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# BRIQUETTING OF PALM KERNEL SHELL BIOCHAR OBTAINED VIA MILD PYROLYTIC PROCESS

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***ABSTRACT***

***The production of Palm kernel shell (PKS) fuel briquette via mild pyrolysis is the focus of this paper. The operating temperature was kept constant at 280 $^0$C during carbonization at 30, 60, and 90 minute residence time. Proximate analyses and elemental composition of the char were determined, and also the calorific value of the briquette was obtained to be 20.27 MJ/kg. The briquette specific fuel consumption and the burning rate determined during the water boil test were 0.021kg/l and 1.18g/min respectively. The use of PKS briquette as high grade solid fuel can reduce considerably both environmental pollution emanating from wastes as well the energy crises in most developing countries.***

**Keywords:** Palm kernel shell, briquette, pyrolysis, biochar, proximate, ultimate

## INTRODUCTION

Deforestation and wood fuel shortages have become pressing problems in many developing countries which has necessitated the search for other types of biomass fuel. One of the ways of limiting the deforestation and protecting the environment is by briquetting of the flammable materials. With the rapid advances in biotechnology and bioengineering, some resources, which could have been classified as waste, now form the centre for energy creation (Mc Kendry, 2002). Briquetting of agro-residues is one of the numerous ways which has been developed to utilise huge volume of wastes from agriculture and agro-processing industries. Briquetting of biomass as an alternative fuel play a significant role to reduce the effects of global warming majorly arising from the combustion of fossil fuels (Deng*et al.*, 2009; Husan*et al*., 2002).

Biomass briquetting is the conversion of agricultural waste into uniform shapes which are easy to use, convey and store. It is a process of binding together pulverized carbonaceous matter, often with aid of binder (Felfi, 2005). Briquetting is a high pressure process which can be done at elevated temperature, or at ambient temperature depending on the technology applied. In some briquette techniques, the materials are compressed without addition of adhesive (binder less briquette) while in some adhesive materials are added to assist in holding the particles of the material together (Chin *et al.*, 2013; Mohammed, 1999).

According to Chin *et al*, (2013), palm kernel shell is among the numerous biomass feed stocks including rice straws, maize cobs, sugarcane bagasse, sawdust, melon and groundnut shells suitable for briquetting. The palm oil plants are mostly found in the southern parts of Nigeria. In the palm oil processing operations, the solid wastes are the empty fruit bunches (EFBs), palm fibre and palm kernel shell (PKS). PKS are carbonaceous solids, gotten from the processing of the oil palm fruit. It contains high proportion of carbon element and may be converted to a heat energy source by thermal reaction of the carbon content (Husan*et al.*, 2002).

The palm kernel shell briquette can be used in domestic and cottage industries application, it is used to power boilers to generate steam as being utilized in some far eastern countries. Palm kernel shells are lit and the flame used in cooking in rural community levels. However, it burns with a lot of smoke owing to its organic content and the negative effects of such smoke to health cannot be over emphasized. For instance, the smoke from the wood releases pollutants, mainly in the form of particles and toxic gases which results in pollution in the atmosphere (greenhouse gas) and high potential for causing damage to the ozone layer. Also, numerousre searches has shown that mild pyrolysis has the potential of reducing the smoke producing compounds in the biomass (Chen and Kuo, 2010; Agbontalor, 2007; Attun et al., 2003; Bridge water, 2003, 1996; Akinbami, 2001).

Thus, the need for briquetting process to focus on the production of smokeless solid fuels from a palm kernel shell bio-char obtained via mild pyrolysis capable of giving better combustion performance and reduces pollutant emission has become paramount in this study.

**Experimental**

**MATERIALS AND METHODS**

Palm kernel shells were collected from the vicinity of Oro, Kwara state of Nigeria. Starch was processed from cassava obtained from the local market while manual briquetting machine fabricated at the department of agricultural and bio-resources engineering of the Federal University of Technology Minna, Niger state of Nigeria was employed.

**Samples Preparation**

The palm kernel shells collected were air - dried for ten days to reduce the moisture content of the materials. The materials were crushed and grounded using local pestle and mortar and subsequently passed through standard sieve to obtain uniform particles. Preparation of starch was also carried out as follows; Cassava tubers were washed, peeled, ground and pressed to extract the liquid content. The liquid was filtered and the filtrate was allowed to stay for 2 hours so that the starch would separate from the mixture. After that the upper liquid layer was carefully decanted and the starch was sun dried for five days to reduce the moisture content.

**Mild pyrolysis process**

The operating conditions were set at a constant torrefaction temperature of 280$^o$C and varying residence times of 30, 60 and 90 minutes respectively. The PKS residue was weighed and placed inside the reactor and the door kept closed. Pure $N_2$ gas was supplied continuously in order to create an inert atmosphere inside the reactor. Then, the residence time was set by a timer and the required torrefaction temperature was set by adjusting the digital temperature controller button. A T-type thermocouple placed inside the reactor was connected with the temperature controller. After the setting time, the timer switch cut out the electricity and left to cool to room temperature. The sample was then weighed and stored in airtight containers for subsequent analysis.

**Preparation of the Briquette Samples**

The PKS was pulverised using mortar and pestle and screened through sieve to a particle size of 2mm. Cassava starch was used as binder. 20 g of the cassava flour was dissolved in 40ml cold water. 100ml of water was put to boil in a container after which it was added into the cassava paste and then mixed properly with a stirrer.135 g of the pulverized Palm kernel shell charcoal were gradually added into the gel and mixed using a stirring stick until a thick, black compound was formed. Part of the thick paste was manually pressed into cylindrical moulds. The moulded thick paste was sun dried for 7 days to reduce its moisture content and compactness. The following tests were conducted on the briquette after one week of sun drying:

**Proximate Analysis**

The Moisture Content, Ash Content, Volatile Matter and the Fixed Carbon of the carbonized PKS were determined at the three different residence time in line with the ASTM D-3173 specification.

**Ultimate Analysis**

This analysis includes the testing for hydrogen, carbon, nitrogen, sulphur, and oxygen contents. All of which are in weight percent of the organic material. The Carbon (C), Hydrogen (H), Oxygen (O), Sulphur(S) and Nitrogen (N) determination in biomass represents is the elementary analysis carried out.

**Calorific Value:** The values of Carbon and Hydrogen, gotten from the ultimate analysis was used to determine the calorific value using the HHV formula (Yin, 2011; Sheng and Azevedo, 2005).

**Ignition Test:** The briquette sample was ignited at the base; the time taken for the flame to ignite the briquette was recorded as the ignition time using a stop watch.

**Combustion Test:** The sample briquette was ignited on a domestic stove, 100ml of water at room temperature was measured into an iron container and covered after which it was placed on the stove. Using a stop watch, the time it takes for the water to boil was noted. And also, the mass of the briquette fuel used during the test was recorded. During the course of the test fuel properties such as specific fuel consumption and burning rate were also determined (Kuti, 2009). Figure 1 show the moulded PKS briquette obtained.

**Figure 1** Moulded Palm Kernel Shell Briquette

**RESULTS AND DISCUSSION**

The results are presented in Tables 1-3 and Figure 1 to 3. From Table 1, the values of fixed carbon (FC) increases as the residence time increases from 30 min to 90 min with a percentage increase from 23.49% to 28.61%. Result also show that PKS at 280°C and 90 min having the highest fixed carbon composition of 28.61 % compared to the fixed carbon of 23.49 % and 27.56 % respectively at other residence times would provide a better char for making solid fuel. Furthermore, volatile matter (VM) and the moisture contents (MCs) of the torrefied PKS decreases with increase in residence time from 73.15 to 64.56 % and 0.83 to 0.33 wt% respectively. However, the ash content increases with increase in residence time from 2.44 % to 6.50 %., this findings of the moisture, volatile, fixed, and ash contents results is similar to the ones reported in literatures (Chen and Kuo, 2010; Agbontalor, 2007; Attun et al., 2003; Bridgwater, 2003, 1996; Akinbami, 2001).

Table 1.Proximate analysis of PKS at the same temperature and varying residence time

| Temp.°C | Residence time (min) | FC | Proximate (wt.%) MC | ASH | VM |
|---|---|---|---|---|---|
| 280 | 30 | 23.49 | 0.83 | 2.44 | 73.15 |
| 280 | 60 | 27.56 | 0.67 | 3.75 | 66.02 |
| 280 | 90 | 28.61 | 0.33 | 6.50 | 64.56 |

Table 2. Ultimate analysis and calorific value of the torrefied PKS

| | | Ultimate (wt.%) | | | | | Calorific value |
|---|---|---|---|---|---|---|---|
| Temp.°C | Residence time (min) | C | N | H | S | O | HHV (MJ/kg |
| 280 | 30 | 48.90 | 1.02 | 4.10 | 0.22 | 45.76 | 18.99 |
| 280 | 60 | 50.82 | 1.06 | 4.02 | 0.16 | 43.94 | 19.61 |
| 280 | 90 | 52.06 | 1.11 | 3.91 | 0.09 | 42.83 | 19.98 |

Result shows that carbon (C), nitrogen (N) and sulphur (S) contents of the PKS biochar increases with increase in residence time with 48.90 to 52.06 wt.%, 1.02 to 1.11 wt.% and0.22 to 0.09 wt.% respectively. Meanwhile, the percentage of oxygen decreases with increase in residence time from 45.76 wt.% to 42.83 wt.%. It was also noticed from the results that the percent composition of the sulphur was below 1 wt.% with increase in residence time, which makes the PKS biochar an environmental friendly fuel. Also, the higher heating value (HHV) of the biochar increases with increase in residence time with 18.99 MJ/Kg, 19.61 MJ/Kg, and 19.98 MJ/Kg respectively.

Figures 1-3 show the effect of moisture content, volatile matter and fixed carbon on the PKS biochar.

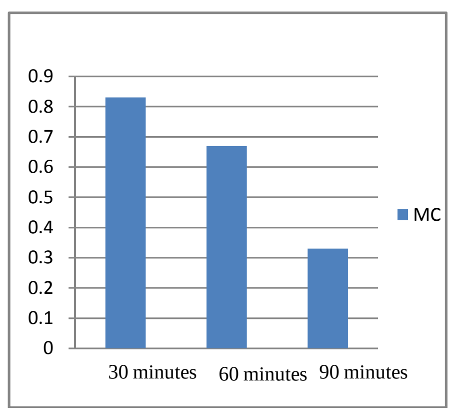


Figure1. Effect of Residence Time on Moisture Content

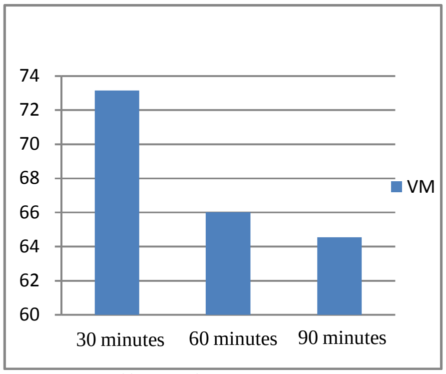


Figure2. Effect of Residence Time on Volatile Matter

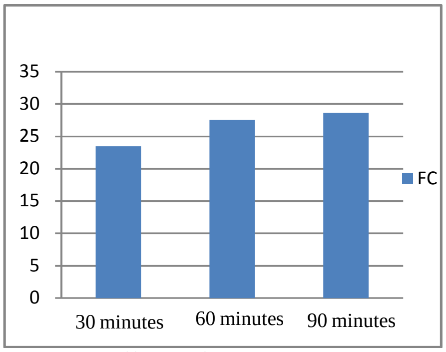


Figure3. Effect of Residence Time on Fixed Carbon

Table 3. Test result on PKS briquette

| Tests | Data |
|---|---|
| The total weight of briquettes used | 154.2g |
| Number of briquettes at the beginning of analysis | 4 |
| The average(dried) weight of each briquette | 38.55g |
| The average weight of briquettes after water boil test | 35.90g |
| Initial volume of water before water boil test | 100ml |
| The final volume of water after boil test | 91ml |
| Density of briquette | 1.27g/cm$^3$ |
| Average moisture content of briquette | 5.58% |
| Carbon content | 53.1% |
| Hydrogen content | 3.8% |
| Nitrogen content | 0.92% |
| Ignition time | 1min 12secs |
| Calorific value | 20.268 kJ/kg |
| Burning rate | 1.18g/min |
| The specific fuel consumption | 0.021kg/litre |

From the ignition test result, the ignition time was observed to be 1min 12secs which gives a lesser value to the one obtained by (Kuti, 2007) as the time it took for the briquette to ignite. The results of the water boil test were used to calculate the burning rate and specific fuel consumption of the briquette. From the result, the burning rate was 1.18g/min which means that 1.18g of the briquette fuel was burnt per minute after ignition. This means that PKS briquette burns for a longer time. The value of the specific fuel consumption was also calculated to be 0.021 kg/litre which means 21g of the briquette fuel will be consumed to boil 1.0 litres of water.

The calorific value of the PKS briquette from the ultimate test shows a value of 20.268kJ/kg which gives a higher value when compared to the calorific value of sawdust briquette 18.936kJ/kg (Nasrin*et al*., 2008) and Palm Empty Fruit Bunches of 18.838kJ/kg. The calorific value also falls within the ASTM standard range for briquetting which is from 18 MJ/kg to 23 MJ/kg.It was observed that briquetting raises the calorific value of PKS from 18.72MJ/kg to 20.268MJ/kg.

**Conclusion**

Effective use of PKS waste into value added briquettes shows that PKS is a promising type of alternate fuel and will go a long way in creating an opportunity to build a bio economy which will in turn give rise to sustainable economic growth and job creation as the major outcomes. The project is economically viable since the materials and methods employed in making the briquette could easily be adopted at the local communities, with minimal training requirement. At 280$^0$C during carbonization of 30, 60, and 90 minute residence time. The calorific value of the briquette was obtained to be 20.27 MJ/kg. The briquette specific fuel consumption and the burning rate determined during the water boil test were 0.021 kg/l and 1.18 g/min respectively.

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# DETERMINATION OF SOME ENGINEERING PROPERTIES OF CASSAVA TUBERS GROWN IN NORTHERN NIGERIA

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*Abstract*
***Several cassava processing operations have been mechanized successfully, but cassava peeling is still largely carried out manually; however, in this work some selected engineering properties of 5 cassava varieties mostly grown in northern part of Nigeria were determined to provide basic data for the design of cassava peeling machine. These properties include thickness of the peel, the length, and axial dimensions - major, intermediate and minor diameter and the Strength of peel (peeling force), and Bioyield(breaking force). The average length of the tubers measured are in the range of 15.4 – 68.51 cm while the maximum and minimum thickness of the peel are 6.01 and 0.54 mm respectively. The peel reduces in thickness from the radicle towards the apex and the larger the diameter of the tuber, the thicker the peel. The highest and lowest values of the peeling force are 2248 kN/m$^2$ and 401 kN/m$^2$respectively. It was observed that the peeling force value increases and reduces along the length of the tuber. Also the peeling force reduces with time after harvest and has the highest value at 24 hours after harvest. This could be due to the deterioration of the tuber with time. The major, minor and intermediate diameters of the tubers determined are in the range of 3.00 –10.35 cm, 2.15 – 10.05 cm and 0.87 – 6.04 cm respectively. The maximum bioyield force was 3880 kN/m$^2$ and minimum was 769.3 kN/m$^2$. All these are important in the design of a cassava peeling machine.***

**Keywords:** Cassava peeling, Engineering properties, Strength and bioyield force

## INTRODUCTION

Cassava (*Mahihotesculenta*)is a woody shrub of the *Euphorbiaceae*with numerous uses and by-products. It is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root(Aregheoreand Agunbiade, 1991; Rehm and Espig, 1991; Kawano, 2000). Cassava is the third largest source of carbohydrates for human food in the world. Cassava is classified as "sweet" or "bitter" depending on the level of toxic cynogenicglucosides (CBN Newsletter, 1996; Wheatley, Chuzel and Zakhia,2003).

Cassava roots are very rich in starch, and contain significant amounts of calcium (50mg/100g), phosphorus (40mg/100g) and vitamin C (25mg/100g). However, they are poor in protein and other nutrients. In contrast, cassava leaves are a good source of protein if supplemented with the amino acid methionine despite its cyanide content (IITA, 1990; RMRDC, 2004; Williams and Chew, 1980). It is an important food in many South and Central American countries, parts of West Africa, where it is processed into a product known as '*garri*'. The tubers are used as animal feed, for making glucose and sodium glutamate and in preparation of high grade starch (Williams and Chew, 1980; Jeon and Halos, 1992). Some varieties have high concentrations of toxic substances (hydrocyanic glucosides) which form cyanide when the tubers are harvested or the tissue is damaged. The yield varies from as low as 5 tonnes to more than 60 tonnes per hectare (CBN Newsletter, 1995; Mohsenin, 1970). World production of cassava root was estimated to be 184 million tonnes (FAO, 1991). The majority of production is in Africa where 99.1 million tons are grown. Fifty-one and a half (51.5) million tons were grown in Asia and 33.2 million tons in Latin America and the Caribbean. Nigeria is the world's largest producer of cassava. However, based on the statistics from the Food and Agricultural Organization (FAO) of the United Nations, Thailand is the largest exporting country of dried cassava with a total of 77% of world export in 2005. The second largest exporting country is Vietnam, with 13.6% followed by Indonesia (5.8%) and Costa Rica (2.1%). Worldwide cassava production increased by 12.5% between 1988 and 1990 (RMRDC, 2004).

Before cassava tuber is processed into any of its food and non-food products, it must be peeled (Odigboh, 1976; Polson and Spencer, 1991; Felix, 2004). Several cassava processing operations have been mechanized successfully, but cassava peeling had been a serious global challenge to design engineers involved in cassava processing (Olukunle, 2005, RMRDC, 2004;Olukunle*et al.,* 2006, Olawale, 2007).

In the food industry, the peel must be completely removed without removing the useful tuber flesh (Odigboh, 1976, Asogwa, Umeh and Ater, 2006). It is worthy to note that the peel represent about 15 percent of the weight of the root and its cyanogens content is usually 5 to 10 times greater than the root parenchyma.

In Nigeria, peeling is usually done by using a knife. On the average one woman can peel about 20 to 25kg of roots in an hour. It is reported that 30kg of fresh weight is lost during the manual peeling because woody tips are removed. The process is slow and labour-intensive, averaging 25kg per man-hour, but it gives the best result. Various peeling machines have been developed but they are not effective,resulting in high wastage. The available locally developed mechanical peelers are generally wasteful in the peeling process with low peeling efficiency (Bokanga, 2010, Adetan, Adekoya and Aluko, 2002; Ezekwe, 1979) while the imported ones are very expensive costing up to $7,500.00equivalent to 1 million Nigerian Naira and inadaptable to our local conditions.

It is worthy to note that the major problem in cassava peeling arises from the fact that cassava roots exhibit appreciable differences in weight, size and shape (Alade, 2005). There are also differences in the properties of the cassava peel, which varies in thickness, texture and strength of adhesion to the flesh (Agbetoye, 2003). Another major constraint of cassava is that the roots deteriorate rapidly (IITA, 1990). Cassava tubers have a shelf life of 24-48 hours after harvest (Akintunde, Oyawale and Tunde, 2010). Fresh roots must be processed within 2 to 3 days from harvest.

Thus for the aforementioned reasons there is therefore the need to determine some engineering properties of Cassava tubers to aid in the design of more effective cassava tuber peeling machine.

## MATERIALS AND METHODS

Some engineering properties of 5varieties of cassava tubers(TSM 82/00661, TMS 81/00110,TMS30001, TSM 4(2)30572 and TSM 82/0249) were determined. These physical properties include length, axial dimensions (major, minor and intermediate diameters) and thickness of peel while the mechanical properties are the force required to peel cassava tubers and the bioyield (breaking) force.

The materials used in executing this research work include five(5) varieties of cassava tubers obtained from Kure – Ultra modern market, Minna, Niger State. A variety of tools and instruments were used to carry out different measurements on the root tubers. A tap measure was used to measure the lengths of roots while the diameters of the roots were measured using a pair of Vernier caliper. The weights of roots before and after peeling and that of the peels were measured with an electronic weighing balance while the thickness of the root peel was measured by micrometer screw gauge. A penetrometer (dynamometer - 4682.6332kN/m$^2$) was used to measure the peeling force while developed peeling knives (with peeling section width of 26 mm) (Figures 1abc) were used in peeling the peel. Developed plastic supportswere used to determine the bioyield(breaking force). In the course of the experiment, the tubers were categorized into three different classes namely; small, medium and large sizes.

a – Peeling knife with hand b – Penetrometer c – Assembled Peeling Tool

Figure 1: The developed Peeling tools

### Determination of Physical properties of cassava tuber

A cross section of a typical cassava tuber (Figure 2) is labeled to show its component parts such as the periderm, sclerenchyma, cortical parenchyma and phloem. The peel (1 – 4) is the most important during peeling because it has to be removed from the food storage section of the cassava tuber.

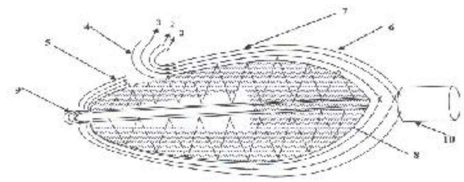

Figure 2: Cross section of cassava tuber

**Legend:**1. Periderm, 2. Sclerenchyma, 3. Cortical parenchyma, 4. Phloem, 5. Cambium, 6. Storage parenchyma, 7. Xylem, 8. Xylem vessels and fiber, 9**.** Apex, 10. Radicle

In Figure 3, a cassava tuber is marked according to the diameters to be measured in the study as follows:

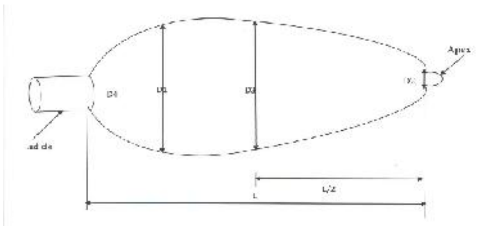

Fig. 3: Dimensions of interest of cassava tuber

Figure 4: Hand peeling at 5 – 15 degrees vertically downward placed on tuber

**Determination of Mechanical properties of cassava tuber**

**Determination of peeling force**

This is the force generated by the peeling knife to remove the peel. As the peel is being removed using the assembled tool (penetrometer attached to the peeling knife) for the two methods, the peeling force was taken/read from the scale of the penetrometer which served as the handle. This was replicated thrice.

**Bioyield force**

This is the force required to break the cassava under pressured. This force was determined by horizontally placing the tuber on two plastic supports and by pressing the penetrometer

Legend: L= Length of cassava tuber, $D_1$ = Major diameter, $D_2$ = Minor diameter, $D_3$ = Intermediate diameter, $D_4$ = Diameter at the radicle.

**Determination of Length and Axial dimensions**

The tap measure was used to measure the length of the roots while the diameters of the roots were measured using a pair of vernier calipers.

**Determination of thickness of peel**

The peel is the skin covering the storage parenchyma of the tuber. It consists of four layers, the periderm, sclerenchyma, cortical parenchyma and phloem. Two methods of peeling were used in removing the peel using the developed peeling tools namely;

- by forcing the sharp edge of the knife at an angle 5 to 15 degreesalong the length of the tuber (Adetan*etal*., 2003) as shown in Figure 4 and,
- by forcing the sharp edge of the knife or peeling tool vertically downwards on the tuber and levering the peel while rotating the tuber so that the peel is completely removed from the storage parenchyma (Figure 5).

After removing the peel, the thickness is then measured by using a micrometer screw gauge.

Figure 5: Hand peeling with knife along the length of tuber

vertically thereby reading off the force from the scale of the penetrometer (Figure6).

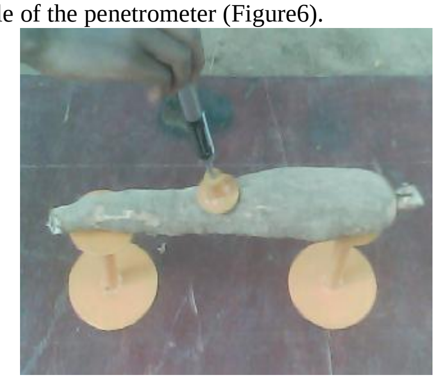

Figure 6: Determination of bioyield force

The peeled cassavas with the developed tools are shown in Figure 7.

Figure 7: Peeled cassava tubers using the developed peeling tools

**RESULTS**

The results on physical properties of the five (5) selected varieties of cassava are shown in Table 1 while the results on the mechanical properties are shown in Table 2.

Table 1: Physical properties of some selected varieties of cassava mostly grown in northern Nigeria

| S/No. | Cassava Variety | Length, cm | | | Diameter, cm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Aver. | Major | | | Intermediate | | | Minor | | |
| | | | | | Min. | Max. | Aver. | Min. | Max. | Aver. | Min. | Max. | Aver. |
| 1 | TMS 82/000661 | 23.30 | 68.51 | 45.91 | 3.00 | 4.49 | 3.75 | 2.15 | 3.92 | 3.04 | 0.92 | 4.87 | 2.90 |
| 2 | TMS 81/00110 | 15.40 | 39.50 | 27.45 | 3.26 | 4.68 | 3.97 | 3.25 | 4.99 | 4.12 | 0.87 | 1.95 | 1.41 |
| 3 | TMS 30001 | 27.10 | 43.20 | 35.15 | 3.36 | 4.20 | 3.78 | 3.10 | 3.89 | 3.44 | 1.45 | 1.99 | 1.72 |
| 4 | TMS 4(2)30572 | 23.61 | 44.30 | 33.96 | 4.05 | 5.75 | 4.90 | 3.28 | 5.39 | 4.34 | 1.38 | 5.56 | 3.47 |
| 5 | TMS 82/0249 | 23.95 | 31.45 | 27.7 | 5.89 | 10.35 | 8.12 | 5.35 | 10.05 | 7.70 | 3.17 | 6.04 | 4.61 |

Table 2: Mechanical properties of some selected varieties of cassava mostly grown in northern Nigeria

| S/No. | Cassava Variety | Peeling Force, kN | | | Bioyield Force, $kN/m^2$ | | | Thickness of peel, mm | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Max. | Aver, | Min. | Max. | Aver. | Min. | Max. | Aver. |
| 1 | TMS 82/000661 | 602 | 1940 | 1271 | 1940 | 3211 | 2575.5 | 0.86 | 1.99 | 1.43 |
| 2 | TMS 81/00110 | 468 | 1405 | 936.5 | 1771 | 3880 | 2825.5 | 1.00 | 2.58 | 1.79 |
| 3 | TMS 30001 | 401 | 1472 | 936.5 | 1739 | 2408 | 2073.5 | 0.54 | 3.36 | 1.95 |
| 4 | TMS 4(2)30572 | 535 | 2074 | 1304.5 | 3345 | 4181 | 3763 | 0.68 | 2.98 | 1.83 |
| 5 | TMS 82/0249 | 1241 | 2248 | 1744.5 | 769.3 | 9237 | 5003.2 | 2.00 | 6.01 | 4.01 |

**Discussion of results on Physical Properties**

Table 1 presents the physical properties of the five (5) selected varieties of cassava mostly grown in northern part of Nigeria. The average length of the 5 varieties TMS 82/00661, TMS 81/00110, TMS 30001, TMS 4(2)30572 and TMS 82/0249 were 45.91 cm, 27.45 cm, 35.15 cm, 33.96 cm and 27.70 cm respectively. TMS 81/00110 variety has the shortest length of 27.45 cm while TMS 82/000661 has the longest length of 40.75 cm. The TMS 82/0249 cassava variety has the maximum average values of major, intermediate and minor diameters of 81.2 cm, 7.70 cm and 4.61 cm respectively while TMS 82/000661 has major and intermediate diameters as 3.75 cm and 3.04 cm respectively. The TMS 81/001100 has the least average value for minor diameteras 1.41 cm. The results on the tuber diameters fall within the range reported by Adetan*et al.* (2003) and Ezekwe (1979).

**Discussion of results on Mechanical Properties**

The mechanical properties of the five (5) varieties of cassava mostly grown in the northern part of Nigeria are presented in Table 2. The TMS 82/00661, TMS 81/00110, TMS 30001, TMS 4(2)30572 and TMS 82/0249 varieties have average peeling force of 1271 kN, 936.5 kN, 936.5 kN, 1304.5 kN and 1744.5 kN respectively. Also the peeling force reduces with time after harvest and has the highest value at 24 hours after harvest. This could be due to the deterioration of the tuber with time.TMS 4(2)30572 has the highest average bioyield force of 3773 kN/m$^2$ while TMS 81/001100 and TMS 30001 have the least average value of bioyield force of 936.5 kN/m$^2$. The average thickness of the peel for TMS 82/00661 –1.43 mm, TMS 81/00110 – 1.79 mm, TMS 30001 –1.95 mm, TMS 4(2)30572 –1.83 mm and TMS 82/0249 – 4.01 mm. TMS 82/0249 has the maximum thickness of peel as 4.01 mm while TMS 82/000661 has the least value of thickness of peel of1.43 mm. The results on the peeling and bioyield forces are closely in agreement with the report of the work (Adetan*et al.*, 2003; Ezekwe, 1979). The peel reduces in thickness from the radicle towards the apex and the larger the diameter of the tuber, the thicker the peel. All these are important in the design of a cassava peeling machine.

**CONCLUSION**

Some engineering properties of Cassava Tubers grown in northern Nigeria were determined. These properties include thickness of the peel, the length, and axial dimensions - major, intermediate and minor diameter and the Peeling force, and breaking force (bioyield force). The highest and lowest values of the peeling force are 2248 kN/m$^2$ and 401 kN/m$^2$ respectively. The maximum bioyield force is 3880 kN/m$^2$ and minimum is 769.3 kN/m$^2$. It could be concluded that the larger the diameter of the tuber, the thicker the peel. The peeling force also reduces with time after harvest and has the highest value at 24 hours after harvest. All these are important in the design of a cassava peeling machine.

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