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Some Engineering Properties of Bambara Groundnut (*Vigna subterranea* (L) Verdc) Relevant for its Sorting, Shelling and Cleaning

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ABSTRACT

Dried unshelled Bambara groundnut (BGN) was bought from Northbank Market, Makurdi Benue State, Nigeria. Some engineering properties of the material relevant to its sorting, shelling and cleaning were determined. The biomaterial under study was categorized into three groups of sizes namely; large, medium and small for the pod and seed. Measurements of some engineering properties at the initial moisture content (MC) of 6.27% was carried out and the average geometric mean diameters of BGN large pod, medium pod and small pod are 16.78±0.49 mm, 15.15±0.49 mm and 13.24±0.56 mm, respectively. The average geometric mean diameters of BGN large seed, medium seed and small seed are 11.98±0.58 mm, 9.97±0.55 mm and 8.60±0.54 mm, respectively. The average cracking strength of BGN pod was measured as 0.17±0.03 N/mm^2. The average terminal velocity of the BGN seeds was determined to be 20.19±2.75 m/s. The angle of repose and static coefficient of friction for large pod on metal sheet averaged $29.2±0.79^0$ and 0.56±0.02, respectively.

Key words: Sorting, Shelling, Cleaning, Moisture Content, Terminal Velocity

1. INTRODUCTION

Bambara groundnut (*Vigna subterranean* (L.) Verdc.) is an indigenous African crop grown across the continent from Senegal to Kenya and from the Sahara to South Africa [1]. Alhassan and Egbe, [2] carried out investigation on participatory rural appraisal of Bambara groundnut production in Southern Guinea Savanna of Nigeria and reported that in Nigeria, like in many parts of Africa, Bambara groundnut is grown by subsistence farmers mostly women, in small patches of land, and is frequently intercropped with cowpea, maize and sorghum. Engineering properties are important in many problems associated with design of a specific machine or analysis of the behaviour of the product in handling of the material [3]. The ever increasing importance of agricultural products together with the complexity of modern technology for their production, processing and storage need a better knowledge of their engineering properties so that machines, processes and handling operations can be designed for maximum efficiency and the highest quality of the final end products [4]. The clearance between two adjacent spikes of spike-tooth cylinder and concave assembly influences threshing loss due to cracked grains. For optimum performance of thresher, the clearance has to be appropriately selected. The basic information needed for such adequate selection is the size and shape of the grains [5]. Grouping (into large, medium and small) of pods and employing clearance based on engineering data from each group was found to increase the shelling efficiency of Bambara groundnut machine.

Atiku *et al.* [1] found that the axial dimensions (cm) of bamabara groundnut pod at the moisture content of 5%, that is, the average major, intermediate and minor diameters to be 1.89, 1.57 and 1.44, respectively. The true and bulk densities, porosity and one thousand-pod weight averaged 754.83 kg/m^3 and 432 kg/m^3, 42.77% and 1.24 kg, respectively and the angle of repose and static coefficient of friction of the pod on steel sheet averaged 30.4^0 and 0.56. According to Orwua [5], the mean force required for cracking bambara groundnut with two seeds per pod and one seed per pod (Newton, N) are 35.9 and 34.8 moisture content of 3.7 and 4.6%, respectively; which are not significantly different. The mean force (Newton, N) for the seed are 130.5 and 131.1 at 3.7 and 4.6% MC for one seed and two seeds, respectively; which are not significantly different. This implies that the number of seed per pod has no effect on the cracking strength of Bambara nut pod or seeds. The cracking force (N) of Bambara nut pod (49.82) was recommended to be used in the design of multi-thresher for legumes. However, it is required to bring down the value well below that of groundnut seed (52.54N) in order to ensure threshing with minimum mechanical damage to the seeds [6]. Hartley [7] reported that the moisture content of nuts should be less than 16% (MC<16%) if they are to be sufficiently shrunk away from the shells (pods) for easy cracking. Saeeid *et al.* [8] measured the average geometric mean diameter, sphericity, mass and volume of groundnut at moisture content of 8 % (d.b) to be 12.71 mm, 61.12 %, 1.11 g and 1.16 cm^3, respectively

The aim of the study was to determine some engineering properties of locally procured BGN relevant to its sorting, shelling and cleaning. The properties include size, volume and density, terminal velocity, drag force, sphericity, drag coefficient, projected area, angle of repose, static coefficient of friction and cracking strength.

2. MATERIALS AND METHODS

Materials and Study Area

Dried unshelled bambara groundnut was procured from North Bank Market, Makurdi, Benue State, Nigeria (Plate 1). The experiment was carried out in Agricultural and Environmental Engineering and Civil Engineering Laboratories, University of Agriculture, Makurdi, Benue State.

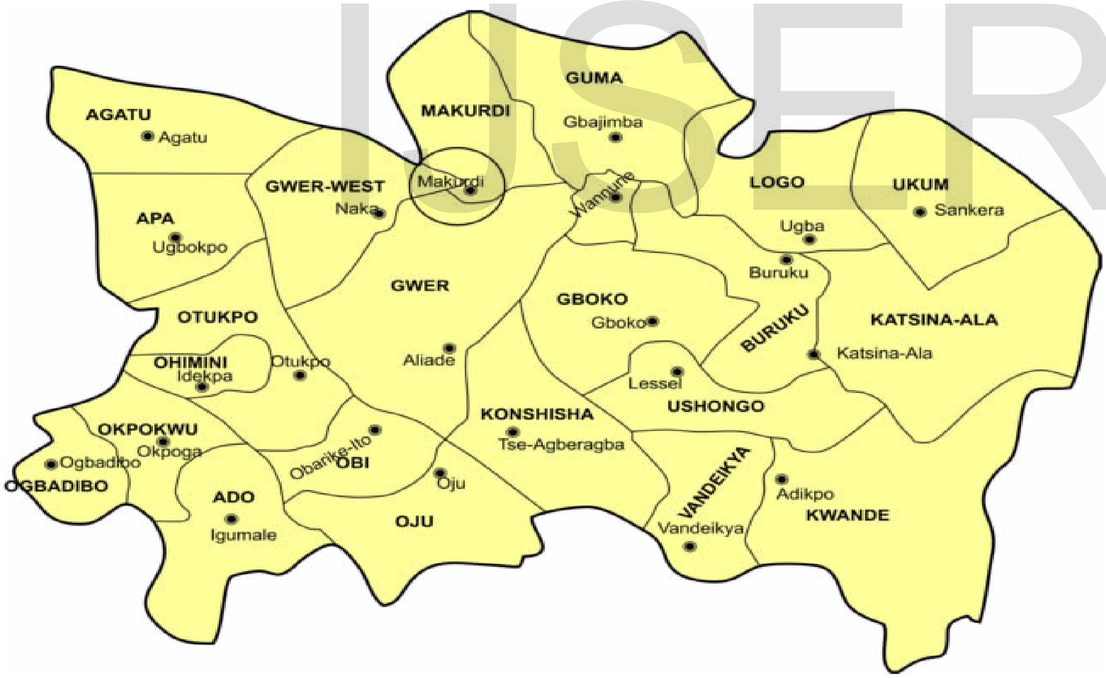

Plate 1: Map of Benue showing study area

Methods of measurement

2.1 Size

Fifty (50) each of Bambara groundnut seeds and pods was randomly selected from the sample bought; they were numbered with a permanent marker. Measurements of dimensions on three mutually perpendicular axes viz. major, intermediate and minor diameter was performed using a vernier calliper. The principal axes were measured by rotating the bambara nut in three directions. The first one was along the length of the nut which represents the major diameter, the second was through the eye of the nut which represents the intermediate diameter and the third direction was across the eye which represents the minor diameter. All the measurement was done by vernier calliper. Values of the axial dimensions of the pods is applicable in the choice of the hole diameter of the sorter sieves as well as the hole diameter and clearance between the roller and concave of machine that engendered effective sorting and shelling of the pods.

2.2 Volume and Density

Volumes of each of twenty (20) Bambara groundnut seeds and pods were determined by water displacement method [9]. Because unshelled pods float on water, a small white stone (Pendulum bob) was used as a sinker tied to the nut with the use of copper wire. Water was poured into a 1000 cm^3 capacity measuring cylinder and the level noted. The bob was immersed and the final level to which the water rose was noted. The difference between the final and initial water level gave the volume of the bob. Afterward, each pod was tied to the sinker and both were immersed in water. The difference between the final and initial levels for both pod and the bob was determined. The volume of the pod was calculated by subtracting the volume of the bob from the difference. The procedure was repeated for all the pods. The mass of each pod was obtained using electronic weighing balance with a least count of 0.1 g. The density was calculated using the relationship in equation 1. Volume among other parameters is an important parameter in the design of storage bins, separation of products from undesirable materials, mechanical compression of material, grading and sorting.

$$\text{True } Density = \frac{M}{V_n}$$

Equation 1

where,
Vn = volume of nut, M = mass of the pod

2.3 Terminal Velocity

Pneumatic separation involves the separation of foreign materials from the grain with the aid of air stream. The air was made to pass through the mixture of materials to separate them. The design of fan for effective grain cleaning takes advantage of the variation between the aerodynamic properties of the grain and the debris [10]. The terminal velocity of the seeds was determined according to Moshennin [11] by using the formulae below (Equation 2).

$$CN_R^2 = \frac{8w\rho_f(\rho_p - \rho_f)}{\pi^2\rho_p}$$

Equation 2

The value of CN_R^2 was used to obtain N_R from a plot of CN_R^2 versus N_R, shown in Figure 1. The terminal velocity, v_t was calculated from the relationship (Equation 3).

$$v_t = \frac{N_{Rf}}{d_p\rho_f}$$

Equation 3

Measurement of terminal velocity is important as it aids in setting the air speed of the blower below the terminal velocity of the material measured so as to produce an air pressure good enough to blow away the chaff and allow the dropping of the seed through the air stream.

2.4 Drag Force

Drag force is the force which acts on a biomaterial in the direction of the relative fluid (air) flow velocity. The value depends on velocity. The general expression for calculating drag force (Equation 4) is;

$$F_D = \frac{C_D A_p \rho_f V_t^2}{2}$$

Equation 4

2.5 Sphericity and Drag coefficient

The criteria used to calculate the drag coefficient of the nuts are the sphericity and assumption equation reported by Gorial and O'callaghan [12]; the drag coefficient, $C_D = 5.31 – 4.884\ \psi$ for low Reynold's (Re) number (with + 4% accuracy) where ψ is sphericity of grain with $2000 < Re < 200,000$.

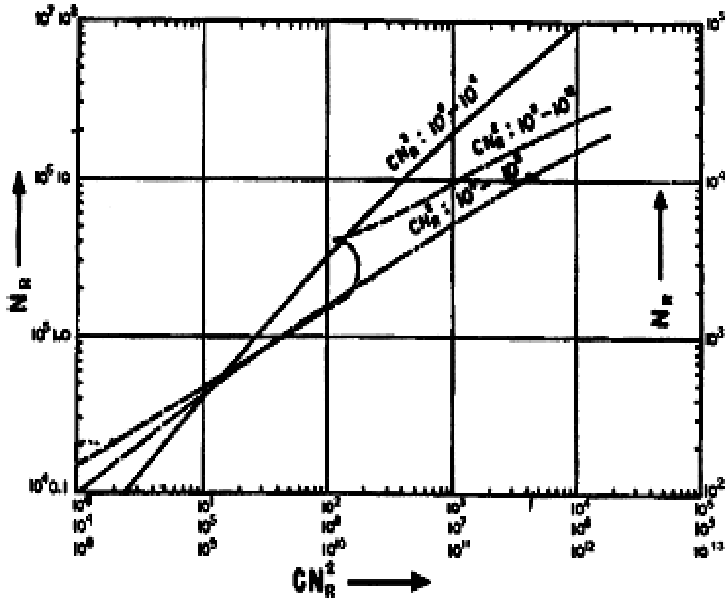

Figure 1: Reynolds number, N_R, versus CN^2_R for spheres

The sphericity (ψ) according to Mohsenin, [4] is given as (Equation 5):

$$\psi = \frac{\sqrt[3]{(abc)}}{a}$$

Equation 5

This parameter was measured to help in the calculation of drag coefficient which in turn was used to calculate terminal velocity;- a parameter that is important for the setting of operational speed of the blower at the cleaning chamber of the machine

2.6 Projected area, A_P

The projected area of the nuts (shelled and unshelled) was calculated with Equation (6):

$$A_p = a \times b$$

Equation 6

where a = major diameter, b = minor diameter

2.7 Angle of repose

The angle of repose was measure according to method described by Sachin *et al.* [13]. The material was placed on the metal surface of the angle of repose measuring machine in Agricultural and Environmental Engineering Laboratory, University of Agriculture, Makurdi, Nigeria. A screw jack was used to gently tilt the table until friction force between the seeds and the metal was overcome by the gravity and moves down the slope. The angle of inclination which is the angle of repose was read from the graduated protractor attached to the tilting table. The experiment was replicated ten (10) time and the values were recorded and tabulated. This parameter capable of aiding the construction of sorter screens and seed conveying chutes in a sorter of shelling machine at an angle good enough to allow the material flow.

2.8 Static coefficient of friction

The inclined plane method described by Aviara *et al.* [14] was used to determine the static coefficient of friction of the pod on metal sheet. The values were calculated with the use of equation 7. All the experiment was replicated ten (10) times at the initial moisture content and the average values were recorded.

$$\mu = \tan\theta$$

Equation 7

where,

μ = static coefficient of friction

α = angle of tilt in degrees.

The coefficient of friction was measured to determine the relative ease with which the Bambara groundnut is capable of sliding on the metal surface used in constructing sorter screen.

2.*9* Measurement of cracking strength

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The cracking strength measurement was carried out with California Bearing Ratio (CBR) machine (with factor of 0.122) in Civil Engineering Laboratory; University of Agriculture, Makurdi, Benue State, Nigeria. Twenty Bambara groundnut pods were randomly selected. One pod at a time was placed between the two metal plates (fixed bottom plate and variable top plate) of the machine. The top plate was slid down against the fixed bottom plate; the biomaterial was compressed between the plates and the force at which the pod experienced no further increase in crack was read and recorded. The procedure was repeated for all the other 19 pods, the values were read and recorded. This parameter was measured to aid in the design of power required to break Bambara groundnut pod.

2.10 Measurement of Moisture content (MC)

The moisture content determination was carried out according to ASAE [15], Standards and Equation (8) was used to calculate moisture content of Bambara groundnut on wet basis.

$$M_w = \frac{w_w}{w_t} \times 100$$

Equation 8

This parameter was measure to ascertain the moisture content of the material at which the research was carried out.

2.11 Statistical Analysis

The results obtained from some engineering properties of the biomaterial were subjected to descriptive statistical analysis and student t-test using Statistical Package for Social Science (SPSS) version 20.

3. RESULTS AND DISCUSSIONS

Table 1: Principal dimensions for manually shelled nuts and unshelled pods at moisture content of 6.27%

Size		**Shelled Nuts (mm)**				**Unshelled Pods (mm)**			
		Max.	**Min.**	**Mean**	**Stdev**	**Max.**	**Min.**	**Mean**	**Stdev**
Large	a	14.80	11.54	13.04	0.78	28.37	18.87	20.72	1.40
	b	13.01	10.09	11.47	0.73	19.73	15.21	16.47	0.86
	c	13.78	10.11	11.59	0.74	16.03	12.08	14.00	0.96
	Gmd	13.43	11.05	11.98	0.58	18.04	16.01	16.78	0.49
Medium	a	11.76	9.55	10.70	0.61	18.94	15.91	17.72	0.83
	b	11.10	8.33	9.67	0.61	16.72	12.64	14.92	0.85
	c	10.95	7.74	9.58	0.70	16.52	11.07	13.22	0.85
	Gmd	11.16	8.98	9.97	0.55	16.09	14.11	15.15	0.49
Small	a	10.51	7.92	9.27	0.62	16.90	13.10	15.30	0.95
	b	9.65	7.08	8.31	0.58	14.49	11.33	13.00	0.72
	c	9.62	0.71	8.27	0.59	13.26	9.05	11.68	0.67
	Gmd	9.66	7.50	8.60	0.54	13.98	11.25	13.24	0.56

Average of 50 measurements. a = major diameter, b = minor diameter, c = intermediate diameter and Gmd = geometric mean diameter.

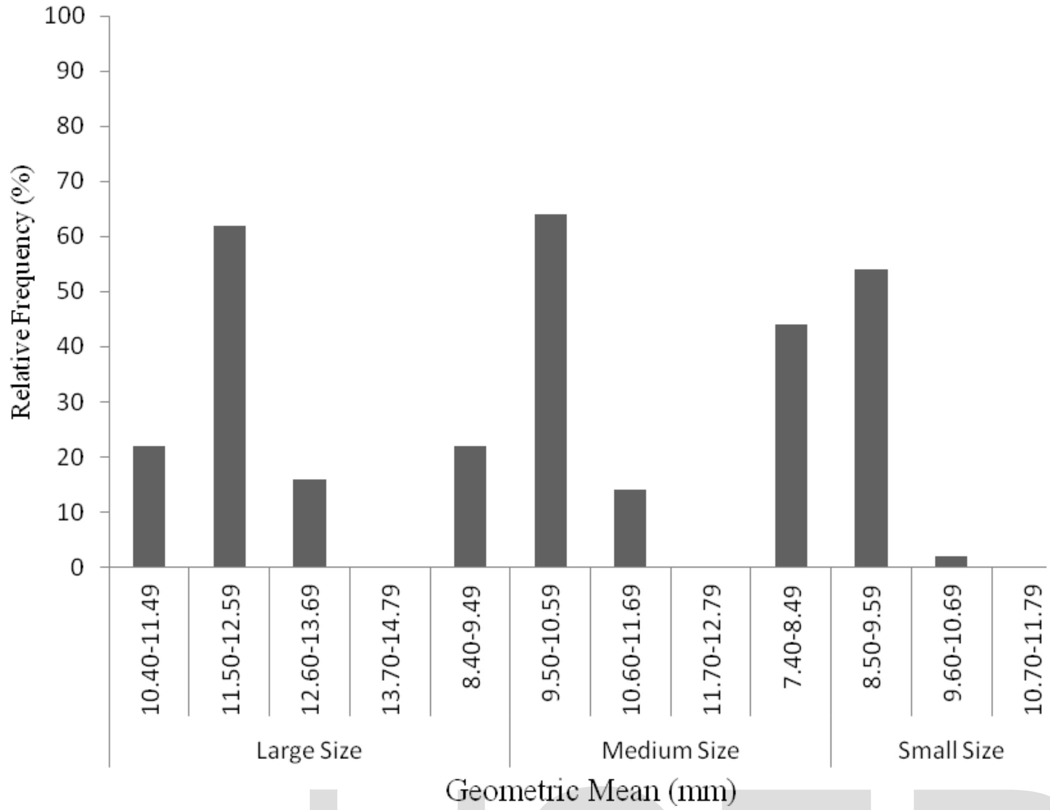

Fig. 2: Frequency curve of geometric mean diameter for three groups of shelled nuts.

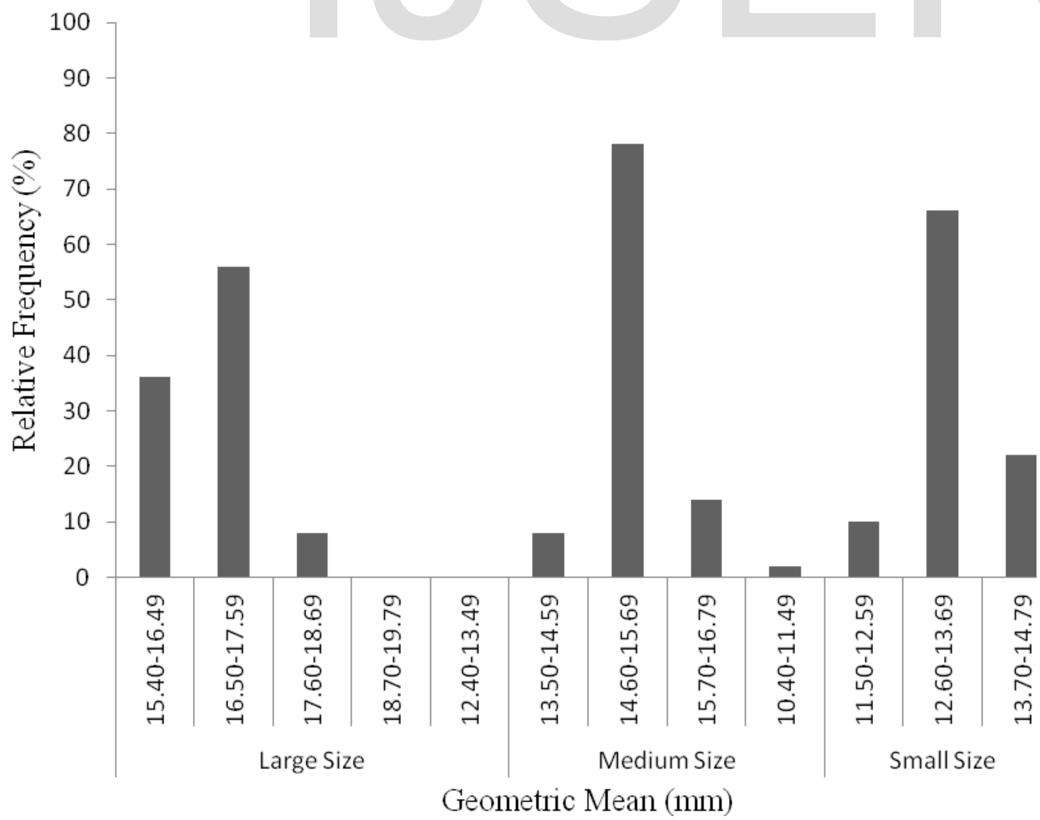

Fig 3: Frequency curve of geometric mean diameter for three groups of unshelled pods.

Table 2: Some physical, aerodynamic and mechanical properties

Measured parameters	Shelled Nuts				Unshelled Pods			
	Max	**Min**	**Mean**	**Stdev**	**Max**	**Min**	**Mean**	**Stdev**
Volume (cm^3)	2.50	1.00	1.49	0.44	3.10	1.10	2.35	0.68
Mass (g)	1.26	0.60	1.05	0.20	2.31	0.80	1.45	0.46
Density (g/cm^3)	0.98	0.60	0.73	0.13	1.25	0.36	0.63	0.19
Sphericity (%)	98.00	88.00	92.80	4.10	91.00	79.00	86.90	3.13
Projected area (cm^2)	1.43	0.86	1.24	0.20	3.52	1.68	2.46	0.54
Reynolds number	180000	120000	146500	18715.32	210000	100000	155000	28377.16
Drag force (N)	0.37	0.37	0.09	0.16	0.28	0.09	0.16	0.06
Drag coefficient	5.00	4.23	4.76	0.20	4.64	4.03	4.44	0.15
Terminal velocity (m/s)	27.45	16.25	20.18	2.75	21.60	13.46	15.82	2.46
Load (N)	-	-	-	-	2.0	1.2	1.56	0.28
Machine factor	-	-	-	-	0.122	0.122	0.122	7.11915E-17
Cracking strength (N/mm^2)	-	-	-	-	0.33	0.17	0.24	0.05

***** Average of 20 measurements

Table 3: Angle of repose and coefficient of friction for Bambara groundnut

Size	Shelled Nuts				Unshelled Pods			
	Max	**Min**	**Mean**	**Stdev**	**Max**	**Min**	**Mean**	**Stdev**
Large pods								
Angle of repose (^{0})	11.00	10.00	10.02	0.42	28.00	24.00	25.4	1.17
Coefficient of Friction	0.19	0.18	0.18	0.04	0.53	0.45	0.47	0.02
Medium pods								
Angle of repose (^{0})	11.00	10.00	10.80	0.004	29.00	26.00	27.00	1.05
Coefficient of Friction	0.19	0.18	0.19	0.004	0.53	0.49	0.51	0.02
Small pods								
Angle of repose (^{0})	13.00	11.00	11.90	0.89	30.00	28.00	29.20	0.79
Coefficient of Friction	0.23	0.19	0.21	0.02	0.58	0.53	0.56	0.02

Average of 10 measurements

3.1 Size of Bambara Groundnut

The Bambara groundnut was grouped in different sizes (Plate 2). As shown in Table 1, for shelled nuts; the major diameter for large size pods ranged from 14.80 to 11.54 mm with 13.09 mm as the mean, the minor diameter ranged from 10.09 to 13.01 mm with 11.47 mm as the mean, the intermediate diameter ranged from 10.11 to 13.78 mm with 11.59 mm as the mean. This is in close range with the measurement carried out by Edward [16], as grain length, width and thickness increased from 10.5 to 14.65 mm, 9.48 to 11.65 mm and 8.50 to 10.90 mm, respectively.

For medium size pods, the major diameter ranged from 9.55 to 11.76 mm with 10.70 mm as the mean, the minor diameter ranged from 8.33 to 11.10 mm with 9.67 mm as the mean, the intermediate diameter ranged from 7.74 to 10.95 mm with 9.58 mm as the mean. For small size pods, the major diameter ranged from 7.92 to 10.5 mm with 9.27 mm as the mean, the minor diameter ranged from 7.08 to 9.65 mm with 8.31 mm as the mean, the intermediate diameter ranged from 7.21 to 9.62 mm with 8.27 mm as the mean. From Figure 2, maximum of 62% of the geometric mean diameter fall within 11.50 to 12.59 mm for large size seeds, 64% fall within 9.50 to 10.59 mm for medium size seeds and 54% fall within 8.50 to 9.59 mm.

Furthermore, principal dimensions of unshelled pods; the major diameter for large size pods ranged from 18.87 to 28.37 mm with 20.72 mm as the mean, the minor diameter ranged from 15.21 to 19.73 mm with 16.47mm as the mean, the intermediate diameter ranged from 12.08 to 16.03 mm with 14.00 mm as the mean (Table 1). For medium size pods, the major diameter ranged from 15.91 to 18.94 mm with 17.72 mm as the mean, the minor diameter ranged from 12.64 to 16.72 mm with 14.92 mm as the mean, the intermediate diameter ranged from 11.07 to 16.52 mm with 13.22 mm as the mean. This is in line with the values measure for average major, intermediate and minor diameters of 18.9 mm, 15.7 mm and 14. 4 mm measured by Atiku *et al.* [1]. For small size pods, the major diameter ranged from 13.10 to 16.90 mm with 15.30 mm as the mean, the minor diameter ranged from 11.33 to 14.49 mm with 13.00 mm as the mean and the intermediate diameter ranged from 9.05 to 13.26 mm with 11.68 mm as the mean (Table 1).

From Figure 3, maximum of 56% of the geometric mean diameter fall within 16.50 to 17.59 mm for large size seeds, 78% fall within 14.60 to 15.69 mm for medium size seeds and 66% fall within 12.60 to 13.69 mm. The mean values of the principal dimensions for shelled and unshelled nuts were compared with student t-test and the result showed significant for medium and small categories of pod sizes at ($p<0.05$).

Plate 2: Grouped local variety of Bambara groundnut bought from North Bank market, Makurdi, Nigeria.

3.2 Terminal velocity, Drag force and sphericity of Bambara groundnut

As showed in Table 2 for Shelled Nuts, the terminal velocity (ms^{-1}) of shelled nut was found to vary from 16.25 to 27.45 with 20.18 as the mean. These values are in the range of terminal velocity measured by Mahbobeh *et al.* [17], for ascorn nut and kernel at moisture content of 5.84 % as 19.52 and 16.80 ms^{-1} respectively. About 80% of this value was within the range of 16.25 and 21.00 ms^{-1}. While for unshelled pods, the terminal velocity ranged from 13.46 to 21.60 with 15.82 as the mean. The results showed that about 95% of the nuts have terminal velocity less than 20. From the results obtained, it shows that separation of shelled nuts from unshelled pods by the application of pneumatic force cannot be effective because the values of the terminal velocities are closed, but it can be inferred that, the pneumatic separation can be very effective when the shelled nut is mixed with the shells of the nut after threshing.

Also from the same Table, the drag force (N) for shelled nuts was found to vary from 0.09 to 0.37 with 0.17 as mean. About 90% of this value was within the range of 0.09 and 0.20. While for unshelled nuts, the drag force ranged from 0.09 to 0.28 with 0.16 as the mean. About 80% of the nuts had drag force ranging between 0.09 and 0.21. From the results obtained, it showed that drag force of shelled and unshelled nuts is very small, this owe to the fact that the shape of the nuts are highly spherical. The sphericity ranged from minimum of 79% (unshelled) to 98% (shelled), this is in the same range with the measurement of Orhevba *et al.* [18]. It can be inferred that the nuts can be efficiently transported with the application of pneumatic force since the area of the nuts in contact with the layer of the fluid does not offer appreciable opposition to the air pressure.

3.3 Volume and density of Bambara groundnut

The volume of shelled nuts (cm^3) ranged from 1.0 to 2.5 with 1.49 as the mean. About 70% of the nuts have volume ranging from 1.00 to 1.5. This is in line with volume of groundnut measured as 1.16 cm^3 by Saeeid *et al.* ([9]. The unshelled nut ranged from 1.10 to 3.10 cm^3. About 65 % of the nuts have volume between 1.10 and 2.90 cm^3. From the same table, the density of shelled nuts (g/cm^3) ranged from 0.60 to 0.98 with 0.73 as the mean. About 95 % of the nuts have density between 0.36 and 0.83 g/cm^3.

3.4 Cracking strength of Bambara groundnut

The summary of cracking strength values is shown in Table 2. The force (N) required for cracking unshelled pods ranged from 1.2 to 2.0 with 1.56 as the mean. Ikechukwu *et al.* [19] measured the average force required to break groundnut pod as 2 N The cracking strength (N/mm^2) of the biomaterial ranged from 0.14 to 0.24 with 0.17 as the mean. Zakka [20] used the compression bearing ratio machine (CBR) to exert a force on randomly selected pods and seeds of Bambara nuts and the cracking strength was indicated by a gauge on the equipment. The mean strength obtained by this method for a pod or seed varied from 5 – 11 N depending on the moisture level.

3.5 Angle of repose and static coefficient of friction of Bambara groundnut

Table 3 showed that the angle of repose of the shelled nuts which ranged from average minimum value of 10.2^0 (large size pods) to maximum of 11.9^0 (Small size pods). Also from the same Table, coefficient of static friction ranged from average minimum value of 0.18 (large size pods) to maximum of 0.21 (small size pods). The angle of repose of the unshelled pods as shown in the same Table ranged from average minimum value of 28^0 (large size pods) to maximum of 30^0 (small size pods). The coefficient of static friction ranged from average minimum value of 0.47 (large size pods) to maximum of 0.56 (small size pods). The values of coefficient of static friction are in the same range with those measured by Orhevba *et al.* [18]. Edward [16] measured the coefficient of static friction of Bambara nut and it was found to increase from 0.39 to 0.66, 0.29 to 0.58 and 0.25 to 0.49 for plywood, galvanized iron and aluminum respectively

4. CONCLUSION

The importance of Bambara groundnut to humans and animals cannot be overemphasized, especially for the fact that it is highly proteinous, as such, vital values of some engineering properties of the material were determined. The mean values of some engineering properties of the Bambara groundnut reported should be adopted by anyone who may be interested in the design of machines for processing, handling and separation of the biomaterial.

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