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Determination of some Selected Engineering Properties of Bambara Nut (Vigna Subterranea) Related to Design of Processing Machines

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Abstract: *Bambara nut (Vigna subterranea (L) Verdc) is a major source of vegetable protein in sub-Saharan Africa. The aim of this study was to determine some selected Engineering properties of Bambara nut. Fresh Bambara nuts were bought from Kure market, Minna, Niger State, Nigeria. The pods were cleaned and sorted, and the pods manually cracked using stone to hit the pods on a flat concrete surface. The unharmed nuts were then selected and oven dried and the moisture content determined and calculated to be 14.05%. This study was carried out under approved standard laboratory conditions using standard engineering methods and instruments. Selected physical and mechanical properties of Bambara nut were determined and the values obtained are as follows: the average length, width and thickness, weight, geometric mean diameter, arithmetic mean diameter, surface area, sphericity, volume and density were 1.76mm, 1.45mm, 1.22mm, 1.70g, 1.46mm, 1.56mm, 6.69mm^2, 82.85%, 4.14mm^3, 0.04g/cm^3. The principal dimensions varied with increase in moisture content, though there was no significant change in the major diameter. The coefficient of static friction was highest for galvanized steel and least for glass. From the values obtained, it appears that the increase in size of Bambara nut may aid a decrease in coefficient of static friction. The force required to fracture and compress the biomaterial (Vigna subterranea) were 12.5N and 27.75N on axial loading and 7.25N and 22N on longitudinal loading respectively.*
Keywords: *Crude Protein, Groundnut oil, Physicochemical Properties, Proximate Composition, Storage Period*

I. Introduction

Bambara nut (*Vigna subterranea*) is an indigenous grain legume grown mainly by subsistence women farmers in drier parts of sub-Saharan Africa (Mkandawire, 2007). The crop has advantages over more favoured species in terms of nutritional value and tolerance to adverse environmental conditions. Bambara nut is an annual crop, which resembles groundnut (*Arachis hypogaea L*) in both cultivation and habitat. It is one of the five important protein sources for many Africans (www.feedipedia.org). It is said that the seed is regarded as a completely balanced food because it is rich in iron 4.9-48 mg/100 g, compared to a range of 2.0-10.0 mg/100 g for most food legumes, protein 18.0-24.0% with high lysine and methionine contents, ash 3.0-5.0%, fat 5.0-7.0%, fibre 5.0-12.0%, potassium 1144-1935 mg/100 g, sodium 2.9-12.0 mg/100 g, calcium 95.8-99 mg/100 g, carbohydrate 51-70%, oil 6-12% and energy 367-414 kcal/100 mg (Vurayai et al; 2011).

Nigeria produce over 100,000 metric tonnes of Bambara nuts (Olapade and Adetuyi, 2007), but Bambara nut is still one of the lesser utilised legumes in Nigeria (Alozie *et al.*, 2009). It has not been adequately exploited as human food because of constraints like hard to cook phenomenon, strong beany flavour, presence of anti-nutrients and poor dehulling and milling characteristics (Enwere and Hung, 1996; Alozie *et al.*, 2009). The freshly harvested pods are consumed cooked, shelled and eaten as a vegetable snack, while dry seeds are either roasted and eaten as snack in a manner similar to peanut when boiled (Bamishaiye *et al.,* 2011). The form in which the Bambara nut seed is commonly consumed is *Okpa* (Bambara nut paste) (Enwere, 1998; Onyimonyi and Okeke, 2007).

Okpa is a well cherished food in the eastern part of Nigeria (www.doublegist.com). The product is prepared after the seeds have been dehulled, milled into flour and then mixed with palm oil or crude palm fruit extract, water, salt, pepper and other spices. The paste is wrapped with banana leaves, transparent polyethene pack, tin and plastic containers, before steaming to form the product *Okpa* (Enwere, 1998).

In Nigeria, Bambara nut production is low. Production output was estimated to be between 100,000-168,700 metric tonnes from an area of about 15350 hectares (Tanimu and Aliyu, 1995; NFRA, 2008). While the production of the crop was declining in the Sahel and Sudan Savannah zones due mainly to drought, its production was increasing in the Southern Guinea Savannah due to the fact that the crop fetches higher income now than it did previously (Tanimu and Aliyu, 1995). In Nigeria, like in many parts of Africa, Bambara nut is grown by subsistence farmers mostly women, in small patches of land, and is frequently intercropped with cowpea, maize and sorghum, (Gibbon and Pain, 1985; Mkandawire and Sibuga, 2002; Alhassan and Egbe, 2013). Farmers practice intercropping (Ibeawuchi, 2000) due to high variability in climatic conditions, diverse soil types, population density and socio-economic factors. Mulila – Mitti, (1995) reported that food legumes including Bambara nut enrich the soil by fixing atmospheric nitrogen, and thus resulted in reduced fertilizer requirement for subsequent crops. This has made the crop ideal for the resource poor farmers. Goli (1997) revealed that farmers through successive cultivations have selected Bambara nut genotypes with desirable traits (high yielding and bunchy growth habit).

The pod of Bambara nut is very hard and the cracking methods are still traditional, these cracking methods vary from locality to locality depending on the quantity produced. Some communities use mortar and pestle to crush the dry pods. Some beat them with sticks on flat ground; others use stones to crush pods on flat ground. The methods have the disadvantage of damaging the seeds, and are slow and tiresome, Oluwole *et al.*, (2007). There is a paucity of data concerning the engineering properties of Bambara nut, therefore, this project study is undertaken to investigate and provide concise information and data on selected physical and mechanical properties of *Vigna subterranea* considered to be important for its handling, storage, and processing. The result that would be gotten from this research would serve as a valuable data and information in the design of machine for the harvesting, handling and processing of the nuts.

II. Materials And Methods

2.1 Sample Collection and Preparation of Samples

The freshly harvested *Bambara* pods were bought from Kure market, Minna, Niger State, Nigeria. The nuts were removed from the pods carefully, to prevent damage to the nuts. Freshly harvested *Bambara* pods are shown in Plate 1. Unharmed Bambara nuts are shown in Plate 2.

Plate 1: Bambara Pods

Plate 2: Unharmed Bambara Nuts

2. 2. Selection of Nuts

The unharmed nuts were selected from the impaired ones and the selected physical and mechanical properties were determined.

2.3 Determination of the Physical Properties

2.3.1 Shape Determination

The shape was determined by tracing the longitudinal and lateral cross section of the nut on a cardboard and compared with the shapes listed on the charted standard, the descriptive terms was used to define the shape (Mohsenin, 1970). This was determined using four replicates.

2.3.2 Size Determination

Twenty (20) unharmed nuts were selected. The three principle diameter (axial dimension); major diameter (a), intermediate diameter (b), and minor diameter (c) were measured using vernier caliper and the average was taken.

2.3.3 Geometric Mean Diameter
The geometric mean diameter was determined from the major (a), intermediate (b) and minor (c) diameter using the formula below;

$$\text{Geometric mean diameter } (Dg) = (a \times b \times c)^{1/3} \qquad 3.1$$

2.3.4 Arithmetic Mean Diameter
The arithmetic mean diameter of the nut was determined from the three principle diameter using the relationship (Mohsenin, 1970).

$$Da = \frac{a+b+c}{3} \qquad 3.2$$

2.3.5 Weight Determination
The weight of the nut was determined by using digital electric weighing balance. Results were obtained from twenty replicates and the average was recorded.

2.3.6 Surface Area Determination
The surface area was determined by using the following equation as cited by Sacilik et al., (2003), Tunde-Akintunde and Akintunde (2004) and Altuntas et al., (2005):

$$Sa = \pi GMD^2 \qquad 3.3$$

Where; Sa = surface area (mm^2)
GMD = geometric mean diameter (mm)

2.3.7 Sphericity Determination
The sphericity of the nut was determined and calculated by using the following relationship (Mohsenin, 1970)

$$\text{Sphericity } (\varphi) = \frac{Dg}{a} \times 100, (\%) \qquad 3.4$$

Where, Dg = Geometric mean diameter (mm)
a = major diameter

2.3.8 Volume Determination
The volume of the nut was determined by using the following formula

$$\text{Volume} = \frac{\pi B L^2}{6(2L-B)},\ mm^3 \qquad 3.5$$

Where, $B = (WT)^{1/2}$
L = Major diameter, mm
W = Intermediate diameter, mm
T = Minor diameter, mm

2.3.9 Density Determination
The density of the nut was determined using the ratio of the weight to the volume (Mohsenin, 1970).

$$\text{Density } (\rho) = \frac{weight(g)}{volume\ (cm^3)}, g/cm^3 \qquad 3.6$$

2.3.10 Coefficient of Static Friction
The static coefficient of friction for the Bambara nut was determined for three grades of materials: wood with the nut parallel to the direction of flow, galvanised steel and glass. A topless and bottomless box was used to determine the coefficient of static friction. The surface was raised gradually until the filled cube just start to slide down, the angle at this point was recorded, and three different readings were taken for each sample; and the coefficient of static friction was calculated using the formula below.

$$\mu = tan\theta \qquad 3.7$$

2.3.11 Moisture Content Determination
The moisture content of the nuts was determined by oven drying method at 130^{0}C for 48 hrs. All weight loss was considered to be moisture, according to the standardised procedure for moisture content determination by ASABE standard S352.2 (2007). The moisture content was then calculated using the formula (Mohsenin, 1970).

$$\text{Moisture content } Mc = \frac{W2-W3}{W2-W1} \times 100 \qquad 3.8$$

W_1 = Weight of container, g

W_2 = Weight of wet sample + container, g
W_3 = Weight of dry sample + container, g

2.3.12 Selected Mechanical Properties

The mechanical properties are those having to do with the behaviour of a material under applied forces. The machine used in determining the selected mechanical properties of Bambara nut is the Universal Material Testing Machine of 2.5kN capacity, which was used for determining the fracture and compressive force of the biomaterial.

2.3.13 Test Procedure

The strength of the nut was determined by placing the nut on the platform provided on the machine and the meter reading set to zero. The nut was positioned horizontally with the major axis of the nut being normal to the direction of loading. The value of the corresponding force read directly on the digital meter was taken and recorded as the fracture force. Subsequent computation based on this was reported.

III. Results And Discussion

3.1 Presentation of Results

The determined physical and mechanical properties of Bambara nut are presented as follows:

3.1.1 Shape of the Nut

The shape of the Bambara nut was found to be Round (approaching spheroid) or Elliptical (approaching ellipsoid).

3.1.2 Physical Properties of Bambara Nut

The physical properties of *bambara* nuts are presented in Table 1

Table 1: Physical Properties of *bambara* nuts

Properties	No of samples	Maximum	Minimum	Mean	SD	CV
Major dia, (mm)	20	2.045	1.55	1.76	0.14	0.07
Intermediate dia, (mm)	20	1.87	1.30	1.45	0.12	0.08
Minor dia, (mm)	20	1.45	1.06	1.22	0.09	0.07
Weight, (g)	20	2.98	1.14	1.70	0.08	0.05
Geometric mean dia, (mm)	20	1.65	1.34	1.46	0.99	0.06
Arithmetic mean dia, (mm)	20	1.82	1.41	1.56	3.97	0.04
Surface area, (mm^2)	20	8.59	5.67	6.69	0.78	0.11
Sphericity, (%)	20	90.78	75.26	82.85	0.75	0.18
Volume, (mm^3)	20	6.14	3.21	4.14	0.40	0.24
Density, (g/cm^3)	20	0.07	0.02	0.04	0.10	0.29
Coefficient of static friction, (μ)						
Glass	3	0.45	0.43	0.44	0.01	0.03
Plywood	3	0.47	0.45	0.46	0.02	0.04
Galvanised steel	3	0.49	0.47	0.48	0.03	0.03

3.1.3 Mechanical Properties of Bambara Nut

The results for the mechanical properties of *bambara* nuts are presented in Table 2.

Table 2: Mechanical Properties of *bambara* nuts

Properties	No of samples	Maximum	Minimum	Mean	SD	CV
Fracture force on						
Axial loading (N)	4	15	10	12.5	3.54	0.28
Fracture force on						
Longitudinal						
Loading (N)	4	10	4.5	7.25	3.88	0.54
Compressive force						
On axial loading (N)	4	35	20.5	27.75	10.25	0.37
Compressive force						
On longitudinal						
Loading (N)	4	25.5	18.5	22	4.95	0.22

*SD = Standard Deviation **CV = Coefficient of Variation

IV. Discussion Of Results

The physical properties of Bambara nut were obtained as follows; the moisture content of the nut was determined and calculated to be 14.05%, it was observed that at this moisture content level, nuts can be extracted with minimal damage. Further decrease in moisture content will make the nut to be brittle, while a higher moisture level will make the nut to crush easily on cracking the pod.

The average major, intermediate and minor diameters were obtained to be 1.76 $\pm$ 0.14, 1.45 $\pm$ 0.12 and 1.22 $\pm$ 0.09 respectively. The coefficient of variation (which is an important parameter in determining sieve sizes in drying cleaning operation) for the major, intermediate and minor diameters were found to be 0.07, 0.08 and 0.07. The average value for geometric mean diameter, arithmetic mean diameter, volume and density were obtained as 1.46 $\pm$ 0.99, 1.56 $\pm$ 3.97, 4.14 $\pm$ 0.40, and 0.04 $\pm$ 0.10, while the corresponding coefficient of variation are 0.06, 0.04, 0.24 and 0.29. A relatively high value 82.85 $\pm$ 0.75 of sphericity was obtained with relatively high moisture content was obtained; this property is relevant in the design of grain handling machineries. The average surface area obtained was 6.69 $\pm$ 0.78, the surface area increased with increase in moisture content. Olalusi et al., (2009), also reported that the surface area of Tiger nut increased with increase in grain moisture content which agrees with the findings in this research work. The coefficient of static friction was highest for galvanised steel and least for glass. Chandrasekar and Viswanathan (1999) and Gupta and Das (1997) reported a similar trend for coffee beans and sunflower seeds, respectively. It appears that the increase in size of *bambara* nut may aid a decrease in coefficient of static friction. These frictional properties will find useful application in design and construction of hopper for gravity flow.

The results of the determined mechanical properties are shown in Table 2, the average force required to fracture *bambara* nut for longitudinal loading are 7.5N fracture and 22N compressive with corresponding axial loading of 12.5N fracture and 27.75N compressive. The force required to crack were higher at axial loading compared with the force required to fracture on longitudinal loading. The force required to fracture the nuts at higher moisture content level was also less. The parameters are important in the designing of machines for processing biomaterials. These parameters also give the energy requirement and consideration governing equipment selection in size reduction operations.

V. Conclusions

The physical and mechanical properties of *bambara* nuts were determined; the principal dimensions varied with increase in moisture content, though there was no significant change in the major diameter. This shows that the length of *bambara* nut is negligibly affected by change in moisture content as the nut shrank mainly from the minor and intermediate diameter when the moisture content level was reduced. The value obtained for sphericity indicates the possibility to roll relatively well where necessary. Hopper and other unloading devices need not to be too sloppy because of the relatively low coefficient of static friction of the nut. The result also revealed that it would be economical to load this nut longitudinally to reduce energy demand if loaded axially when necessary to fracture or compress the *bambara* nut.

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