples were removed, drained and the surface mopped up to eliminate posterior weight at 30 minutes interval and weighed electronically until a constant weight was attained (Water loss at infinity). These osmotically pre-treated and fresh samples were then subjected to drying at 40, 45 and 50^{o}C in an oven that was previously run on a no-load mode for 30minutes. Mechanism of mass transfer phenomena was thus studied. Five thin layer drying models (Exponential, Henderson and Pabis, Page, Modified Page and Logarithmic) were compared and fitted into the experimental moisture ratio. Adequacy of fit was based on highest R^2, χ^2 and least RMSE. Effective coefficient of moisture diffusivity and Activation energy were determined using Arrhenius equation.

Results of water loss and solid gains were significant ($p<0.05$) for all variables considered. Different models fit at different temperatures. The Exponential model fitted at 40 &45^{o}C with R^2 value range of 0.8291-0.8981 and 0.9352-0.981 for treated, 0.9453-0.9829 and 0.8281-0.9224 for untreated tomato having the best fit in Page and Modified Page and RMSE value range of 0.07966-0.10089,0.0464-0.364 (treated) and 0.0301-0.0538(untreated). At 50^{0}C, R^2 value ranged between 0.8461-0.8981 (treated) and 0.8281-0.9224 (untreated), with RMSE value of 0.07984-0.09659 and 0.0778-0.1008. Calculated values of effective moisture diffusivity varied from 1.17-3.51x10^{-8} and 1.25-3.13x10^{-8} and activation energy varied from a maximum of 52.61-46.81 KJ/mol in treated and untreated tomato. The present study has shown that the proposed empirical models were able to describe mass transfer process during osmotic dehydration of tomato as the values calculated using the proposed empirical models were in good agreement with the experimental data.

KEYWORDS: Tomato, models, effective diffusion coefficient, pre-treatment, activation energy.

1. INTRODUCTION

Drying is the commonest form of food preservation that extends the shelf life of fruits and vegetables (Doymaz, 2007). Ojediran and Raji, (2010) reported that it is an important unit operation in the food processing industry. The major objective in drying agricultural products is the removal of water in the solid up to a certain level at which microbial spoilage, deterioration and chemical reactions are greatly minimized (Krocxida and Marinos-Kouris, 2003). This allows for safe storage over an extended period, and also brings about substantial reduction in weight and volume, minimizing packaging, storage and transportation costs (Jaiyeoba and Raji, 2012).

Drying of most fruits and vegetables are done in thin layer using different conventional drying methods but these methods have been found to be deficient as most of the nutritional and sensory properties are reportedly lost after drying but pre-treatment of fruits/vegetables have been reported to improve the drying characteristics of dried products. Although much information has been given on the effective moisture diffusivity and activation energy for various agricultural products as some researchers have studied the moisture diffusion and activation energy in the thin layer drying of various agricultural products such as Seedless grapes (Doymaz and Pala, 2002), Plums (Goyal *et al.*, 2007), grapes (Pahlavanzadeh *et al*., 2001), candle nuts (Tarigan *et al*., 2006), potato slices (Akpinar *et al.*, 2003) and onion slices (Pathare and Sharma, 2006). Very little published literature is available on the effective moisture diffusivity and activation energy data for local varieties most especially Ibadan-Local Tomato during drying.

One of the several tomato cultivars grown in Nigeria is Ibadan-Local which is indigenous to the southwestern part of Nigeria with higher fruit yield and longer fruiting tendency (Adedeji *et al*., 2006) when compared with other varieties but has received little or no significant acceptability because of the higher preference of other cultivars to it because of inadequate information on the drying characteristics of this variety (Jaiyeoba and Raji, 2012).

The local variety, from literatures and preliminary investigation has shown to contain a very high percentage of titratable acid and pH values(because of the presence of citric and malic acids which are required for best flavour , palatability and its influence on the brightness of color, stability, consistency and the keeping quality of the product (Kaur *et al.*, 1996). This is a pointer to the fact that the local variety has better qualities that are yet to be harnessed. Published literatures are available on the drying kinetics (effective moisture diffusivity and activation energy) data for different fruits and vegetables including tomato but there is still a dearth of information on the drying kinetics of Ibadan-Local tomato.

This study therefore investigated the drying kinetics of Ibadan-Local variety of tomato. This is with a view to identifying the effect of the optimum processing conditions on the local variety and its drying characteristics.

2. METHODOLOGY

2.1 Experimental Methods

Ibadan-Local (*Lycopersicum esculentum* CV*)* tomato fruits previously sorted for complete ripeness, firm and void of injury/bruises were used for this experiment. Binary osmotic solution containing 45g of sugar and 15g of salt in 100ml of distilled water i.e. (60g/100g) was prepared on a heat stirrer (Stuart model CB162, U.K) previously prepared to have a solution to fruit ratio of 10:1 at a solution temperature of 50^{o}C- Optimum processing condition, (Jaiyeoba and Raji, 2012). Sixteen grams (16g) of Ibadan-Local variety was osmotically pre-treated in the sucrose-salt solutions in a water bath (10 shaker Tecnal TE 421 Model, Germany) previously brought to a relatively higher temperature (to compensate for heat loss when samples were introduced to the solution) and kept at 30, 40, and 50^{o}C temperatures. The temperature within the water bath was maintained thermostatistically, wherein temperature variation was maintained not more than ±1^{o}C and the experiment was conducted in triplicate. Samples were removed, drained and the surface mopped up to remove posterior weight at 30 minutes interval and weighed until a constant

weight was attained (Water loss at infinity). These osmotically pretreated samples were then subjected to oven drying at 40, 45 and 50^oC while untreated (Fresh) samples of this tomato variety were also subjected to the same drying temperature in an oven that was previously run on a no-load mode for 30minutes and the results were used to find the moisture ratio at different temperatures. The moisture ratio, MR is the ratio of free water still to be removed at time t, to the total free water initially available in the food.
The moisture ratio, MR is given by Nieto *et al*., (2001) as:

$$MR = \frac{Mt - Me}{Mo - Me} \qquad (1)$$

Where, M_t is the moisture content of tomato slab after time, t; M_e is the moisture content of tomato slab at equilibrium (gH_2O/g dry solid); and M_o is the moisture content of tomato slab prior to O.D (g H_2O/g dry solid)

The drying time was thereafter plotted against time. The dimensionless moisture Ratio, MR was also plotted against Time at the different drying temperatures. The drying rate against time graph at the three temperatures and the MR plot against Time were further used for the drying kinetics.

Data was hence generated and analyzed. Simulation of results was done and fitted into five existing semi-theoretical models namely: (Exponential (Newton) model, Henderson and Pabis model, Page model, Modified Page model and the Logarithmic model (Table 1**)** to predict mass transfer in the samples.

2.2 Mathematical Modelling of the Drying Process

Moisture ratio data obtained from the drying experiment were fitted to five of the most commonly used thin layer drying models (Table 1) using the non linear regression procedure in SPSS for Windows 14.0 released in 2005. In order to estimate and select the appropriate drying model between five of the commonly used thin layer drying models for grains and legumes were tested. The fit was statistically determined by fitting experimental data to the model equation.

Table 1: Mathematical models used for drying characteristics

Model	**Model Equation**	**References**
Exponential (Newton)	MR = exp (-kt)	Liu and Bakker-Arkema, 1997
Henderson and Pabis	MR = a.exp (-kt)	Henderson and Pabis, 1961
Page	MR= exp ($-kt^n$)	Zhangn and Litchfield, 1991
Modified Page	MR = exp [$-(kt)^n$]	Overhaults *et al., 1973*
Logarithmic	MR = a. exp (-kt)+c	Yaldiz *et al*., 2001

Source: Akpinar and Bicer (2006)

The initial parameter estimates were obtained by linearization of the models through logarithmic transformation and application of linear regression analysis. The least-squares estimates or coefficients of the terms were used as initial parameter estimates in the non-linear regression procedure. Model parameters were estimated by taking the moisture ratio (MR) to be the dependent variable. The Coefficient of determination (R^2), χ^2 and Root Mean Square Error (RMSE) were used as criteria for adequacy of fit. The best model describing the thin layer drying characteristics of tomato samples was chosen as the one with the highest R^2 χ^2 and the least RMSE (Ozdemir and Devres, 1999; Doymaz *et al*., 2004; Ertekin and Yaldiz, 2004; Ojediran and Raji, 2010).

2.3 Effective Coefficient of Moisture Diffusivity

Drying process of food materials generally occurs in the falling rate period (Wang and Berennan, 1992). To predict the moisture transfer during the falling rate period, several mathematical models have been proposed using Fick's second law. By using Fick's second law and considering the following assumptions, proposed equ (1) for the effective diffusivity for an infinite slab (Crank, 1975).

1. Moisture is initially distributed uniformly throughout the mass of a sample
2. Mass transfer is symmetric with respect to the center.
3. Surface moisture content of the sample instantaneously reaches equilibrium with the condition of surrounding air.
4. Resistance to the mass transfer at the surface is negligible compared to internal resistance of the sample.
5. Mass transfer is by diffusion only. Mathematical modeling and simulation of drying carries under different conditions is important to obtain a better control of this unit operation and an overall improvement of the quality of the final product.
6. Diffusion coefficient is constant and shrinkage in negligible

The experimental drying data for the determination of effective diffusivity coefficient (D_{eff}) were interpreted using Fick's second law for spherical bodies according to Geankoplis (1983) and Doymaz (2004a). This is because the shape of the tomato fruits are closer to being spherical than the commonly used flat object (slab assumption). The diffusivity coefficient (Deff) was obtained from the equation for spherical bodies and the moisture diffusivity coefficient (D_{eff}) was calculated at different temperatures using the slope derived from the linear regression of *ln*(MR) against time data.

The effective radius (R) was calculated using the equation given by Aseogwu *et al*., (2006). The activation energy is a measure of the temperature sensitivity of D_{eff} and it is the energy needed to initiate the moisture diffusion within the seed. It was obtained by linearising Equation (5).

$$MR = \frac{M}{M_0} = \frac{8}{\pi^2}\sum_{n-1}^{\infty}\exp\left[-\frac{(2n-1)^2\pi^2}{4L^2}Dt\right] \text{......................................(2)}$$

Where MR is moisture ratio, M is the moisture content at any time (kg water/kg dry matter), M_0 is the initial moisture (kg water/kg dry solid), n = 1, 2, 3,…. the number of terms taken into consideration, t is the time of drying in second, D is the effective moisture diffusivity in M^2/s and L is the thickness of slice (m).

Only the first term of Equation (2) is used for long drying times (Lopez *et al*., 2000),

$$MR = \frac{8}{\pi^2}\exp\left[-\frac{\pi^2 Dt}{4L^2}\right] \text{...(3)}$$

The slope (K_0) is calculated by plotting in MR versus time according to equation (4)

$$K_0 = \frac{\pi^2 D}{4L^2} \text{...(4)}$$

2.4 Energy of Activation

The energy of activation was calculated by using an Arrhenius type equation (Lopez *et al*., 2000; Akpinar *et al*., 2003).

$$D = D_0 \exp\left[-\frac{E_a}{RT_a}\right] \qquad (5)$$

Where: E_a is the energy of activation (kJ/mol), R is universal gas constant (8.3143kJ/mol), T_a is the absolute air temperature (K), and D_0 is the pre-exponential factor of the Arrhenius equation (m^2/s).
The activation energy can be determined from the slope of the Arrhenius plot, Ln (D) versus $1/T_a$.

Models are often used to study the variables involved in the process, predict drying kinetics of the product and to optimize the operating parameters and conditions (Karathanos and Bellesiotis, 1999).

From Equ (5), a plot of Ln D versus $1/T_a$ gives a straight slope of K_1.

$$K_1 = E_a/R \qquad (6)$$

The linear regression analysis was performed using statistic computer program to fit the equation to the exponential data to obtain correlation coefficient (R^2).

The drying process was stopped after no further change in weight was observed. At this point, moisture content decreased from 96.5% to 10.23% (w.b). Moisture content data were converted to moisture ratio and then fitted to the 5 thin layer drying models.

In MR was then plotted against time and the effective diffusivity (D_{eff}) was obtained from the slope of the graph.

The diffusivity coefficient at different temperatures is often found to be well predicted by the Arrhenius equation given by Equation (7) as follows:

$$D_{eff} = \frac{DoeEa}{Rg(T + 273.15)} \qquad (7)$$

Where, D_{eff} is the effective diffusivity coefficient m^2/s, D_o is the maximum diffusion coefficient (at infinite temperature), E_a is the activation energy for diffusion (kJ/mol), T is the temperature (°C) and R_g is the gas constant.

Linearization the equation gives:

$$\ln Deff = -\left[\frac{1}{Rg(T + 273.15)} Ea\right] + \ln Do \qquad (8)$$

D_o and E_a were obtained by plotting ln D_{eff} against $\left[\frac{1}{Rg(T + 273.15)}\right]$

The drying data were used to obtain the following plots:

i. The drying curve of moisture content against drying time at different temperatures
ii. Drying rate against time at different temperatures
iii. Drying rate against moisture content at different temperatures

3. RESULTS AND DISCUSSION

Tables 2 – 4 and Figs 2 – 4 show the results of the fitting statistics of various thin layer models at different drying temperatures. Model constants were derived by linearising the model equation,

Table 2 Results of the fitting statistics of thin layer models of pre-treated Ibadan-Local tomato at 40^{o}C

Model no	Model name	Coefficients and constants	R^2	χ^2	RMSE
i.	Exponential	k = 0.001	0.8981	380.02	0.0797
ii.	Henderson & Pabis	k = 0.001, a = 1.002	0.8981	380.02	0.0798
iii.	Page	k = 0.001, n = 0.980	0.8260	199.37	0.8260
iv.	Modified page	k = 0.001, n = 0.980	0.8219	199.40	0.1009
v.	Logarithmic	k = 0.001, a = 1.002, c = 0.001	0.8981	380.02	0.0798

The result of the fitted model at 40^{o}C showed that the Henderson and Pabis and the Logarithmic model shared the same level of fit.

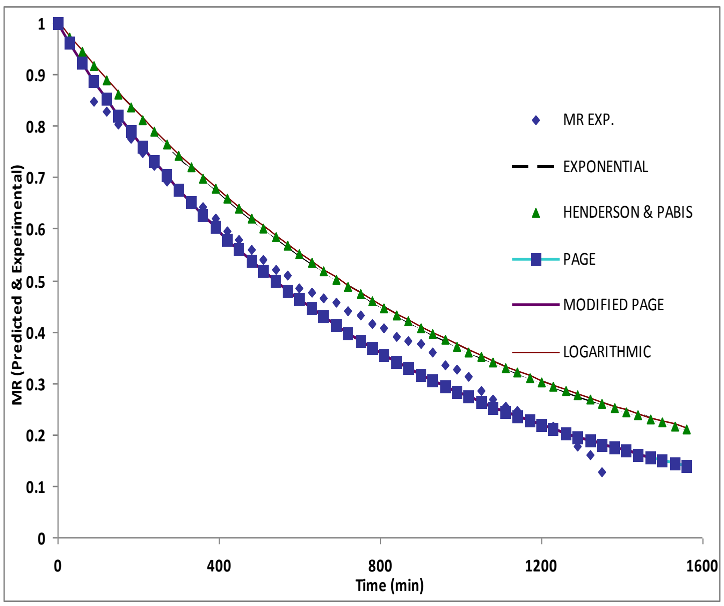

Fig. 2 Experimental and predicted MR for treated tomato at 45/15/50 dried at 40^{o}C

Table 3 Results of the fitting statistics of thin layer models of pre-treated Ibadan-Local tomato at 45^{o}C

Model no.	Model name	Coefficients and constants	R^2	χ^2	RMSE
i	Exponential	k= 0.002	**0.981**	**2706.82**	**0.364**
ii	Henderson & Pabis	a = 1.002, k = 0.002	0.9595	1233.91	0.0464
iii	Page	k = 0.004, n = 0.943	0.9352	735.88	0.06351
iv	Modified page	k = 0.003, n = 0.943	0.9352	735.49	0.06353
v	Logarithm	a = 1.002, k = 0.002, c = 0.002	0.9595	1233.91	0.04652

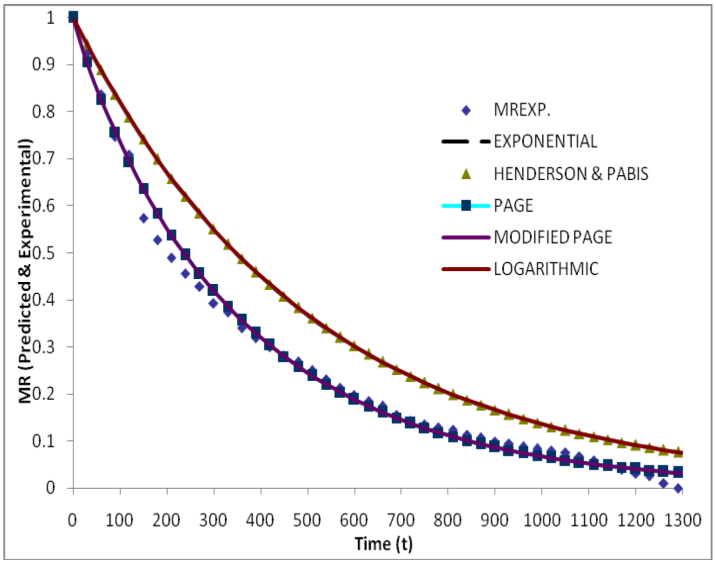

Fig. 3 Experimental and predicted MR for treated tomato at 45/15/50 dried at 45°C

Table 4 Results of the fitting statistics of thin layer models of pre-treated Ibadan-Local tomato at 50°C

Model no	Model name	Coefficients and constants	R^2	χ^2	RMSE
i	Exponential	k = 0.003	0.8664	214.04	0.09241
ii	Henderson and Pabis	k = 0.003, a = 1.023	0.8981	380.02	0.07984
iii	Page	k = 0.003, n = 0.987	0.8624	214.04	0.0945
iv	Modified page	k = 0.003, n = 0.987	0.8461	187.87	0.09659
v	Logarithmic	k = 0.003, a = 1.023, c = 0.003	0.8624	214.04	0.09479

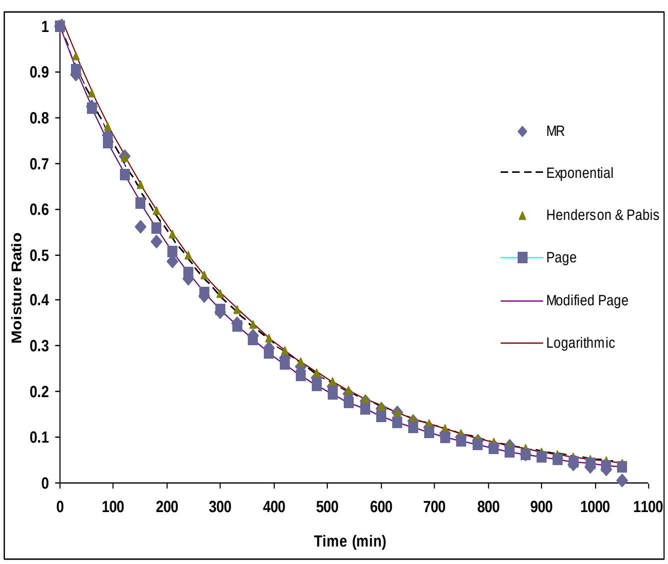

Fig. 4 Experimental and predicted MR for treated tomato at 45/15/50 dried at 50°C

Table 5 Estimated effective moisture diffusivity at different temperature of drying for osmotically pre-treated tomato

Samples	**Diffusion**	**Coefficient**	**10^{-8}(m^2/s)**
	40°C	**45°C**	**50°C**
Pre-treated tomato	1.17	2.34	3.51
Untreated tomato	1.25	2.50	3.13

Table 6 Estimated activation energy and moisture diffusivity constant

Sample	**Diffusion**	**Coefficient**	**10^{-8}(m^2/s)**
	Do (m^2/s)	Ea (KJmol)	R^2
Pre-treated	3.96	52.61	0.977
Untreated	3.85	46.81	0.919

Calculations of the moisture diffusivity and activation energy from Tables 5 and 6 indicated that there is a direct relationship between temperature and the effective spread, which depicts that increase in temperature leads to increase in the effective distribution coefficient. Using the Arrhenius relationship, the dependence of effective coefficient moisture diffusivity to temperature was described correctly. Activation energy and constant effective coefficient diffusivity were calculated from the slope of Arrhenius (Ln (D_{eff}) against $1/T_{abs}$. Changes of effective coefficient moisture diffusivity for tomato were gained from 1.17 x 10^{-8} to 3.52 x 10^{-8} in the temperature range of 40 to 50°C for osmotically pretreated samples of local variety and 1.25 x 10^{-8} to 3.12 x 10^{-8} m^2/s in the same temperature range for untreated local variety of tomato.

4. CONCLUSIONS

All the models used seem to fit but the Henderson and Pabis fitted best for osmotically pretreated tomato and modified page for untreated/fresh tomato as models with the highest value of RMSE, X^2 and R^2 were chosen (These three were the criteria used to determine the degree of fitness of the models). The present study has shown that the proposed empirical models were able to describe mass transfer process during osmotic dehydration of tomato as the values calculated using the proposed empirical models were in good agreement with the experimental data. Diffusivity constant value of 3.96 and 3.85 x10^{-8} m^2/s were obtained for treated and untreated samples. Activation energy is higher in osmotically pre-treated sample (52.61 KJ/mol), Untreated sample of tomato has an activation energy value of (46.81 KJ/mol) and R^2 value of 0.919.

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SOME ENGINEERING PROPERTIES OF DRUMSTICK (*MORINGA OLEIFERA*) SEEDS

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ABSTRACT

Some engineering properties of drumstick seeds were determined following standard methods in the literature. The results show that the mean values of 100 measurements for length, width, thickness and mass of drumstick seeds at a moisture content of 4.64% (w.b) were: 10.96, 10.83, 10.24 mm and 0.35 g for the nut and 7.44, 8.59, 8.29 mm and 0.26 g for the kernel. The kernel-nut ratio showed that the kernel is 74% of the nut weight. Angle of repose and loose and bulk densities were: 46.8º, 212 kg/m^3, 223.6 kg/m^3 for the nut; and 42.5º, 518.1 kg/m^3, 531.2 kg/m^3 for the kernels respectively. Terminal velocities of the nut, kernel and shell were: 8.39, 9.83 and 5.67 m/s respectively. Static coefficient of friction on mild steel, glass, galvanized steel and formica surfaces were 0.69, 0.48, 0.49 and 0.37 for the nuts and 0.37, 0.42, 0.35 and 0.30 for kernels respectively. The rupture force was 54.47 N for the nut and 67.27 N for the kernel. Hydration and swelling capacities were 0.25 g/kernel and 0.47 mL/kernel; while hydration and swelling indices were 0.96 and 1.78 respectively. Minimum cooking time, water uptake ratio, cooked weight, water absorbed and gruel loss were 37 mins., 0.74, 17.43 g/10 g, 7.43 g/10 g and 5.58% for traditionally cooked samples and 20 mins., 0.62 g/g, 15.94 g/10 g, 5.94 g/10 g and 1.47% for the microwave cooked samples.

KEYWORDS: Drumstick, nuts, kernels, engineering properties, cooking, moringa olifera.

1. INTRODUCTION

Among the fourteen known species in the *Moringaceae* genus of plants native to sub-Himalayan region of Asia and naturalized in tropical Africa, the drumstick tree (*Moringa oleifera Lam.)* hereinafter, simply called drumstick is the most widely known (Morton 1991, Fuglie 1999). In India especially, and some other parts of Asia, fresh drumstick leaves, flowers and immature pods are prized vegetables; known for the substitute they provide to spinach when most other vegetables are scarce (Al-Kahtani and Abou-Arab 1993; Makkar and Becker 1997; Foidl *et al.* 2001). The utilization of drumstick leaves as a livestock feed concentrate for poultry, fish and ruminants have also been reported (Chawla *et al*. 1988; Gadzirayi *et al.* 2012).

The pendulous, dark-green, drumstick fruit-pod which has a triangular cross-section is about 30-120 cm in length, tapering at both ends and 1.2-1.8 cm in diameter (Foidl *et al.*, 2001). It turns brown as it matures and splits symmetrically into three leaves when opened. A mature pod contains about 12-25 dark brown seeds in a nutshell; each having three papery wings and encasing a whitish cream, pea-sized kernel which measures about 1 cm in diameter (Foidl *et al.* 2001; Morton 1991; Sabale *et al*. 2008; Aviara *et al.* 2013). Seed weights differ among cultivars; ranging from 3,000 - 9,000 seeds per kg (Roloff *et al*. 2009). Some drumstick tree products are shown in Fig. 1. Although sugary, slightly bitter and astringent in taste, cooked or roasted drumstick kernels are eaten as cooked or roasted snacks in some places (Ogunsina 2010). The kernel is believed to have some medicinal applications, including the treatment and prevention of arthritis and rheumatism (Al-Kahtani and Abou-Arab 1993; Eilert *et al*. 1981), but the most documented use of the powdered kernel or defatted flour is as a natural flocculent for water purification (Sutherland, *et al.* 1994; Gassenschmidt *et al.* 1995; Muyibi and Okufu 1995; Muyibi and Evison 1996; Ndbigengesere and Narasiah 1998; Okuda *et al.* 1999; Katayon *et al.* 2006). With about 40% crude proteins and 41.7% oleic-acid-rich crude fat, drumstick kernel was most recently explored as a valuable source of vegetable protein and edible oil (Ogunsina *et al.* 2010; Ogunsina and Radha 2010; Ogunsina *et al.* 2011[a, b]; Govardan Singh *et al.* 2012).

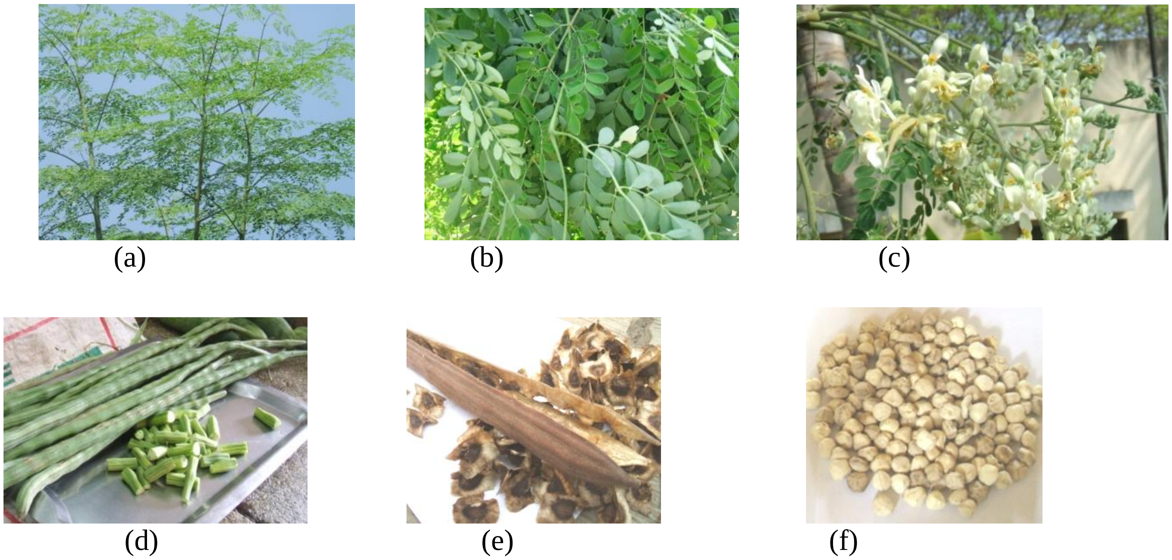

Fig. 1. Some products of *Moringa oleifera* tree

(a) A cross-section of young drumstick trees in India; (b) Tender drumstick leaves; (c) drumstick flowers; (d) Tender green pods prepared for use as vegetable soup; (e) A dry drumstick pod with embedded nuts; (f) Drumstick kernels.

In Nigeria and all over sub-Sahara Africa, there is growing interest in the use of drumstick leaves and seeds as food/nutraceutical; suggesting that it will become an important economic crop in the near future (RMRDC, 2010). The author has personally observed an increase in the cultivation of drumstick tree in gardens and plantations among farmers in South-West Nigeria. A kilogram of drumstick seeds (containing about 3000-3500 kernels) now sells for about five hundred dollars ($500.00).

Some legumes, oilseeds and edible kernels whose properties have been widely documented include soybeans (Deshpande, *et al.* 1993; Paulsen 1978); oilbean (Oje and Ugbor 1991); canola and wheat (Bargale *et al.* 1995); sunflower (Gupta and Das 2000); karingda (Suthar and Das 1997); legume (Laskowski and Lysiak 1999); locust bean (Ogunjimi *et al.* 2002); pigeon pea (Baryeh and Mangope 2002); chick pea (Konak *et al.* 2002) and calabash nutmeg (Omobuwajo *et al.* 2003). Despite growing interests in drumstick cultivation, published literatures regarding the properties of drumstick seeds as an edible oilseed are rarely found. Various post-harvest operations such as cracking, separation, drying and storage of biomaterials and their utilization in food systems require good knowledge of their properties.

In this work therefore, some engineering and cooking properties of drumstick seeds namely: axial dimensions, sphericity, porosity, seed mass, porosity, bulk density, true density, terminal velocity, friction against various surfaces, cracking force, cooking time, hydration capacity, swelling capacity and gruel loss were investigated.

2. MATERIALS AND METHODS

2.1 Samples

Bulk quantity of dry drumstick seeds botanically identified as *Moringa oleifera* Jaffna variety were procured from Veg-Indian Exports, Erode, Tamil Nadu, India. An attrition plate mill (Model A-453, Chandra Manufacturing Co., Chennai, India) was adapted for dehulling one portion of the nuts. Kernels were separated from the shell in an aspirator and all extraneous materials were handpicked. The nuts and kernels sample were kept in airtight containers at −20 °C until the time of use. Moisture content determination was carried out according to official methods of AOAC (2000). All determinations were carried out at a moisture content of 4.64%.

2.2 Physical and Mechanical Properties

Major axial dimensions (major axis, D_M; intermediate axis, D_i and minor axis D_m) of 100 randomly selected nuts and kernels were determined using an electronic venier caliper (0-150 mm, Mitutoyo CD-12, Made in Japan, ±0.05 mm accuracy). For the same randomly selected seeds, 100 seeds mass was determined using a precision electronic balance measuring 0.01 g (Metler Toledo, Model GT 2100, Made in Germany). Based on the foregoing, arithmetic mean diameter, D_a mm; geometric mean diameter, D_g mm; square mean diameter, D_{sm} mm; equivalent diameter, D_e mm; sphericity, ϕ % and aspect ratio, R_a % were calculated as (Mohsenin, 1986):

$$D_a = \tfrac{1}{3}(D_M + D_i + D_m) \qquad (1)$$

$$D_g = \sqrt[3]{(D_M D_i D_m)} \qquad (2)$$

$$D_{sm} = \sqrt{(D_a)} \qquad (3)$$

$$D_e = \tfrac{1}{3}(D_g + D_a + D_{sm}) \qquad (4)$$

$$\phi = \frac{D_g}{D_M} \qquad (5)$$

$$R_a = \frac{D_i}{D_M} \times 100\,; \qquad (6)$$

Bulk density was determined using the mass/volume relationship. A measuring cylinder of tarred weight was filled with the sample, the excess was removed by a strike off stick without any compaction and the weight was determined afterwards. The ratio of the weight of seeds to the volume it occupied in the cylinder was calculated to obtain the loose bulk density (ρ_{bl}). After 10 tappings on a wooden platform, the ratio of the weight of sample to the shrunken volume was calculated to obtain the tap bulk density (ρ_{bt}). There were ten replicates for each measurement.

The method of Troeger *et al.* (1976) was used to determine kernel-nut ratio. About 20 g of nuts were cracked manually and separated into shells and kernels, the weight of each fraction was determined and kernel-nut ratio was calculated as a ratio of the mass of kernels to the mass of nuts. The indicated value was an average of ten determinations.

Coefficient of friction was determined using an inclined plane apparatus (Omobuwajo 1999, Aviara *et al.* 2005) considering glass, mild steel, formica and galvanized steel surfaces. Experimental values were averages of ten determinations.

The angle of repose is the characteristic of a bulk of material which indicates the cohesion among the individual units of the material; the higher the cohesion, the larger the angle of repose. A 200×200×200 mm transparent fiber box which had a removable front panel was filled with the sample to level and afterwards, the front panel was quickly removed, allowing the nuts or kernels to flow and assume a natural slope (Aviara *et al.* 2005; Ozdemir and Akinci 2004). The angle made by the slope with the horizontal was calculated as the angle of repose. There were ten replications of this determination.

The terminal velocities of the nut, kernel and hull were measured using a cylindrical air column (Yalcin *et al.* 2007; Yalcin 2007; Kilickan and Guner 2008). The air stream was directed through a 148.5 mm inner diameter transparent pipe. A rotary positive displacement blower driven by an electric motor (0.37 kW) was used to develop air velocities. For each experiment, a sample was dropped into the air stream from the opened top of the air column, up which air was blown to suspend the material in the air stream (Fig. 2). The terminal velocity was taken as the air velocity when the sample was just momentarily lifted above the contacting netted surface and suspended in the air stream was measured by an electronic anemometer (Delta OHM HD 2103.1, Made in Italy, having a least count of 0.01 m/s). There were five measurements for each of the three test samples

The compressive strength of the nut and kernel was determined using Lloyd LR5K Instron Universal Testing Machine (50 kN capacity, Hampshire, England) having a load cell of 1 kN. Individual nut was loaded between two parallel plates and subjected to 50% compression at a fixed cross-head speed of 50 mm/min using a probe of 35 mm diameter until the shell ruptured. Values reported were averages of fifteen replicates.

Fig. 2. Experimental set for measuring terminal velocity of drumstick seeds

2.3 Water Uptake Properties

Hydration capacity was determined following the method of Tiwari *et al.* (2008). About 20 g of seeds in triplicate were enumerated and transferred to a measuring jar containing 100 mL distilled water and it was left soaked for 24 h at room temperature ($28 \pm 2^{o}C$), later the water was drained and the seeds were blotted to remove adhered water and weighed again. Hydration capacity was calculated as shown in equation 7. Hydration index was obtained as a ratio of hydration capacity to the weight of one seed.

$$\text{Hydration capacity (g/kernel)} = \frac{W_2 - W_1}{N} \tag{7}$$

where, W_1 = weight of kernels before soaking; W_2 = weight of kernels after soaking and
N = number of kernels.

For swelling capacity, about 20 g of kernels of known volume were enumerated and soaked in 100 mL distilled water for 24 h at 28±2°C. The volume of kernels was determined again after soaking (Singh *et al*. 2005; Tiwari *et al.* 2008). The experiment was replicated thrice and swelling capacity as stated by equation 8. Swelling index was calculated as the ratio of swelling capacity to the weight of one seed.

$$\text{Swelling capacity (mL/kernel)} = \frac{V_2 - V_1}{N} \tag{8}$$

where, V_1 = weight of kernels before soaking; V_2 = weight of kernels after soaking and
N = number of kernels.

2.4 Cooking Properties

Minimum cooking time was investigated using the parallel glass plate method Chakkaravarthi *et al.* (2008). About 20 g of kernels were cooked in 200 mL of boiling distilled water. Few kernels were drawn periodically as cooking progressed, taking note of the time from when cooking started. The kernels were pressed between two flat glass slides. The sample was considered to be completely cooked when it showed no white/uncooked core between the pressed slides. The minimum cooking time was considered as the time it took a kernel that showed no uncooked core on the pressed glass slides to boil (Singh *et al*. 2005; Tiwari *et al.* 2008).

For cooked weight, 10 g of kernels were cooked in distilled water for the minimum cooking time; the water was drained and blotted to remove surface moisture. Cooked weight was expressed in g/10 g of cotyledon. Water absorbed by the cooked samples was taken as the difference between cooked samples and uncooked cotyledon and expressed as mL/10 g of cotyledon.

Gruel solids loss was determined following the modified method of Tiwari *et al*. (2008). About 100 g of cotyledons were cooked in distilled water for the minimum cooking time; the gruel was transferred to 500 mL standard flasks after three washing and made up to volume with distilled water. Aliquot of gruel was evaporated to dryness at 110 °C to determine the percent gruel solids.

3. RESULTS AND DISCUSSION

3.1 Axial Dimensions, Mass and Dimensional Relationships

Table 1 presents the physico-mechanical properties of drumstick seeds. The mean values of 100 measurements for length, width, thickness and mass of drumstick seeds at a moisture content of 4.64% (w.b) were: 10.96, 10.83, 10.24 mm and 0.35 g for the nut and 7.44, 8.59, 8.29 mm and 0.26 g for the kernel. These values are close to 10.5, 9.48 and 8.50 mm for bambara groundnut (Baryeh 2001). Drumstick seed is smaller when

Table 1. Physico-mechanical properties of drumstick seeds

Property	Nut	Kernel	Hull
Moisture content (w.b. %)	4.64(0.19)	7.6(0.07)	8.69(0.24)
Axial dimensions			
Major diameter (mm)	10.96(1.51)*	7.44(1.21)	NA
Intermediate diameter (mm)	10.83(1.02)	8.59(0.71)	NA
Minor diameter (mm)	10.24(1.21)	8.29(0.56)	NA
Hull thickness (mm)	NA*	NA	1.76
Shell/kernel ratio	NA	NA	26/74
Shape indices			
Sphericity (%)	98.26(10.71)	110.62(15.68)	NA
Aspect ratio (%)	100.27(13.00)	119.53(28.01)	NA
Geo. mean diameter (mm)	10.63(0.85)	8.05(0.53)	NA
Arith. mean diameter (mm)	10.68(0.81)	8.10(0.51)	NA
Square mean diameter (mm)	3.27(0.12)	2.85(0.09)	NA
Equivalent diameter (mm)	8.19(059)	6.33(0.37)	NA
Gravimetric properties			
100 seeds mass (g)	34.74(7.6)	26.32(4.7)	NA
Bulk density (kg/m^3)			
-Loose	212.0(5.3)	518.1(11.2)	86.1(3.2)
-Tap	223.6(5.8)	531.2(8.9)	97.8(2.1)
Hausner ratio	1.05(0.01)	1.02(0.01)	1.14(0.01)
Frictional properties			
Coefficient of static friction			
-on mild steel	0.69(0.02)	0.37(0.02)	0.42(0.02)
-on glass	0.48(0.01)	0.42(0.01)	0.43(0.03)
-on galvanized steel	0.49(0.05)	0.35(0.01)	0.43(0.01)
-on formica	0.37(0.01)	0.30(0.01)	0.37(0.03)
Dynamic angle of repose (^{o})	46.79(0.6)	42.52(1.42)	71.88(2.07)
Aerodynamic property			
Terminal velocity (m/s)	8.39(0.29)	9.83(0.08)	5.67(0.11)

*All values are averages of replicates (standard deviation) *NA= determination not applicable

compared with other nuts such as cashew, almond, pistachio and filbert nuts for which length, width and thickness were 32.24, 23.23 and 17.02 mm (Oloso and Clarke 1993); 25.49, 17.03 and 13.12 mm (Aydin 2003); 16.86, 12.1 and 11.81 (Kashaninejad, *et al.* 2004) and 25.32, 20.54 and 17.93 mm (Pliestic *et al.* 2006) respectively. However, it is bigger than sweet corn which has 10.47, 8.33 and 3.83 mm of length, width and thickness respectively (Karababa and Coskuner 2007). These results showed drumstick seed to be of lighter weight than peanut, pistachio and almond which have 100 seeds weight of 216, 115 and 264 g respectively (Aydin 2007; Kashaninejad *et al.* 2004; Aydin, 2003).

The kernel-nut ratio of drumstick seed was obtained as 0.74; implying 74% of the nut weight accounts for the kernel while the remaining 24% accounts for the shell. This compares favourably with 0.75 for *kariya* seed (Ogunsina *et al.* 2012) but far greater than 0.25 for cashew nut (Andrighetti *et al.* 1994). Pattee *et al.*

(1977), Pattee *et al.* (1980), Pattee *et al.* (1981), Nautiyal (2002) and Ogunsina *et al.* (2012) used this ratio to estimate expected kernel yield from a given lot of seeds in a nutshell. It provides useful information regarding the kernel quality and may be used to make revenue projections in industrial processing.

The ratios of the dimension and mass of nut to that of the kernel are presented in Table 2; however, the following general expression can be used to describe the relationship between the axial dimensions and mass. For the nuts:

$$D_M = 1.015D_i = 1.092D_m = 33.471M, \quad (9)$$

and for the kernels:

$$d_M = 0.874d_i = 0.903d_m = 30.319m; \quad (10)$$

Table 2. Ratios of drumstick nut and kernel dimensions at a moisture content of 4.64% (w.b)

*Parameters	Ratio			SD
	Mean value	Minimum value	Maximum value	
D_M/D_i	1.015	0.811	1.370	0.142
D_M/D_m	1.092	0.610	1.752	0.242
D_M/M	33.471	21.279	70.952	10.800
d_M/d_i	0.874	0.443	1.327	0.169
d_M/d_m	0.903	0.542	1.229	0.163
d_M/m	30.319	13.772	50.950	7.758
D_M/d_M	1.522	0.806	2.860	0.374
D_i/d_i	1.271	0.856	1.857	0.173
D_m/d_m	1.244	0.698	1.870	0.188
M/m	1.409	0.627	2.408	0.397

* M, D_M, D_i, D_m and m, d_M, d_i, d_m represent the mass, major, intermediate and minor diameters of the nut and kernel respectively.

The frequency distribution of the length, width, thickness and mass of drumstick nuts and kernels shows a normal trend (Figs. 3a and 3b). In Table 3, it is shown that about 17% (by number) of drumstick seeds had lengths greater than 12 mm (termed the large fraction), whereas 58% had lengths in the range of 10-12 mm (termed medium fraction) and 25% had lengths less than 10 mm (termed small fraction).

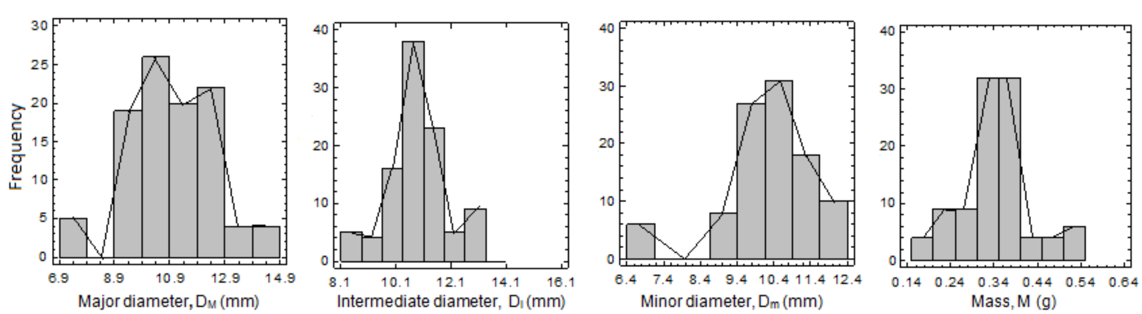

Fig. 3 a. Frequency distribution of drumstick nuts

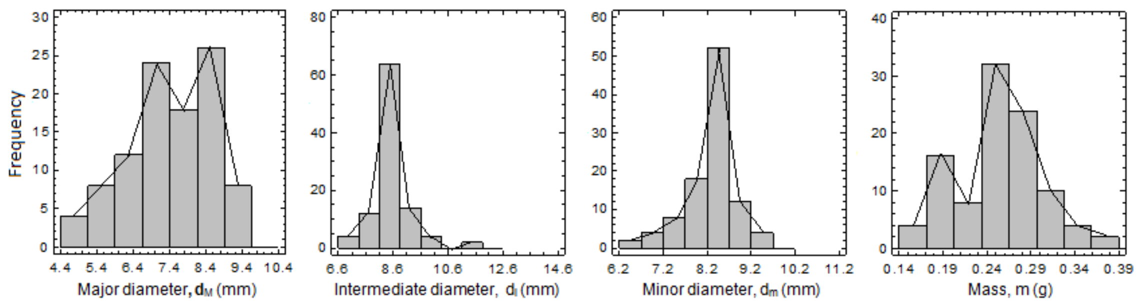

Fig. 3 b. Frequency distribution of *Drumstick* kernels

Fitted linear models that describe the relationship between the mass and axial dimensions of the nut and kernel are presented in Table 4. In equation 11, p>0.05 hence there was no significant relationship between D_M and M; whereas in equation 12 and 13, the relationship between D_M versus Di and D_M versus D_m was statistically significant ($p<0.05$). The R^2 statistics indicate that the fitted model explains 0.26, 11.12 and 4.67% of the variability in D_M respectively.

Table 3. Size distribution of *Drumstick* nuts and kernels at a moisture content of 4.64% (w.b)

Size category	Ungraded	Large	Medium	Small
Length of nut, mm	7.32-14.36	L>12	10-12	<10
Sample size				
By number and percentage	100	17	58	25
By mass (Percentage)	4.74(100)	7.85(22.6)	20.98(60.4)	5.94(17.0)
Average dimensions, nut				
Major diameter D_M, mm		13.04(1.07)	11.73(0.67)	9.09(0.95)
Intermediate diameter D_i, mm		12.44(0.46)	10.88(0.34)	9.58(0.66)
Minor diameter D_m, mm		11.76(0.32)	10.42(0.44)	8.71(1.21)
Mass M, g		0.46(0.05)	0.36(0.02)	0.25(0.05)
Average dimensions, kernel				
Major diameter d_M, mm		8.94(0.18)	7.71(0.63)	5.71(0.58)
Intermediate diameter d_i, mm		9.61(0.87)	8.61(0.15)	7.82(0.43)
Minor diameter d_m, mm		8.97(0.34)	8.40(0.15)	7.53(0.50)
Mass m, g		0.32(0.03)	0.26(0.02)	0.19(0.02)

Table 4. Fitted models that describe the relationship between the mass and axial dimension of drumstick seeds and nuts

Fitted models	Correlation Coefficient	Df	R-squared (%)	Standard Error of Estimate	Mean absolute error	Standard Error of Estimate	*P-Value*	Equation s/no.
$D_M = 10.61 + 1.01*M$	0.0510	1	0.2601	1.5150	1.1615	1.5150	0.6143	(11)
$D_M = 5.60 + 0.49*Di$	0.3335	1	11.1229	1.4301	1.1075	1.4301	0.0007	(12)
$D_M = 13.72 - 0.27*D_m$	-0.2161	1	4.6702	1.4811	1.1663	1.4811	0.0308	(13)
$d_M = 7.81 - 1.46*m$	-0.0567	1	0.3215	1.2150	0.9952	1.2150	0.5753	(14)
$d_M = 11.37 - 0.46*d_i$	-0.2674	1	7.1485	1.1727	0.9617	1.1727	0.0072	(15)
$d_M = 8.88 - 0.17*d_m$	-0.0804	1	0.6470	1.2130	0.9964	1.2130	0.4263	(16)
$M = 0.31 + 0.16*m$	0.0987	1	0.9749	0.0764	0.0526	0.0764	0.3284	(17)
$D_M = 11.95 - 0.13*d_M$	-0.1070	1	1.1447	1.5083	1.1452	1.5083	0.2894	(18)
$D_i= 13.04 - 0.26*d_i$	-0.1785	1	3.1859	1.0059	0.7348	1.0059	0.0756	(19)
$D_m = 14.4 - 0.50*d_m$	-0.2332	1	5.4390	1.1810	0.8408	1.1810	0.0195	(20)

The correlation coefficients in all cases indicate a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals in each model to be 1.51, 1.43 and 1.48 respectively. In equations 14 and 16, since $p>0.05$, the relationship between the variables was not statistically significant; whereas in equation 15, a statistically significant relationship exists between the variables because $p<0.05$. The R^2 statistics in equations 14, 15 and 16 indicate that the fitted model explains 0.32, 7.15 and 0.65% of the variability in d_M respectively. The correlation coefficients showed relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals in each model to be 1.22, 1.17 and 1.21 respectively. In equation 17, with $p>0.05$, there is no significant relationship between M and m. The R^2 statistic indicates that the fitted model explains 0.99% of the variability in M and the correlation coefficient (0.099) indicates a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.076. In equation 18, p-value in the ANOVA table was greater than 0.05, hence no statistically significant relationship exist between D_M and d_M at the 95.0% or higher confidence level. The fitted model explains 1.15% of the variability in D_M as indicated by the R^2 statistic while the correlation coefficient (-0.107), indicates a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.51. In equation 19, $p>0.05$, there is no statistically significant relationship between D_i and $d_{i.}$ The R^2 statistic indicates that the model as fitted explains 3.19% of the variability in D_i. The correlation coefficient equals -0.18, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.01. In equation 20, since the $p<0.05$, the relationship between D_m and d_m is statistically significant at the 95.0% confidence level. The R^2 statistic indicates that the model as fitted explains 5.44% of the variability in D_m while the correlation coefficient equals -0.23, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 1.18. The design of functional units of most machines is decisively influenced by the size, shape and density characteristics of the materials for which the machine is built and for most oilseeds, these properties are indices of product quality (Ozdemir and Akinci 2004).

The sphericities of drumstick nuts and kernels were 98.26 and 110.62% (Table 1). These values are higher than that of pistachio 79.54% (Kashaninejad, *et al.* 2004), filbert nut, 82.86% (Pliestic *et al.* 2006) and bambara groundnut which varied from 87-90% (Baryeh 2001); showing that drumstick seed is more spherical. This information finds relevance in the development of cracking and separation machines for drumstick seeds and other agricultural products with similar physical properties. The geometric mean, arithmetic mean, square mean and equivalent diameters were 10.63, 10.68, 3.27 and 8.19 mm, for the nut; and 8.05, 8.10, 2.85 and 6.33 mm for the kernels. These are less than values obtained for pistachio (Kashaninejad *et al.* 2004), filbert (Pliestic *et al.* 2006) and pea nut (Aydin 2007); which implies that drumstick is a smaller nut/kernel than any of the forementioned.

Further, the results showed that loose bulk density increased from 212 in drumstick nuts to 518.1 kg/m^3 in the kernels. For the nuts, the value is similar to 213.5 kg/m^3 for peanuts (Aydin 2007); while that of the kernels compares favourably with 520.79, 590, 585.8 and 795 kg/m^3 for pistachio (Kashaninejad *et al.* 2004), almond (Aydin 2003), chestnut (Yildiz *et al.* 2009) and bambara groundnut (Baryeh 2001) respectively. As expected, an increase was observed in number of kernels per unit volume than nuts and in both cases, tap bulk density was greater than loose bulk density. Generally, bulk density is an important parameter in the specification of products derived from size reduction or drying processes. Hausner ratio (H_R) of the nut and kernel were observed to be less than 1.4 which implies that drumstick seeds will fluidize easily (Barbosa-Canovas *et al.* 2005). This behavior of drumstick seed is similar to that of kariya seeds (Ogunsina *et al.* 2012).

The air velocities required for suspending the nut, kernel and shell were found to be 8.39, 9.83 and 5.67 m/s, respectively. The trend of these values agrees with 8.02, 7.71 and 2.90 m/s reported for African breadfruit (Omobuwajo 1999). For peanut, wheat kernels, pea and pumpkin seeds, terminal velocities varied from: 7.25-7.93 m/s; 6.81-8.63 m/s; 9.0-9.4 m/s and 2-7 m/s (Joshi *et al*. 1993; Aydin 2007;, Khoshtaghaza and Mehdizadeh 2006; Yalcin 2007). Air velocity greater than the terminal velocity of a given particle lifts it; and when adjusted to a point just below the terminal velocity, it allows greater fall (Mohsenin 1980). The difference between the suspension air velocities of the kernel and the hull indicate that pneumatic separation of one from the other is possible; hence these data in conjunction with gravimetric properties will be useful in the design of aspiration unit for drumstick kernel-shell separation.

Angle of repose of the nuts and kernels were 46.8 and 42.5º. This is close to the range of 30-52° for pumpkin seed and 34-42° for pumpkin kernel (Joshi *et al*. 1993); but higher than 22.36-33.66° for *Balanite aegyptiaca* nuts (Aviara *et al*. 2005), 28.07-43.58° for guna seeds (Aviara *et al*. 1999) and 27.3-37.5° for cocoa beans (Bart-Plange and Baryeh 2003). It was observed that angle of repose of the kernels is lower than that of the nuts, and this may be attributed to the rough nature of the hull which offers resistance to motion when sliding on the test surface. Hopper walls are mostly inclined at an angle greater than the angle of repose so as to allow for free gravitational flow of the products being processed. Static coefficient of friction on mild steel, glass, galvanized steel and formica surfaces were 0.69, 0.48, 0.49 and 0.37 for the nuts and 0.37, 0.42, 0.35 and 0.30 for kernels respectively. On all the surfaces considered, coefficient of friction of kernels was lesser than that of nuts due to the smoother surface of the kernel. For the nuts, values of static coefficient of friction on glass and galvanized steel were almost same; it was highest on mild steel and lowest on formica. However for the kernels, it was highest on glass and lowest on formica. Information about the frictional properties of biomaterials is usually required in the design of hopper and conveyors systems. Overall, the data for frictional properties obtained for the drumstick seed appear to indicate the probable order of roughness of the surfaces, thus indicating that the forces of solid friction were least on formica. Omobuwajo (1999) reported similar observation for breadfruit seeds on formica in comparison with other surfaces considered.

The cracking characteristics of drumstick nut and kernels are shown in Table 5. The average compressive force required to cause rupture for the nut (54.47 N) was less than that of the kernel (67.27 N); implying that the kernel offered more resistant to fracture than the nut. The energy required for cracking the nutshell under quasi-static compression was 100.75 mJ for the nut and 106.71 mJ for the kernel. The higher resistance offered by the kernel to fracture may be due to the incompressibility of the oil-bearing cells inside the kernel. Such behaviour helps in minimizing kernel breakage during cracking. The cracking force is an important parameter in the design of cracking machines. The magnitude of applied force and direction of loading determine the extent of mechanical damage and kernel recovery during cracking and separation.

The hydration and swelling capacities of drumstick kernel were 0.25 g/kernel and 0.47 mL/kernel; while the hydration and swelling indices were 0.96 and 1.78 respectively. The minimum cooking time, water uptake ratio, cooked weight, water absorbed and gruel loss of cooked drumstick kernels are shown in Table 7. Observed values are far greater than a range of 14.33 – 18.03 mins of cooking time, 1.64 – 2.29 of water uptake ratio and 0.31 – 1.49 % of gruel loss reported for brown and parboiled rice (Sareepuang *et al*. 2008). From ANOVA, the values obtained for traditionally kernels were significantly higher than the microwave cooked samples. Water uptake during cooking of soft seeds increases with duration of cooking due to denaturation and disorganization of the cellular structure by heat. The more time it takes to cook, the more water the material will likely absorb (Lisle *et al*. 2000) and implicitly, the more gruel solids will be lost. This may be the reason why more gruel solid was lost in the traditionally cooked kernels than the microwave cooked. Cooking quality of food crops is usually measured in terms of water uptake ratio, grain elongation during cooking, gruel solids loss in cooking water and cooking time. When a grain of seed is cooked, water uptake and swelling of the food item is a diffusive process during which starch undergoes gelatinization. Although microwave cooking of food is faster, it will not suffice for small scale application for cost reasons. Most legumes and oilseeds contain moderate amount of protein, calories, minerals and vitamins, some are rarely known as food in some places due to the presence of some anti-nutritional factors such as saponins, tannins, phenols and alkaloids. Processing methods and traditional treatments such as soaking, cooking/boiling, fermentation and germination are known proven methods for improving their nutritional quality (Chi-Fai *et al*. 1997; El-Adawy 2002; Mubarak 2005; Khattab and Arntfield 2009). Cooking improves protein quality and destroys or in-activate heat-labile anti-nutritional factors (Mubarak, 2005). However, cooking causes considerable losses of soluble solids, especially vitamins and minerals (Barampama and Simard 1995).

4. CONCLUSIONS

Some engineering properties of drumstick seeds were investigated and the following conclusions may be drawn

1. The mean values of 100 measurements for length, width, thickness and mass of drumstick seeds at a moisture content of 4.64% (w.b) were: 10.96, 10.83, 10.24 mm and 0.35 g for the nut and 7.44, 8.59, 8.29 mm and 0.26 g for the kernel.
2. The kernel-nut ratio of drumstick seed was obtained as 0.74; implying 74% of the nut weight accounts for the kernel while the remaining 24% accounts for the shell.
3. The sphericities of drumstick nuts and kernels were 98.26 and 110.62%; while geometric mean, arithmetric mean, square mean and equivalent diameters were 10.63, 10.68, 3.27 and 8.19 mm, for the nut; and 8.05, 8.10, 2.85 and 6.33 mm for the kernels.
4. Loose and tap bulk densities were 212 and 223.6 kg/m^3 for the nuts and 518.1 and 531.2 kg/m^3 in the kernels.
5. The air velocities required for suspending the nut, kernel and shell were found to be 8.39, 9.83 and 5.67 m/s, respectively.
6. Angle of repose of the nuts and kernels were 46.8 and 42.5º. Static coefficient of friction on mild steel, glass, galvanized steel and formica surfaces were 0.69, 0.48, 0.49 and 0.37 for the nuts and 0.37, 0.42, 0.35 and 0.30 for kernels respectively.
7. The average compressive force required to cause rupture for the nut (54.47 N) was less than that of the kernel (67.27 N).
8. The hydration and swelling capacities of drumstick kernel were 0.25 g/kernel and 0.47 mL/kernel; while the hydration and swelling indices were 0.96 and 1.78 respectively. The minimum cooking time, water uptake ratio, cooked weight, water absorbed and gruel loss were 37 mins., 0.74 g/g, 17.43 g/10 g, 7.43 g/10 g and 5.58% for traditionally cooked samples and 20 mins., 0.62 g/g, 15.94 g/10 g, 5.94 g/10 g and 1.47% for the microwave cooked samples.
9. Given the growing interests in the cultivation of drumsticks across Africa and Asia, findings from this study will provide useful information for the development of devices for its cracking, separation, drying, storage and processes that will extend its utilization in various food systems.

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EFFECTS OF EFFLUENT DISCHARGE FROM OIL MINING ON THE PHYSICO-CHEMICAL PROPERTIES OF WARRI RIVER

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ABSTRACT

The insatiable passion for oil as a source of energy worldwide has placed enormous pressure on oil producing communities with consequent high risk of pollution of their soil and water resources. Physico-chemical parameters of Warri River by Ubeji community were assessed in May, 2012 to determine the effects of effluent discharge from oil mining on the river water quality. Samples were collected upstream of the discharge point, at the discharge point and downstream of the discharge point. The parameters were analysed using standard methods. The mean values of the parameters obtained were 44.70, 78.86, 5.38, 766.7, 12.33, 0.04 and 100.56 mg/L for Total Suspended Solids (TSS), Oil and grease, Nitrate, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Lead and Sodium, respectively. Those of Electrical Conductivity and Sodium Adsorption Ratio were 0.48 dS/m and 2.29, respectively. Results showed that values of most of the parameters were above the World Health Organization (WHO) guidelines for drinking water quality. Therefore, the water cannot be consumed without treatment. Though the quality of the water may depress aquatic development, it satisfied the criteria for irrigation.

KEYWORDS: Oil mining, Warri river, pH, effluent, irrigation.

1. INTRODUCTION

Over the years, water quality has been an important parameter used to verify the integrity of water supply. Most streams and river systems are affected by the indiscriminate disposal of effluent. These effluents could be from atmospheric deposition, runoff, and domestic and industrial sources (Lomniczi et al., 2007). More than half of the major rivers around the world today are highly depleted and polluted that they now threaten human health and poison the surrounding ecosystem.

With the high rate of population growth in the developing countries, the rate of demand for fresh water has also increased, thus making it necessary to ascertain the quality of water being supplied. About 25,000 people are estimated to die daily through the use of contaminated water, while millions of others suffer varying and frequent water borne illness (WHO, 2006). Supply of good quality water to ensure good health condition, food production of high quality and yield and sustainable development is one of the major challenges facing Nigeria. For water to be used for irrigation, drinking, and industrial processes or for recreation it must meet some basic requirements in terms of quality.

Although industrialization and waste production is quite inevitable, some major environmental degradation and pollution has been occurring in great magnitude, thereby threatening ecological and human safety. In Nigeria, about 98% of its export earnings are derived from oil resources and that accounts for about 83% of the government's total revenue (Ekundayo, 1998). Oil activities especially in the Niger Delta region is a key source of environmental pollution. With the development of oil industry, contamination of aquatic environment by crude oil and petroleum products constitute an additional source of stress to aquatic organisms (Omoregie *et al.*, 1997).

Industrialization is without doubt an avenue of improving a nation's economic standard. However, toxic elements and oil may get to surface water from day to day operations as a result of accidents, waste discharge, oil spillage, gas emission, agricultural runoff and other reasons, leading to environmental pollution and health hazards . Thus, it becomes imperative to carry out an assessment of the quality of the water bodies in order to establish the extent of contamination and hazard to the environment as a result of oil exploration.

The objectives of this study were to determine the effects of effluent discharge from oil mining activities on the physico-chemical quality of Warri river; and to compare the results obtained with internationally established standards.

2. METHODOLOGY

2.1 Study Area

Warri River by Ubeji community lies between latitude 5°30"N and 5°38"N and longitude 5°38"E and 5°45"E and is situated in Warri South Local Government Area of Delta State, Southern Nigeria. The area is typified by mangrove swamp vegetation with a very high presence of Rhizophorasis specie. The relative humidity of the area ranges between 80% and 92%, while average annual rainfall exceeds 2800mm. The period between the months of April and October is regarded as the wet season, while that between November and March is considered as the dry season. However, a measurable amount of rainfall is recorded virtually in every month of the year. Air temperature ranges between 27^{o}C and 29°C (Egborge, 1994). Figure 1 shows the map of Nigeria indicating the study area.

2.2 Water Sampling and Analysis

Water samples were collected serially using 1.5litre plastic containers at a depth of between 15cm – 30cm below the water surface at different locations namely: upstream, discharge point and downstream of the Warri river. The upstream and downstream are at a distance of approximately 2.5km either away from the discharge point.

The upstream refers to the point where the search for potential underground or underwater oil fields, recovery and production of crude oil and natural gas takes place, while the downstream refers to the point where the sell and distribution of natural gas and other products derived from crude oil takes place. The discharge point refers to the region where effluents from oil mining activities are released into the river. Water sampling, preservation, transportation as well as analysis followed standard methods (APHA, 1998; ASTM, 2001). The pH, TDS and conductivity were measured in-situ using Jennway pH meter model 3510 and Jennway conductivity meter model 4520, respectively. All samples were collected mid-May, 2012.

Sodium Adsorption Ratio (SAR) was computed using equation 1.

$$SAR = \frac{Na^{+}}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}} \quad (1)$$

Cations were expressed in miliequivalent of charge per litre.

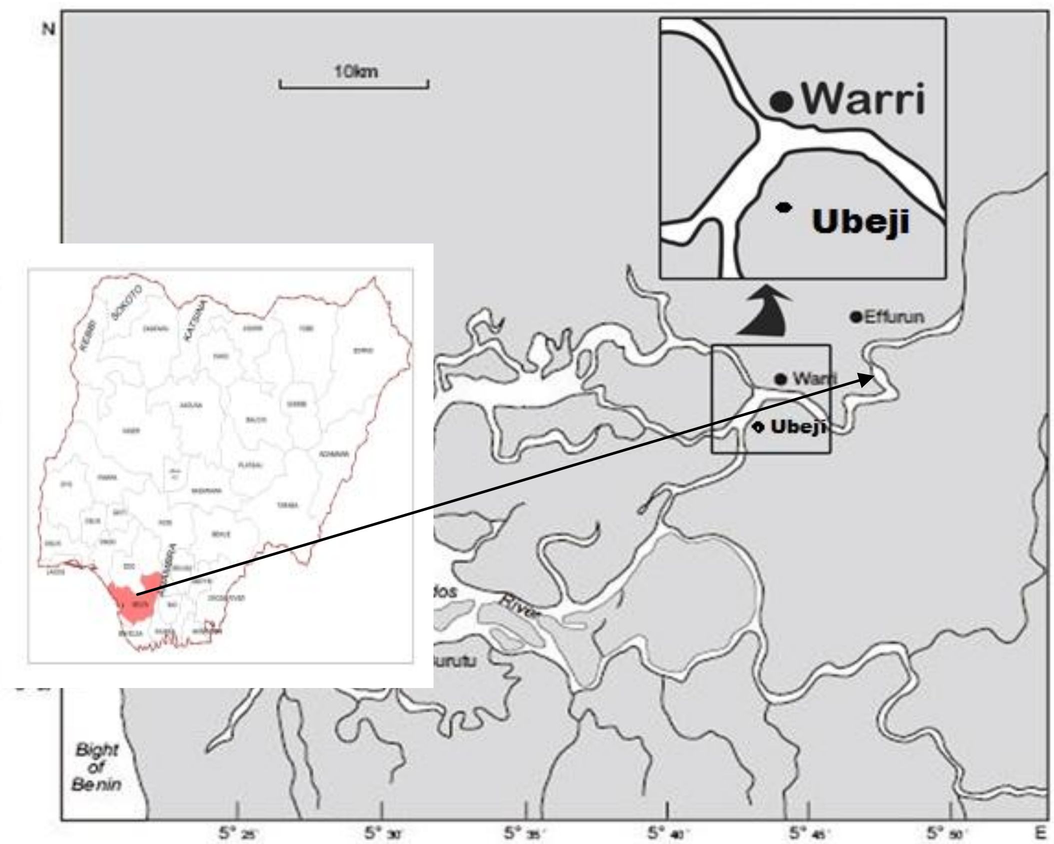

Fig 1: Map of Nigeria Showing Study Area

2.3 Statistical Analysis

Descriptive statistics were used to compute the mean, range and standard deviation, while Pearson's correlation analysis was performed among the various physico- chemical variables in order to fully understand their relationships.

3. RESULTS AND DISCUSSION

The results of the physico-chemical analysis of Warri river are presented in Table 1. Correlation coefficients between various physico-chemical parameters are shown in Table 2. The results were compared with WHO and FAO guidelines for drinking water and irrigation water quality to ascertain the suitability of the water for both drinking and irrigation.

Table 1: Physico-Chemical Properties of Warri River by Ubeji Community.

Parameters	Upstream discharge point	Discharge point	Stations Downstream discharge point	Range	Mean	Stdev limits	WHO limits	FAO limits
T S S (mg/L)	33	62	39	33-39	44.7	15.31	30.00	-
EC (uS/cm)	389	566	493	389-493	483	88.9	1000	200-250
TDS (mg/L)	192	293	239	192-293	241.33	58.31	1000	200-500
pH	5.92	5.11	5.36	5.11-5.92	5.50	0.41	7.0-8.50	200-500
Oil and grease (mg/L)	11.34	207.11	18.1	11.12-207.11	78.86	111.12	10	-
Nitrate (mg/L)	1.6	9.75	4.0	1.6-9.75	5.38	4.11	0.2	≤ 30
Nitrate (mg/L)	0.16	0.96	0.21	0.16-0.96	0.44	0.45	50	0 – 10
Phosphate (mg/L)	BDL	0.26	BDL	0 – 0.26	0.26	0.15	0.30	0.1
Sulphate (mg/L)	10.21	13.22	9.89	9.89 - 13.22	11.11	1.84	250	0 – 20
Iron (mg/L)	0.36	0.63	0.49	0.36 – 0.63	0.5	0.31	0.30	-
Chloride (mg/L)	64.83	94.33	73.1	64.83 – 94.33	77.45	15.21	200	0 – 30
BOD (mg/L)	8	17	12	8-17	12.33	4.51	< 4	-
COD (mg/L)	320	1600	380	320-1600	766.7	722.31	< 10	-
Total Hardness (mg/L)	22	31	26	22 - 31	26.33	4.51	100	-
Copper (mg/L)	< 0.001	< 0.001	< 0.001	-	-	0.00	0.05	0.2
Zinc (mg/L)	0.03	0.10	0.05	0.03 – 0.10	0.06	0.03	5	2.0
Manganese (mg/L)	< 0.001	< 0.001	< 0.001	-	-	0.00	0.05	0.2
Lead (mg/L)	0.02	0.06	0.04	0.023 – 0.0	0.04	0.02	0.001	-
Sodium (mg/L)	81.04	117.92	102.71	81.04 – 117.92	100.56	18.53	200	0 – 40
Calcium (mg/L)	56.38	82.03	71.45	56.38 – 82.03	69.95	12.90	75	0 – 20
Magnesium (mg/L)	36.69	53.40	46.51	36.69 – 53.40	45.53	8.40	200	30 , 50

BDL = Below detection limit; Stdev = Standard deviation

Table 2 Pearson's correlation coefficients between the physico-chemical parameters

	pH	**EC**	**TDS**	**TSS**	**O&G**	**COD**	**BOD**	**Ph**	**NO_3**	**NO_2**	**SO_4**	**Cl**	**TH**	**Fe**	**Zn**	**Pb**	**Na**	**Mg**	**Ca**
pH	1.00																		
EC	-0.993	1.0																	
TDS	-0.954	0.912	1.00																
TSS	-0.856	0.910	0.660	1.00															
O&G	-0.758	0.829	0.526	0.986	1.00														
COD	-0.765	0.835	0.536	0.988	1.00**	1.00													
BOD	-0.961	0.986	0.832	0.966	0.909	0.914	1.00												
Ph	-0.738	0.811	0.500	0.981	1.00*	0.999*	0.896	1.00											
NO_3	-0.942	0.975	0.797	0.980	0.933	0.937	0.998*	0.922	1.00										
NO_2	-0.744	0.843	0.548	0.990	1.00*	1.00**	0.920	0.998*	0.942	1.00									
SO_4	-0.676	0.757	0.423	0.960	0.993	0.992	0.854	0.996	0.844	0.990	1.00								
Cl^-	-0.895	0.941	0.719	0.997	0.969	0.972	0.984	0.962	0.993	0.975	0.934	1.00							
TH	-0.961	0.986	0.832	0.966	0.909	0.914	1.00**	0.896	0.998*	0.920	0.854	0.984	1.00						
Fe	-0.996	0.978	0.977	0.804	0.694	0.702	0.931	0.672	0.907	0.712	0.605	0.850	0.931	1.00					
Zn	-0.837	0.895	0.633	0.999*	0.991	0.993	0.956	0.987	0.972	0.994	0.969	0.993	0.956	0.782	1.00				
Pb	-0.992	1.00**	0.906	0.916	0.836	0.842	0.989	0.819	0.978	0.850	0.766	0.945	0.989	0.975	0.901	1.00			
Na	-0.993	1.00**	0.912	0.910	0.829	0.835	0.986	0.811	0.975	0.843	0.757	0.941	0.986	0.978	0.895	1.00**	1.00		
Mg	-0.993	1.00**	0.912	0.910	0.829	0.835	0.986	0.811	0.975	0.843	0.757	0.941	0.986	0.978	0.895	1.00**	1.00**	1.00	
Ca	-0.993	1.00**	0.912	0.910	0.829	0.835	0.986	0.811	0.975	0.843	0.757	0.941	0.986	0.978	0.895	1.00**	1.00**	1.00**	1.00

* Correlation is significant at $p < 0.05$ level (2- tailed) ** Correlation is significant at $p < 0.01$ level (2- tailed)

3.1 Drinking Water Quality

Values of pH are important in ascertaining the suitability of water for different purposes, including toxicity to man and plants. The pH values obtained from the upstream, discharge point, downstream and their mean are 5.92, 5.11, 5.36 and 5.46, respectively. None of the values obtained fell within the permissible limit prescribed by WHO (2006) as shown in Table 1. The discharge of the effluent had a marked effect on the acidity of the river leading to lowered pH. Chetana and Somasekhar (1997) in a similar study of River Cauvery, observed the same trend. Correlation analysis showed that pH exhibited significant negative correlation with EC, Fe, Pb, Na, Mg and Ca (r=-0.993, -0.996, -0.992, -0.993, -0.993, -0.993, respectively).

The values of electrical conductivity obtained at the upstream (389µS/cm), discharge point (566 µS/cm), and downstream (493 µS/cm) were all within the permissible limit set by WHO. Conductivity however increased after the discharge of the oil effluent. The increased level of conductivity and the cations after effluent discharge indicates the effect of decomposition and mineralization of organic materials as reported by Abida and Harikrisha (2008). Electrical conductivity showed a significant positive correlation with lead, sodium, magnesium and calcium ($r = 1.00$ for each at $p < 0.01$), and total dissolved solids, total hardness ($r = 0.912$ and 0.986, respectively). This result is in agreement with the findings of Venkatesharaju et al. (2010).

When the electrical conductivity concentration of water is too high or too low, it may limit the survival, growth or reproduction of aquatic organisms.

The TDS for the upstream (192mg/L), discharge point (293mg/L), the downstream (239mg/L) and the mean (241.33mg/L) of the study area all fell within the allowed limit set by WHO , and is therefore not considered a threat to human health. TDS is not regarded as a primary pollutant to water, but it is used as an indication of the aesthetic quality of drinking water.

The concentrations of the total suspended solids obtained were higher than the maximum limit of <30mg/L recommended by WHO as shown in Table 1. The high value of TSS may reduce water clarity, affect photosynthesis appreciably and depress plankton development. TSS showed a significant positive correlation with zinc ($r = 0.999$ at $p < 0.05$).

All sulphate concentrations obtained were within the WHO limit as shown in Table 1, and thus poses no health problems. Sulphate concentration in excess of 250mg/L may give water a bitter taste and also has a laxative effect on individuals that are not adapted to using such water.

Total phosphorous was below detection level both at the upstream and the downstream, while the discharge point concentration (0.26mg/L) was also below the limit specified by WHO as shown in Table1. Absence of phosphorus in the study area will limit aquatic plant growth. The total hardness concentrations recorded for the study sites were all within the permissible limit set by WHO (Table 1).

The total hardness concentrations obtained does not pose any health hazard to human health. Values above the prescribed limit causes poor leathering with soap, skin irritation and formation of scales. Hardness of water also helps to reduce metal toxicity to fishes by preventing them from absorbing toxic metals like lead, arsenic and cadmium.

The nitrate and nitrite concentrations obtained in the study sites were below the maximum limit set by WHO (Table 1). High concentration of nitrate can cause methemoglobenia (blue baby syndrome), a condition commonly found in infants below 6 months.

The presence of high nitrite concentration in the blood encourages the conversion of hemoglobin to methemoglobin which causes methemoglobania (blue baby syndrome). Pregnant women and adults with insufficient stomach acidity, and people with inadequate enzymes that changes methemoglobin back to hemoglobin can suffer severe methemoglobenia which can result to brain damage and death.

The concentrations of oil and grease in the water at the sampled stations far exceeded the permissible limit of 10 mg/L (Table 1). The discharge point recorded the highest concentration of 207.11mg/L, the upstream concentration was 11.34mg/L, and the downstream was 18.12mg/L. The high values implies that aquatic species are at risk of being killed directly through coating and asphyxiation, contact poisoning or from water soluble components when exposed to them. This is because aerobic oxidation of oil required large quantities of oxygen. Oil and grease exhibited significant positive correlation with COD ($r = 1.00$ at $p<0.01$), phosphorus and nitrite ($r = 0.05$ at $p < 0.05$, respectively).

The values of BOD obtained were higher than the maximum permissible limit of 4mg/L (Table 1). The discharge point had the highest concentration of 17mg/L, followed by the downstream (12mg/L), and the upstream (8mg/L). High value of BOD implies a high rate of oxygen depletion and thus less oxygen available for higher form of aquatic life, as aquatic organism become stressed, suffocate and die. BOD showed significant positive correlation with nitrite and total hardness ($r = 0.998$ at $p < 0.05$ and $r = 1$ at $p < 0.01$, respectively).

Chemical oxygen demand (COD) value determines the quantity of organic matter in water and dictates the level of oxidation of reduced chemicals. COD concentration observed was higher than the WHO recommended value of 10mg/L (Table 1). High COD levels in the study area could be attributed to an increasing level of organic and inorganic substances being added from the environment, which may be due to oil pollution. Chemical oxygen demand was found to have significant positive correlation with phosphorus ($r = 0.999$ at $p < 0.05$), nitrite ($r = 1.00$ at $p <0.01$) and oil and grease ($r = 1.00$ at $p < 0.01$), respectively.

Two heavy metals Fe and Pb were above the permissible limits (Table 1), while Zn and Cu, were below the limits. High iron concentration in water causes slight toxicity and makes water to have a stringent taste and causes laundry and porcelain stain. Pregnant women with elevated blood lead level are susceptible to lead poisoning and thus could give birth prematurely or to a child with low birth weight. High lead concentration also affects the mental development in infants, it causes cancer and it is also established to be toxic to the central and peripheral nervous system.

Calcium concentration at the discharge point (82.029mg/L) exceeded the permissible limit, while the upstream (56.337mg/L) and downstream (71.449mg/L) values were below the permissible limit (Table 1). Calcium concentration above the acceptable maximum limit encourages incrustation of pipes, poor leathering and cloth quality deterioration. When calcium is absorbed in excess, the excess intake is excreted by the kidney in most healthy individuals.

The concentrations of manganese and sodium in the study area were all below the maximum permissible limit prescribed by WHO (Table 1), and thus are not source of health problems. Sodium correlated positively with conductivity and lead.

The mean concentrations of magnesium at the upstream (36.689mg/L), discharge point (53.396mg/L) and the downstream (46.509mg/L) were all above the maximum recommended limit by WHO (Table 1). Sulphate values were found to be below the permissible limit. Magnesium correlated positively with EC, Pb and Na. Drinking water high in magnesium and sulphate concentration causes laxative effect.

3.2 Suitability for Irrigation

The pH values of the discharge point and downstream point of the study area all fell below the FAO recommended range of 5.5 - 6.5 for irrigation (Table 1). The upstream figure, however, is within the accepted limit with a value of 5.92. The result shows that effluent discharge from oil mining impacted acidity to the river. Acidic water can cause some nutritional problems that affect plant growth.

Table 3 shows the calculated values for the electrical conductivity in decisiemens per meter (dS/m) and sodium adsorption ratio for the study area, while Table 4 presents irrigation water quality standards based on FAO (Ayres and Westcott,1985) and the Canadian Council of Ministers of the Environment (CCME, 1999) guidelines.

Table 3: Calculated Values for Electrical Conductivity and Sodium Adsorption Ratio

	Upstream	Discharge point	Downstream	Mean
Electrical conductivity (dS/m)	0.339	0.566	0.493	0.483
Sodium adsorption ratio	2.056	2.479	2.314	2.293

Table 4 Standard irrigation water quality values.

Parameter	pH	Electrical conductivity (dS/m)	Sodium adsorption ratio
Limiting Values	5.5-6.5	< 0.7	0 – 3
FAO	6.5-8.5	< 1	< 4
CCME			

Salinity is usually evaluated using the electrical conductivity (dS/m) and/or the total dissolved solids. Electrical conductivity is a reliable indicator of total dissolved solids (salts) content of water. The addition of irrigation water to soils adds to the concentration of salts in the soil. Concentration of these salts will give rise to increased osmotic potential in the soil solution, thus interfering with extraction of water by the plants. Toxic effects may also result with increased salinity. Comparing the figures in Table 3 with that of the irrigation water quality guidelines (Table 4) shows that each study site had no potential of causing salinity hazard as they are within the recommended range. The only perceived hazard is the acidity impacted on the river by the effluent discharge which lowered the pH values at the discharge point and downstream of the discharge point, respectively.

Sodium adsorption ratio is an indicator of sodium hazard of water. Excess sodium in relation to calcium and magnesium concentration in soils destroys soil structure and may lead to reduced infiltrability of water into the soil. Sodium in excess may be toxic to some crops.

Based on the irrigation water quality guidelines (Table 4), the Warri river by Ubeji community has no sodicity problem but can be used for irrigated agriculture with caution because of the high acidity of the effluent.

4. CONCLUSIONS

The study assessed the effect of effluent discharge from oil mining activities on the physico-chemical qualities of Warri river. The results indicate that Warri river by Ubeji community is highly polluted and not safe for human consumption without treatment. This assertion is based on the high concentration of parameters obtained at the discharge point which were much higher than those at both the upstream and the downstream sites of the study area.

The results revealed that the discharge effluent quality fell short of standard requirements critical to the provision of safe drinking water such as pH and organic waste (measured as TSS, BOD, COD, nitrate and nitrite). The results also indicated that the effluent discharge impacted acidity to the river system. The results of this study has shown that the discharge effluent could pose serious health and environmental challenges to Ubeji community dwellers who rely on the river water for their domestic use without treatment and may also affect aquatic life in the receiving water. The suitability of the river water for irrigation is not in doubt as it satisfied the basic irrigation water quality requirements. Arising from this study is the need for continuous quality monitoring of surface waters in rural areas similar to Warri river.

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DESIGN AND CONSTRUCTION OF A DEVICE FOR MEASURING STREAM FLOW IN SMALL IRRIGATION CHANNELS

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ABSTRACT

A low cost technology device for measuring streamflow in small streams and irrigation channels was designed, constructed and tested. Adequate monitoring of stream flow will provide a good information for planning and management of any irrigation project. Hydrograph which shows depth of flow was produced through the plotting mechanism from which also discharge can be calculated. The plot identifies peak rates of flow and distribution of rates of flow. It is recommended for further improvement.

KEYWORDS: Irrigation, streamflow measurement, hydrograph, discharge, low cost device.

1. INTRODUCTION

The need for accurate stream flow measurement cannot be over stressed as effective measurement and monitoring will lead to the solution of soil and water management problems. The conservation of these vital resources implies utilization without waste so as to make possible a high level of production that can predict erosion yield, evapotranspiration, and water balance etc. Sound streamflow measurement will reduce the engineering problem involved in soil and water conservation such as erosion control, drainage, irrigation, flood control, moisture conservation, and water resources development. More importantly, information concerning the relationship between water, soil and plant cannot be utilized in irrigation practice without the correct and efficient measurement of water flow.

The irrigation or hydraulics engineer involved in the design of structures to handle natural surface flow is mainly and basically concerned with peak rate of stream flow (runoff), volume, and temporal distribution of the rate and volume. If the rate and volume are excessive or high, it may become undesirable and may result to erosion, flood and consequent disturbances of plant and animal life on the agricultural land (Walters, 1979). The effective and efficient use of water for irrigation depends largely on runoff measurement.

The problem of estimating runoff of rivers is very complex, as it involves the consideration of the area and time variation of the input (rainfall), the geological structure of the basin, variation in climatic conditions, vegetation cover, water use, etc. The time variation of precipitation includes differences with respect to an individual rainfall event as well as daily, monthly and seasonal changes. In dealing with large basins, therefore, daily, monthly or yearly average of rainfall are used. In working with time averages, the length of time of records becomes important. The longer the periods of observations the more valid the average computations. Forecast for future stream flow could also be based on the graph of some of the streams with similar periodic variations (Bonella et al 2000; Weight and Sonderegger, 2001; Mason, et al., 1995; Rantz, 1982).

The shape of any runoff measuring device is mainly influenced by the choice of the designer, cost of manufacture installation, and maintenance of the device etc. The shape (geometry), roughness and permeability of a channel affect the flow through it. Irregularities and other minor obstacles (stones, vegetation etc) to flow are represented by a friction factor for each particular reach of channel (Gerraro 2000; Uzege, 2011 and Onyeamu, 2012).

The objective of the study is to design and construct an effective and efficient lowcost device for measuring stream flow on small streams and irrigation channels for low income irrigation farmers.

2. MATERIALS AND METHOD

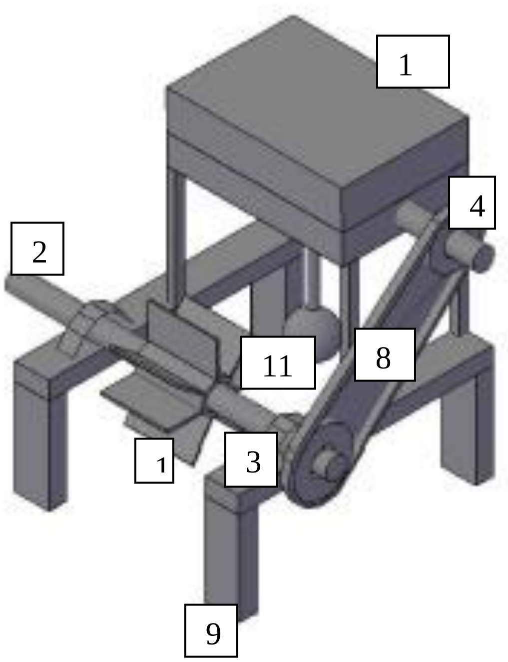
2.1 Study Area

Makurdi (Benue State of Nigeria) which is situated in the Lower Benue River Basin is located between 7˚ 45"North and Longitude 8˚ 32"East. The climatic condition in Makurdi is influenced by two air masses; the warm moist Southwesterly and the warm dry Northeasterly. The Southwesterly air mass is a rain-bearing wind that brings about rainfall from the month of April to October and the dry Northeasterly air mass brings dry season from November to March. The mean annual rainfall is about 1,290mm. The land is generally low lying, gently undulating, broad open valleys and flood plains.

The soils are mainly oxisols and ultisols (tropical ferruginous) which vary over space with respect to texture, drainage, gravel content, etc. A typical profile is highly weathered with sandy surface layer overlying clay mottled subsoil. Benue State lies in the Southern Guinea Savannah, and agriculture is widely practiced and this has earned the State the appellation, 'Food Basket of the Nation'.

2.2 Description of the Device (The Components)

Figures 1a and 1b show an orthographic and top views of the device respectively. The design was conceived to overcome the problem of high cost of imported device for measuring flows in small channels or streams. It was fabricated locally with available materials and it is affordable; easy to operate and to maintain. Figure 2 shows the plotting mechanism. The component parts are described below.



Key

No.	Component	No.	Component
1	Turbine wheel	7	Turbine pulley
2	Turbine Shaft	8	Belt Drive
3	Bearings	9	The Frame
4	Helical Gears	10	Glass window
5	Rollers	11	Float Ball
6	Plotter wire	12	Plotting box

Figure 1a: Orthographic diagram of the measuring device

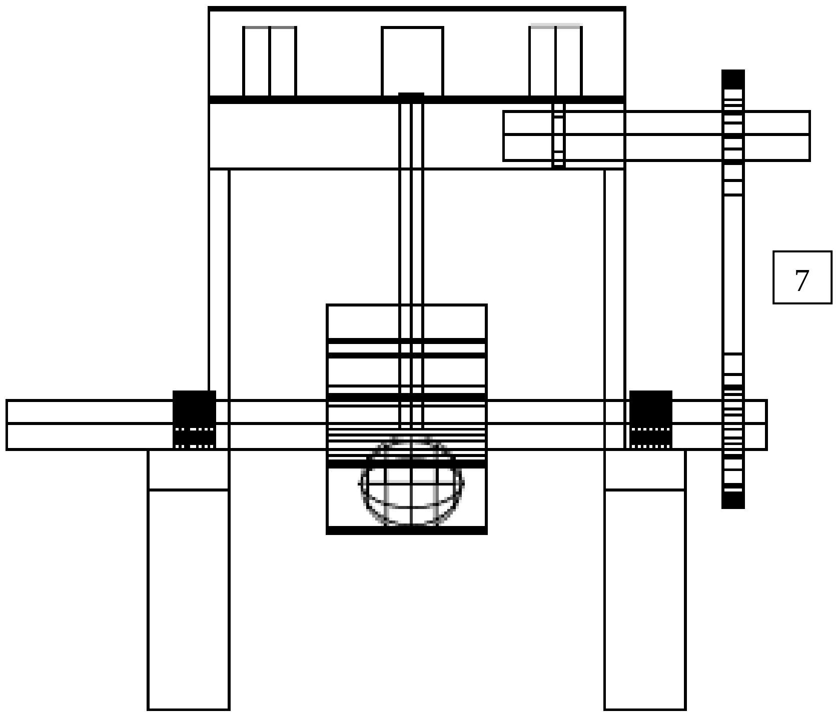


Figure 1b Top view of the measuring device

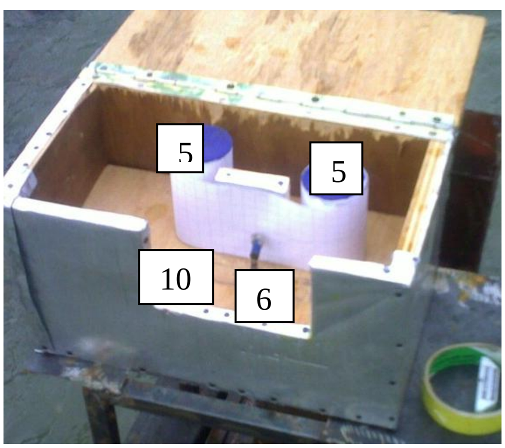


Fig 2: Showing the graph and plotting components

2.2.1 Turbine Wheel

A turbine wheel (also called a rotary wheel) propels as flowing water strikes the blades or paddles at the bottom of the wheel. There are eight blades of size 25 X 18.5 cm coated with rust resistant material and distributed 22.5^{o} on the circumference of the turbine shaft. The power from the wheel is transmitted to the roller by means of pulley, rope drive and gear system.

2.2.2 Shaft

The shaft is a rotating member used to transmit power by torsion. It is usually of circular cross section. Mild steel was used for the hollow shaft of 15mm outer diameter and 10mm inner diameter because of its ductility and fatigue resistance properties. The shaft can withstand the rotational force and does not buckle due to action of the component on it vertically. Two shafts made of mild steel were used. Shaft 1 supports the turbine wheel and transmits power through rope and pulley system while shaft 2 connects the gears and the second pulley. Shaft 1 which is hollow is 22mm in diameter and 40mm in length. Shaft 2 is solid with 15mm diameter and 220mm in length.

2.2.3 Bearings

A bearing is a machine member or component which permits other members connected together to either rotate or translate relative motion to one another. Two ball bearings of 25mm internal diameter were used for the turbine wheel shaft while two bearings of internal diameter 15mm were used for the gear shaft. This will help to reduce the friction from a particular point and balance the shaft from wobbling effect.

2.2.4 Rope Drive and Pulley

A rope drive was employed to transmit power from the driving pulley to the driven pulley. Two pulleys made of iron were used which gave an advantage of continous operation of device in water without damage. The bigger pulley (155mm in diameter) was used for the shaft whereas the smaller pulley (25mm in diameter) was used for the turbine shaft. Rope was selected to transmit power between the two pulleys. This was choosen for its flexibility and to minimize slip between the pulleys and the belt.

2.2.5 Roller and Roller Frame

Two plastic cylinderical rollers 80mm in length and 50mm diameter were positioned vertically on the plot board. The two rollers were separated by a distance of 120mm. The master roller is mounted on the gear shaft and it recoils the hydrograph after plot. The slave roller on which the graph is wound releases it to the plot board where the plotter marks the level of the stream on the graph. The roller frame was made of the plywood (covered with aluminium sheet) and its dimension is 330 X 180 X 180mm. It has two chambers – the upper chamber which houses the two rollers, plot board and the plotter; the lower chamber houses the gears, gear shaft and gear shaft bearings. The chamber is provided with door at the top to enable the operator load chart (graph) and collect hydrograph. Glass window is also provided at the front to enable the operator view the condition of the rollers without opening the door. The wooden frame was covered with alluminium sheet which is an advantage in operating the device all through the year.

2.2.6 Gear

Gears are used for transmitting power generated at a constant velocity ratio between two shafts whose axes intersect at a certain angle. Helical gears were used to provide smooth drive with a high efficiency of transmission. On one helix is wound right handed and on the other it is wound left handed. The arrangement of the helix gave advantage of transmitting motion from horizontal to vertical axis.

2.2.7 Plotter

The plotter is made of pencil (pointing perpendicular to the plot board) attached to a thin wire which dropped down through a small pipe of 5mm diameter fixed in front of the plotting board. The plotter is connected to the float ball (a plastic ball of 80mm in diameter attached to the wire connected to the plotter) with a wire and the float ball rests on the surface of water during operation. The plotter rises and falls as the level of water increases and decreases.

2.3 Operation of the Device

The device mechanically converts a counter weight float resting on the surface of the flowing water into curve or a straight line depending on the level of the stream. As the flowing water turns the turbine wheel, the turbine shaft transmits motion to the gear shaft by the means of rope and pulley system. The horizontal motion of the gear shaft is converted to vertical motion with the help of two helical gears positioned perpendicular to each other. The master roller fixed on the second helical gear turns the graph sheet over the surface of the board. As the graph sheet moves over the plot board which is fixed between the master and slave rollers, the plotter (on which a pencil is fixed) makes traces of the water level on the graph sheet as the float ball moves up and down due to the level of the flowing water.

The discharge of the stream at a section is calculated using equation 1 below.

$$Q = VA \ \ (m^3/s) \tag{1}$$

where $V = \frac{1}{n} R^{2/3} S^{1/2}$ (2)

$A = by$ (3)

and $R = \frac{by}{b+2y}$ (4)

where V = Velocity of flow across the section (m/s), A = Area of cross-section (m^2), y = height of flow as recorded by the device (m), b = breath of channel (m), S = slope of the channel, n = Mannings roughness coefficient.

2.4 Costing

The cost of producing the device in terms of materials and labour based on the prevailing market prices at the time of design and construction was ₦13,860.00 (Nigerian currency) or USD 90.00 (at the exchange rate of ₦154/ $).

3. RESULT AND DISCUSSION

Sample of runoff graph (hydrography) as plotted by the plotter of the device is shown in Figure 3.

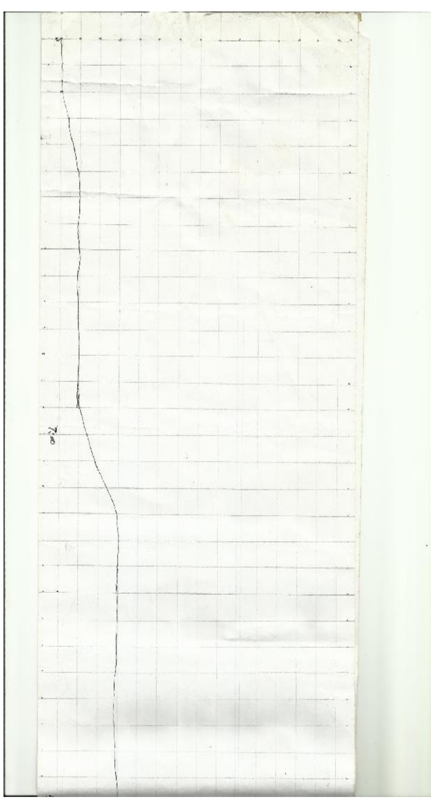


Figure: 3 Runoff hydrograph as plotted by the device.

Stream guaging will provide information to the farmer whether the stream will have enough yield for his irrigation through the year for effective and continuous crop production. Flood- flow prediction that is sometimes based on permanent characteristics can also be achieved with this hydrograph. Transient influences include the storage capacity of bedrock and soil, the interrelationships of infiltration, evaporation, and interception and detention (especially by vegetation), storm characteristics, which vary widely in amount, duration, intensity, and location.

The time-discharge or time-stage characteristics of a given flood peak tends to assume a trend for a given station in response to a given input of water. The peak flow produced by a single storm is superimposed on the base flow, the water already in the channel and being supplied from the groundwater reservoir. Rise in peak discharge is relatively swift in small basins and on torrents where the duration of the momentary peak is also short. On very large streams, by contrast, peak discharge can be sustained for lengths of days. Recession from peak discharge is usually exponential as shown in the sample hydrograph. The form of hydrograph for any station or stream is affected by characteristics of the channel, drainage net, and basin geometry. This means that the channel's configuration and pattern, and the presence of vegetation in and along the channel will also have effect on the hydrograph shape. A stream with longitudinal profile will show a more rapid response and will produce high peak discharge than one that is not as steep. Shorter and wider catchments produce more discharge than longer and narrower ones because of the shorter travel time.

For the equipment to perform optimally the following recommendations are imperative:

i. the upstream area must be kept free of weeds and trash. Sediment must be removed as it accumulates.
ii. the bearings should be lubricated regularly as lubricants periodically in small amounts will slow the rate of wear.
iii. yearly painting is recommended to prevent corrosion and rust formation.

4. CONCLUSION

The device for guaging small streams was designed and constructed. The device was installed and tested. The installation and maintenance are simple. The device was able to produce a hydrograph that shows the flow pattern. From the hydrograph the discharge across a stream or channel section can be calculated.

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EVALUATION OF THE COMPRESSIVE STRENGTHS OF SOME LOCAL CANAL LINING MATERIALS

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ABSTRACT

The compressive strengths of some local materials were determined to ascertain their strength and suitability for canal lining. These materials were: (i) Concrete (GC): which comprised of Cement, Sand and Granite of average sizes of between 9.0 mm and 14 mm, in a ratio of 1:2:4. (ii) Termite Mound (TM) (iii) Clay Cement (CLC) (iv) Cementitious Clay (CCL), and (v) Clay Soil (CLS). These materials were moulded into 100 mm x 100 mm x 50 mm and allowed to cure for 28 days. The compressive strengths were determined at 7, 14, 21 and 28 days during the curing period. Concrete had the highest compressive strength of 2.373 N/mm^2, followed by Burnt Cementitious Clay, Clay Soil, Clay – Cement and Termite Mound, with values of 1.233 N/mm^2, 1.188 N/mm^2, 0.692 N/mm^2 and 0.315 N/mm^2, respectively. Results also showed that the compressive strengths increased as the curing days increased, while the dry density decreased. The materials can compete favourably with concrete in terms of strength.

KEYWORDS: Irrigation, compressive strength, canal lining, demoulded sample.

1. INTRODUCTION

The conveyance of water from the source to the farm and the losses encountered had been the greatest headache of farmers. The volume of water lost in conveyance is so enormous that if judiciously harnessed, it can be used to expand area of irrigation. Saving water is very Germaine to the production of food and meeting the urban water requirements. Therefore, lining of a canal is essential for efficient use of land and water resources (Swamee *et al.,* 2000).

Kasali *et al. (*2002), enumerated the materials currently used globally for canal lining as concrete, Polyvyl chloride (PVC), Asphaltic material, Polyethylene compounds, stone and brick masonries, etc. In many countries, low cost materials such as impermeable earth, bentonite, polythene sheets, etc, are being used as low cost linings to minimize water losses in irrigation at varying degrees of success but their durability is very uncertain (Khair *et al.,* 1991).

The conventional lining materials are expensive. It is therefore necessary to search for potential lining materials that are local and found in the vicinities of small holder irrigation farmers. The use of these materials will necessitate having the knowledge of their compressive strengths. Concrete which is usually used for lining in Nigeria and globally is particularly expensive due to the high cost of two of its components; cement and granite.

The escalating cost of cement is as a result of the energy crisis in Nigeria, which has an astronomical effect on its cost of production. Most of these local lining materials, especially Termite Mound and Clay soil have been confirmed to be efficient in lining of irrigation canals (Akamigbo, 1984; Hong *et al*., 2007); but little is known on their strength, an attribute that allows lining materials to withstand scouring. Compressive strength is the most often used property for determining the response of a material to maximum compressive loading per unit area. This property can be used as one of the indices to ascertaining the durability of a material.

The objective of this study was to determine the compressive strength of these materials to ascertain their suitability in irrigation canal lining.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was carried out at the National Centre for Agricultural Mechanization (NCAM), Ilorin. Ilorin is geographically located in the middle belt of Nigeria with a vegetation of derived savannah, and is situated on a longitude of 4^0 30' E and latitude of 8^0 26 N.

2.2 Sample Preparation

Samples of each of the treatment materials of dimension 100mm x 100mm x 50mm were prepared. The concrete samples were mixed at a ratio of 1: 2: 4 (Cement: Sand: Aggregate) in accordance with BS 1881(1970). A coarse aggregate of average sizes between 9.0 and 14.0 mm was used in the mix. The metal moulds were cleaned and oiled to ease the quick removal of the moulded concrete samples from the boxes without cracks. The mix was then moulded into the metal boxes. The moulded specimens were demoulded after 24 hours of casting and air-dried under a shed during the curing period.

Other samples; Clay, Termite and Cementitious - Clay, were also mixed with water and moulded into plastic mixtures. The samples were moulded in metal boxes of dimension 100mm x 100mm x 50mm. The moulded samples were air-dried under the shed to avoid cracking that could have occurred under direct sun- drying.

The resulted Cementitious - Clay moulds were demoulded after 24 hours of casting when the specimen had attained certain level of strength for handling. The Cementitious - Clay moulds were then arranged in a heap and traditionally fired at a temperature between 600 ^{0}C- 1300 ^{0}C (Apebo *et al.*, 2013).

Each specimen was weighed at 7. 14, 21 and 28 days, before the determination of the compressive strengths at the specified days. The weights were then used to compute the dry densities of the specimen to ascertain the changes in dry densities as the curing days increased.
The dry density was determined as:

$$\rho = \frac{Wms}{Vms} \quad \textbf{(1)}$$

where: ρ = Density of specimen (kg/m^3); W_{ms} = Weight of moulded specimen (kg);

V_{ms} = Volume of moulded specimen (m^3)

2.3 Compressive Strength of the Samples

Three samples from across the treatments were removed from the bulk samples for testing. The compressive strengths of the specimens were determined during the 28 - day curing period with the Universal Testing Machine (UTM) at ages of 7, 14, 21 and 28 days, respectively. At each measurement, the load was applied smoothly and gradually at the rate of 10mm/min. until the sample failed.

The compressive strength is given as:

$$\sigma = \frac{F_{\max}}{A_{ms}} \qquad (2)$$

where: σ = Compressive strength (N/mm^2); F_{max} = Maximum load (N); A_{ms} = Area of moulded specimen (mm^2)

3. RESULTS AND DISCUSSION

Figure 1 shows the compressive strengths of treatments at 7, 14, 21 and 28 days of curing after lining. Results from Figure 1 show that the compressive strengths of all the treatments increased with increasing days of curing. This is expected because as the days of curing increased, the void in the specimen continued to reduce due to loss of moisture leading to loss of weight of samples and hence reduction in dry density (Table 1).

Table 1: Dry Density of Treatments Specimen

Treatment	Average Weight, Kg				Dry Density, kg/m^3			
	Curing Days							
	7	**14**	**21**	**28**	**7**	**14**	**21**	**28**
Clay-cement	1.875	1.179	1.061	0.923	1875	1179	1061	923
Concrete	3.000	1.598	1.535	1.500	3000	1598	1535	1500
Burnt Clay	0.900	1.181	1.160	1.200	900	1181	1160	1200
Clay	1.109	1.061	0.848	1.001	1109	1061	848	1001
Termite Mound	2.250	1.258	1.182	0.923	2250	1258	1182	923

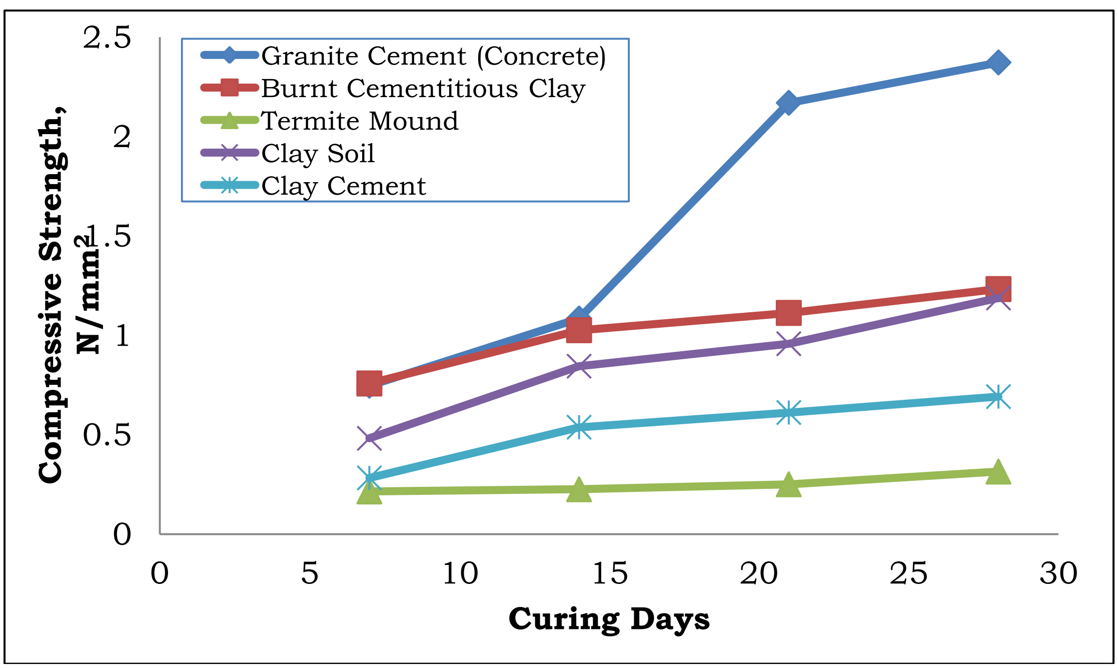

Figure 1: Compressive Strength of lining Materials

The compressive strength of Concrete of 2.373 N/mm^2 was the highest, followed by Burnt Cementitious Clay, Clay Soil, Clay – Cement and Termite Mound, with values of 1.233 N/mm^2, 1.188 N/mm^2,0.692 N/mm^2 and 0.315 N/mm^2, respectively. The values of the compressive strength of the samples were indicative of the stiffness of the composites of the samples and its resilience to scour and cracks that may lead to seepage. Since the forces acting on the lining are supposed to be the water pressure which is not a static load but evenly distributed along the channel, then the compressive strengths of the materials are adequate to resist scouring.

The low compressive strength of Termite Mound sample might be due to the high level of organic matter in the sample while, that of Clay - Cement sample might be due to the stabilization of the clay with cement. Ata *et al. (*2007), observed a decrease in compressive strength of sandcrete block as the percentage of laterite content increased.

Contrary to this, Aguwa (2009), reported a decrease in strength of stabilized laterite as the cement content increases. It could be deduced that the low value of the compressive strength of Clay – Cement might not be unconnected with the low proportion of cement in the clay in conformity with the results of Ata *et al. (*2007). Ithnin (2008), using various ratios of cement, sand and clay, obtained compressive strengths ranging between 0.29 N/mm^2 and 1.38 N/mm^2, which are similar to the range of results obtained in this study.

4. CONCLUSION

The study determined compressive strengths of some local materials as potential lining materials. The materials responded differently to maximum loading. The values of the compressive strengths revealed the resilience and stiffness of the materials. Since the lining materials are not subjected to static load bearing but being acted upon by hydrostatic forces, it is therefore concluded that these local materials have the potential and requisite strength for canal lining.

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