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SOME NUTRITIONAL AND ENGINEERING PROPERTIES OF *KARIYA* (*HILDEGARDIA BARTERI*) SEEDS

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ABSTRACT

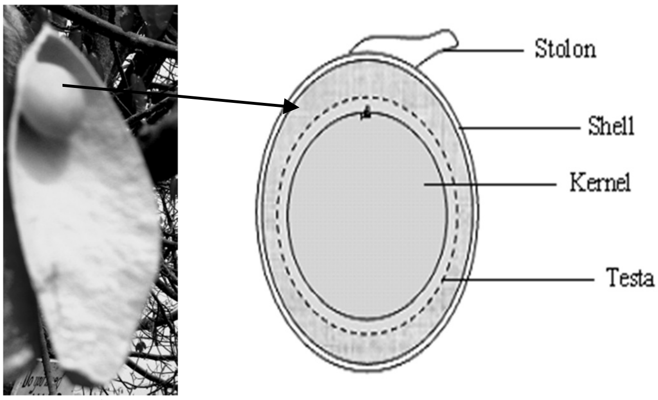
Kariya is an ornamental tropical tree which produces an underutilized edible seed. Some nutritional and engineering properties of *kariya* seeds were investigated. The results show that *kariya* seeds contain 17.5, 13.8, 2.8, 37.5 and 6.5% of crude protein, moisture, ash, fat and crude fibre, respectively. The crude fat was largely made up of myristic, palmitic, stearic and linolenic acids. The length, width, thickness, equivalent diameter and mass were 14.1, 10.2, 9.6, 11.1 mm and 0.5 g for the nut and 10.2, 7.20, 7.2, 8.1 mm and 0.4 g for the kernel, respectively. The volume, surface area, sphericity and aspect ratio were respectively 719.81 mm^3, 387.13 mm^2, 79.26, 73.78% for the nut and 324.28 mm^3, 203.60 mm^2, 80.45, 71.33% for the kernel. The true and bulk density, and porosity were 787.2, 375.4 kg/m^3 and 47.7% for the nuts and 1058, 508 kg/m^3 and 52% for the kernels, respectively; while the angle of repose and coefficient of friction on wood, aluminum and galvanized steel surfaces were 38.22°, 0.32, 0.34 and 0.35 for the nut and 33.37°, 0.23, 0.30, 0.31 for the kernel. The rupture force of the nut in the longitudinal axis (91.65 N) was less than in the transverse direction (104.87 N) and the corresponding values of stiffness and maximum deformation at nutshell rupture were 29.71 and 13.53 N/mm; and 3.39 and 4.18 mm, respectively. Knowledge of these properties will be useful for designing various systems for processing of *kariya* seeds.

Keywords: *Hildegardia barteri, nuts, kernels, nutritional and engineering properties*

1. INTRODUCTION

Kariya (Hildegardia barteri) belongs to a genus of *Malvaceous* trees comprising eleven species that are found in the dry tropical forests of West Africa from Ivory Coast to southeastern Nigeria (Hinsley, 2009). Although it grows mostly in the wild, it is specifically grown for ornamental purpose tree due to the bright red flowers it produces during the dry season (Fig. 1). The flowers, usually born on leafless branches mature into one-seeded pods; each about 50 mm in length ((Inglett *et al.*, 1973), bearing a peanut-like seed in a nutshell (Fig. 2).

Fig. 1: A typical kariya (Hildegardia barteri) tree on Obafemi Awolowo University Campus, Ile Ife, Nigeria.



Pod Nut

Fig. 2: Longitudinal section through kariya pod and nut

Kariya wood, due to its light weight is reported to be useful in making fishing net floats and traditional household utensils. Fibre ropes and gum obtainable from the bark have also been found to be of high industrial value if properly harnessed. In some parts of West Africa, raw or roasted *kariya* kernels are eaten like peanuts (Inglett *et al.*, 1973)

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or used as a traditional food condiment. However, in Nigeria and most other places where it is grown as ornament, when the mature pods dry up and get completely shed, they are disposed or incinerated as refuse.

The properties of agricultural materials have been widely studied. Physical and mechanical properties such as axial dimensions, mass, volume, equivalent diameter, sphericity, bulk density, true density, porosity, projected area, coefficient of friction and cracking force provide useful information for designing threshing, separating, handling, pneumatic conveying and storage systems. For most oil seeds and legumes, knowledge of nutritional properties provides useful information on their exploitation for industrial or food purposes. Some of the previously researched seeds include peanut (Aydin, 2007); filbert nut (Pliestic *et al.*, 2006); pistachio (Kashaninejad *et al.*, 2004); walnut (Koyuncu *et al.*, 2004); almond (Aydin, 2003); hazelnut (Aydin, 2002); macadamia nut (Braga *et al.*, 1999) and neem (Viswanathan *et al.*, 1995).

The sizes of these products were determined by measuring their axial dimensions as documented by Dutta *et al.* (1988) and Mohsenin (1986) using linear measurement tools such venier callipers and micrometer screw gauge. The axial dimensions of a material give information about its natural position at rest and this is useful when applying compressive force to induce fracture in a nutshell. The one thousand seed weight is a measure of seed size in grams of 1,000 seeds; it is important when calculating seeding rates, calibrating seed drills and estimating shattering and combine losses (Agri-Facts, 2007). Dutta *et al.* (1988) and Aviara *et al.* (2005) determined 1,000 seed weight by weighing one thousand randomly selected seeds using high-precision electronic balances. Ogunjimi *et al.* (2002) and Shepherd & Bhardwaj (1986) determined the true or particle density of locust beans and pigeon pea respectively using the liquid displacement method. Aviara *et al.* (2005) coated balanite nuts with a thin layer of epoxy resin to prevent the sample from absorbing water during determination of true density by water displacement. In a similar study, Omobuwajo *et al.*, (1999) packed African breadfruit seeds in a sinker made from mosquito wire net. The relationship between porosity, true density and bulk density documented by Mohsenin (1986) has been frequently used for determining the porosity of agricultural products. The mass and density characteristics of agricultural products are quite useful in estimating product yield and throughput of processing machines. Hull-seed or shell-kernel ratio as an index of maturity was first proposed by Troeger *et al.* (1976) and Pattee *et al.* (1977) especially for groundnuts. It is obtained as a percent ratio of the mass of the hull (kernel) to mass of the entire seed (nut) obtained on the basis of fresh or dry seed mass. It gives an idea of what percentage of the whole seed is the hull and this has been used subsequently by other researchers (Pattee *et al.*, 1980, 1981; Nautiyal, 2002). The extent of maturity of seeds in nutshell affects their behaviour during processing and resistance to static and dynamic forces. For instance, an immature seed will yield less oil than mature one. The static coefficient of friction of several agricultural products on several structural surfaces has been determined using the inclined plane method (Ramakrishna, 1986; Dutta *et al.*, 1988; Joshi *et al.*, 1993; Aviara *et al.*, 2000, Aviara *et al.*, 2005). Fraser *et al.* (1978), Dutta *et al.* (1988), Aviara *et al.* (1999 and 2005) used a specially constructed box with removable front panel to determine the angle of repose of grains and seeds.

Although, information on the production statistics of *kariya* seeds is quite sparse, it is reported to be an edible oil seed (Inglett *et al.*, 1973) which could be exploited for food or industrial purposes. Consequently, this study was carried out to investigate some nutritional and engineering properties of *kariya* seeds.

2. MATERIALS AND METHODS

2.1. Source of materials

Dry *kariya* pods were gathered on Obafemi Awolowo University campus, Ile-Ife during the month of January, 2008. About 5 kg of nuts that were extracted from the pods were winnowed manually to remove stones and other extraneous particles. About 2 kg of the nuts were dehulled manually and cleaned with an air screen cleaner to remove all dust, chaff, broken, shrivelled, immature kernels and broken seeds.

2.2. Determination of proximate composition and fatty acid profile

***Moisture content*:** The moisture contents of the nuts and the kernels were determined according to American Society of Agricultural and Biological Engineers standard S410.1 (ASABE, 1998). Approximately 10 g of nuts and kernels were weighed to the nearest 0.01 g inside aluminium dishes of known weights; each in three replicates. Samples were oven dried at 130°C for 6 h and removed afterwards from the oven, cooled in desiccators and weighed. The moisture content (w.b.) was calculated from the percent difference in weight before and after oven-drying.

Proximate composition: The proximate composition of the samples was determined according to AOAC (2002) method. Nitrogen estimation was done by micro-Kjeldhal method. The protein content was determined by multiplying the nitrogen value with 6.25. The greyish white residue formed after charring and incineration of sample in a muffle furnace at 600°C for 6–8 h comprised of the total ash. Fat content was estimated by soxhlet extraction and total carbohydrate was obtained by difference. All values were averages of three determinations.

***Fatty acid analysis*:** Fatty acid methyl esters (FAMEs) of the extracted crude fat were prepared by transesterification using methanolic KOH according to method Ce 2-66 of AOCS (1997). The FAMEs were separated in a gas chromatograph (Model GC-15A, Shimadzu corporation, Japan) equipped with a hydrogen flame detector (FID) using a S.S. column coated with 15% DEGS on chromosob w/HP 80-100 mesh as the stationary phase. The column oven temperature was 180°C. Injector and detector temperatures were 220 and 230°C respectively and the carrier gas, nitrogen was maintained at a flow rate of 40 ml/min. The fatty acids in the oil were identified by comparing retention times of FAMEs with those of standard FAME mix C8 – C24 (Supelco, Belle, USA). There were three observations and the average was expressed as relative percent.

2.3. Determination of physical and mechanical properties

***Axial dimension, Shape indices and Gravimetric properties*:** To determine the average size of the seed, 100 nuts and kernels were picked randomly and their three linear dimensions namely, length L, width W and thickness T were measured using a micrometer reading to 0.01 mm (Özarslan, 2002; Vilche *et al.*, 2003; Yalcin, 2007). From the axial dimensions, the equivalent diameter, D_e mm; sphericity, ϕ %; and aspect ratio, R_a % were calculated using the following equations (Mohsenin, 1986; Aydin, 2002, 2003; Joshi *et al.*, 1993; Isiaka *et al.*, 2006):

$$D_e = (LWT)^{1/3} \tag{2}$$

$$\varphi = \frac{D_e}{L} \times 100 \; ; \tag{3}$$

$$R_a = \frac{W}{L} \times 100 \tag{4}$$

The following equations were used to obtain the volume, *V* (Pliestic *et al.*, 2006; Du & Sun, 2006) and arithmetic mean diameter, D_a (Dursun & Dursun, 2005; Mohsenin, 1986; Rasavi *et al.*, 2007):

$$V = \frac{\pi LWT}{6} \quad (5)$$

$$D_a = \frac{L+W+T}{3} \quad (6)$$

Surface area, S_a was calculated according to Equation (7) below (McCabe *et al.*, 1986; Koocheki *et al.*, 2007)

$$S_a = \pi D_e^2 \quad (7)$$

The respective mass of the individual nuts and kernels and one thousand seeds mass were determined using a precision electronic balance Mettler Toledo PB153 weighing to 0.001g degree of accuracy. Density of the sample was determined by water displacement method. Ten nuts of known mass coated with a thin layer of epoxy resin were immersed inside a known volume of water inside a measuring cylinder using a sinker made of mosquito wire netting (Omobuwajo *et al.*, 1999). From preliminary investigation, the average increase in mass of the sample due to the epoxy resin coating was 2.23%. The ratio of the mass of the nuts to the net volume of water displaced due to the immersion was used to calculate the average density of one nut. For bulk density, a measuring cylinder of pre-determined weight and known volume was filled to the top with the sample, the excess was removed by a strike off stick without any compaction and the weight was determined afterwards (Dutta *et al.*, 1988). The ratio of the weight of the nuts to the volume of the cylindrical container was calculated to obtain the bulk density (ρ_b). In both cases, there were ten replicates. Based on Mohsenin (1986), density ratio (ρ_r) was calculated as the ratio of true density to the bulk density of the material while porosity (p) was calculated using equation (8):

$$\text{Porosity, } \varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (8)$$

Hull-seed ratio (HSR) was obtained as a percent ratio of the mass of hull (shell) to the mass of the entire seed (nut). Five nuts of known total weight were dehulled, the total weight of the hull was determined and HSR was calculated. The indicated value was an average of ten replicates.

Frictional Properties: The coefficient of friction of the material was determined using the inclined plane method described by Dutta *et al.* (1988); Suthar and Das (1996) and Aviara *et al.*, (2005). Three structural surfaces were considered; namely, wood (with grains parallel to the direction of slide), aluminum and galvanized steel, each in three replicates. As soon as the material began to slide on the selected surface, the angle at which the plane was inclined to the horizontal (β) was measured with a protractor and the coefficient of friction (μ) was calculated as:

$$\mu = \tan\beta \quad (9)$$

This was carried out in ten replicates. The angle of repose (Φ) was determined using a 200 × 200 × 200 mm transparent fibre box which had a removable front panel. The box was filled with the samples 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 & Akinci, 2004; Baryeh, 2001; Joshi, *et al.*, 1993). The angle made by the slope with the horizontal was calculated as the angle of repose and there were ten replicates.

Force Deformation Characteristics: The cracking force of *kariya* nuts was determined in the longitudinal and transverse axis using the Instron Universal Testing Machines (UTM 3369 series, 50 kN capacity). Individual nut was loaded between two parallel plates and compressed at a fixed cross-head speed of 10 mm/min until the shell ruptured. The bio-yield point was taken as the point at which rupture occurred after which there was a sudden drop in force on the force deformation curve. As soon as the bio-yield point was attained, loading was discontinued. The magnitude of the load applied on the sample and the deformation during compression was read through the monitor of the desktop computer fitted with the Instron UTM. The software has an X-Y plotter which generates the force-deformation curve of each sample. This was carried out in fifteen replicates.

3. RESULTS AND DISCUSSION

Proximate composition: The results showed that *kariya* kernels contain 17.54, 37.45, 2.79, 6.48 and 21.91% of crude protein, crude fat, ash, crude fibre and carbohydrate respectively (Table 1). The crude protein content *kariya* compares favourably with 18.3% for gingelly seeds; 15.6% for walnut and 19.8% for both pistachio and sunflower seeds; whereas, it is less than 21.2 % for cashew nut; 20.8 % for almond; 26.25 for groundnut; 20.3 % for linseed and 20 % for mustard seeds (Gopalan *et al.*, 2007). The crude fat content can be compared with 39.3 % for sponge gourd seeds (Ogunsina *et al.*, 2009); 39.8 % for groundnut; 37.1 % for linseed; 39.7 % for mustard and 39 % for niger seeds (Gopalan *et al.*, 2007). Given its relatively high protein content, and subject to investigation of its anti-nutritional components, defatted *kariya* flour may be explored as a good source of vegetable protein.

Table 1: Proximate composition of kariya kernel

Constituent	% composition
Moisture	13.83±0.13
Crude Protein	17.54±0.25
Ash	2.79±0.15
Fat	37.45±1.18
Crude Fiber	6.48±0.57
Carbohydrate	21.91±0.46

Table 2: Fatty acid composition of kariya seed oil

Fatty acids	% Composition
Saturated fatty acids	
Lauric	0.60
Myristic	23.32
Palmitic	29.38
Stearic	23.74
Total	77.04
Unsaturated fatty acids	
Oleic	0.03
Linoleic	1.43
Linolenic	21.50
Total	22.96

Fatty acids: The fatty acid profile of *kariya* seed oil is presented in Table 2. A total of 77.04% of saturated fatty acids comprising 29.38% palmitic, being the most abundant; 23.32% myristic, 23.75% stearic and trace amount of lauric (0.6%) were observed in *kariya* seed oil. Unsaturated fatty acids totaled 22.96% with 21.5% of linolenic acid as the most abundant; and a small amount of linoleic acid (1.43 %) and trace amount of oleic (0.03%) were also observed. Oils with a high proportion of saturated fats are generally important for energy, hormone production, cellular membranes and organ padding. They are usually stable under oxidative conditions (Rossel *et al.*, 1985) and serve important dietary functions in human nutrition and immune system. Enig (2000) reported that myristic and palmitic acid are important to body metabolism and proper functioning of vital body organ among other things. Subject to further investigation, the suitability of *kariya* seed oil may be exploited for edible industrial products.

Physical and mechanical properties: Data on axial dimensions, shape indices, gravimetric properties, density characteristics and frictional properties of *kariya* nuts and kernels are shown in Table 3. The average axial dimensions (*i.e.* length, width, thickness, geometric mean diameter) and mass of *kariya* were 14.06, 10.02, 9.57, 11.1 mm and 0.47 g, for the nuts and 10.16, 7.20, 7.16, 8.05 mm and 0.35 g for the kernels respectively. The volume and the surface area were 719.81 mm^3 and 387.13 mm^2 for the nuts and 324.28 mm^3 and 203.60 mm^2 for the kernels. These axial dimensions are close to 10.5, 9.48 and 8.50 mm for bambara groundnut (Baryeh, 2001), whereas with an average width and thickness of 16.68 and 15.71 mm respectively, *kariya* is smaller than peanut (Aydin, 2007). Similarly, when 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 & 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, *kariya* is smaller in size. It is however bigger in size than sweet corn which has 10.47, 8.33 and 3.83 mm of length, width and thickness, respectively (Karababa & Coskuner, 2007). It was observed that *kariya* nut is lighter in weight compared to peanut, filbert, pistachio and almond which weigh 2.16, 3.88, 1.09, 1.15 and 2.64 g, respectively (Aydin, 2007; Pliestic *et al.*, 2006; Kashaninejad *et al.*, 2004; Aydin, 2003). The following general expressions were derived for the relationship between the principal dimensions and mass for the nut and the kernel.

$$L = 1.38W = 1.47T = 31.15M, \qquad (10)$$

$$l = 1.42w = 1.43\,t = 29.54\,m; \qquad (11)$$

The relationships between the respective parameters for the nut and kernel are derived as follows:

$$L = 1.39l, \qquad (12)$$

$$W = 1.47w, \qquad (13)$$

$$T = 1.40t, \text{ and} \qquad (14)$$

$$M = 1.24m. \qquad (15)$$

where mass, length, width and thickness are M, L, W, T for nut and m, l, w, t for the kernel, respectively.

A lower mass ratio of 1.241 of nut indicates a relatively high yield of kernels per unit weight of *kariya* nuts which is greater than that of sunflower seeds (Gupta & Das, 1997) and sponge gourd seeds (Ogunsina *et al.*, 2009). The frequency distribution curves of *kariya* nut and kernels for length, width and thickness are shown Figs. 3 and 4. Table 4 shows the dimension and mass of *kariya* nuts and kernels based on their size distribution. The trend shown by each curve is that of normal distribution. The geometric mean diameter of *kariya* is less than 13.38 mm for pistachio (Kashaninejad, *et al.*, 2006); 20.96 mm for filbert (Pliestic *et al.*, 2006) and 12.6 mm for pea nut (Aydin, 2007). These properties of *kariya* seeds are essential for the design of equipment and facilities for handling, conveying, separation, drying, aeration, storing and processing. Various types of cleaning grading and separation equipment are designed on the basis of their physical properties.

The sphericity of *kariya* nut (79.26) and kernel (80.45%) compares favourably with that of palm nut, 80% (Sanni & Adegbenjo, 2002); pistachio 79.54% (Kashaninejad, *et al.*, 2006) and filbert nut, 82.86% (Pliestic *et al.*, 2006), but are less that of bambara groundnut

Table 3: The Physical Properties of kariya Seeds

Property	Nuts	Kernels
Axial dimension and Shape indices		
Length (mm)	14.06±1.1	10.16±0.64
Width (mm)	10.2±0.59	7.2±0.41
Thickness (mm)	9.57±0.40	7.16±0.50
Geometric mean diameter (mm)	11.1±0.47	8.05±0.32
Volume (mm^3)	719.81±2.22	324.28±8.31
Surface area (mm^2)	387.13±2.34	203.60±1.86
Sphericity (%)	79.26±4.34	80.45±0.05
Aspect ratio (%)	73.38±0.07	71.33±0.07
Gravimetric properties		
Mass (g)	0.47±0.08	0.35±0.04
Thousand seeds mass (g)	485.61±10.2	396.23±8.54
True density (kg/m^3)	787.17±31.63	1058.02±78.3
Bulk density (kg/m^3)	375.39±10.81	508.02±22.01
Density ratio (%)	56.42±4.29	45.37±4.01
Porosity (%)	47.69±4.27	51.98±3.97
Hull-Seed Ratio (%)	24.73±0.06	-
Frictional properties		
Coefficient of static friction		
-on wood (with grain parallel to axis of slide)	0.32±0.05	0.23±0.04
-on aluminum	0.34±0.04	0.3±0.02
-on galvanized steel sheet	0.35±0.04	0.31±0.01
Dynamic angle of repose (°)	38.22±2.09	33.37±2.59

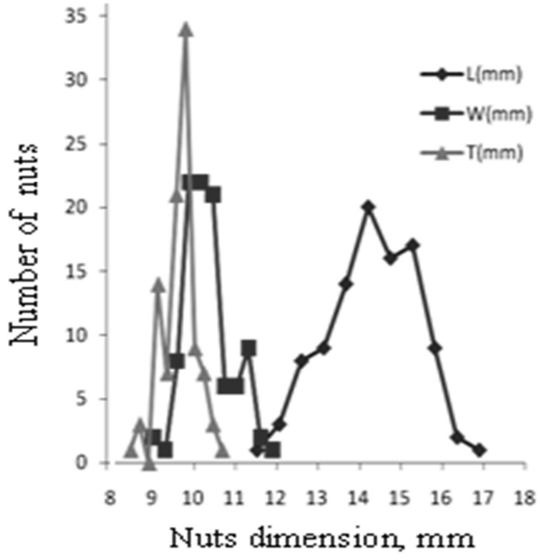

Fig. 3: Frequency distribution curves of kariya nuts dimensions

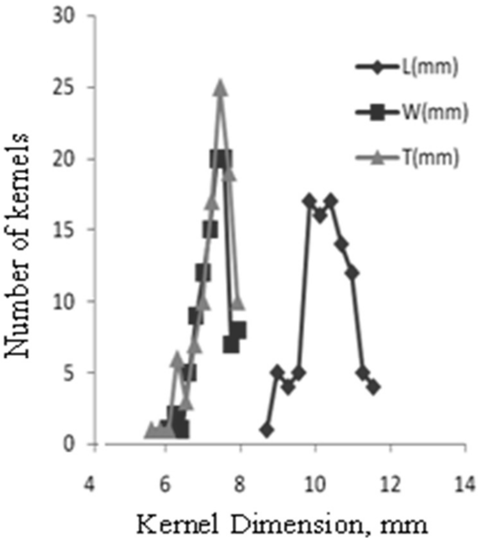

Fig. 4: Frequency distribution curves of kariya kernels dimensions

Table 4: Dimension and mass of kariya nuts on size distribution

Properties	Size distribution		
	Large	Medium	Small
Nut			
Length (L), mm	15.48±0.48	14.05±0.53	12.32±0.39
Width (W), mm	11.25±0.24	10.19±0.29	9.54±0.21
Thickness (T), mm	0.13±0.22	9.63±0.13	9.04±0.24
Mass (M), g	0.58±0.03	0.48±0.04	0.36±0.06
Kernel			
Length (l), mm	10.90± 0.33	10.03±0.29	9.03±0.25
Width (*w*), mm	7.69± 0.16	7.25±0.15	6.64±0.25
Thickness (*t*), mm	7.69± 0.15	7.14±0.27	6.12±0.25
Mass (*m*), g	0.40± 0.03	0.34±0.02	0.28±0.03

which varied from 87-90% (Baryeh, 2001). These values indicate that *kariya* has a near spherical shape and provides useful information for the design of nutcracker, kernel-shell separator, milling machine for *kariya* seeds and other similar agricultural products where the flow pattern of the material on flat surfaces is an important factor.

The true density, bulk density, density ratio and porosity are 787.17, 375.39 kg/m^3 56.42 and 47.69% for the nut and 1058.02, 508.02 kg/m^3, 45.37 and 51.98% for the kernel, respectively. The bulk density of *kariya* kernels is greater than 213.5 kg/m^3 for peanuts (Aydin, 2007) and 492 kg/m^3 for filbert nut (Pliestic *et al.*, 2006); but lesser than 520.79, 590, 585.8 and 795 kg/m^3 for pistachio (Kashaninejad *et al.*, 2006), almond (Aydin, 2003), chestnut (Yildiz *et al.*, 2009) and bambara groundnut (Baryeh, 2001), respectively. Similarly, the true density of *kariya* nuts is greater than 484.5 for peanut and lower than 868 for filbert; 1141.77 for pistachio; 1285 for bambara groundnut and 1135.68 kg/m^3 for chest nut. The porosity of kariya nuts compares with that of almond and balanite which ranges from 35.32 - 53.21 and 41.86 - 47.46%, respectively (Aydin, 2003; Mamman, *et al.*, 2005) but higher than 41.53 - 45.24%; for filbert nuts (Pliestic *et al.*, 2006), and sunflower seeds (Gupta & Das, 1997). Bulk density and porosity affect structural loads of most biomaterials. The HSR of *kariya* compares with 24.5% for *Moringa oleifera* seeds (Ogunsina, 2009) and far below 70-75% for cashew nut (Andrighetti *et al.*, 1994). Hull seed ratio measures the extent of maturity of a particular seed in a nutshell and provides information regarding its further processing and utilization.

The angle of repose of *kariya* nut and kernel are 38.22 and 33.37º respectively. The static coefficient of friction on wood, aluminum and galvanized sheet are 0.32, 0.34, and 0.35 for the nut and 0.23, 0.3 and 0.31 for the kernel, respectively. The angle of repose compares very closely with that of balanite which varies from 22.36 to 33.66 (Aviara *et al.*, 2005). It was observed that for the kernel, angle of repose is lower than that of the nut and this may be attributed to the rough nature of the hull which offers resistance to motion when sliding on the test surface. Both the nut and the kernels are near spherical in shape thus they both glide easily on one another. The hopper walls are mostly inclined at an angle greater than the angle of repose to allow material flow by gravity (Sanni & Adegbenjo, 2002). The static coefficient of friction of *kariya* kernel on all the surfaces considered is lesser than that of the nut due to the smoother surface of the kernel. Information about the frictional properties of biomaterials is important in the design of hopper and conveyor systems.

The force deformation curve of *kariya* nuts during quasi-static compression tests in both axial and longitudinal directions are shown in Fig. 5 and Table 5. The average compressive force required to cause nut rupture during longitudinal loading (91.65 N) was less than during transverse loading (104.87 N). The average maximum deformations of kariya nuts at nutshell rupture were 3.39 and 4.18 mm and the corresponding values for stiffness were 29.71 and 13.53 N/mm. It was observed that maximum rupture force occurred in the transverse axis while minimum force was in the longitudinal axis. Similar behaviour had been reported for almond (Aydin, 2003) and green gram (Nimkar & Chattopadhyaya, 2001). The converse was true for filbert (Pliestic *et al.*, 2006). This implies that the nutshell is more resistant to fracture in the transverse axis as compared to the longitudinal. These are contrary to the findings of Aydin (2002) for hazelnut, Braga *et al.* (1999) for macadamia nut and Koyuncu *et al.* (2004) for walnut. This contradiction could be due to differences in the shape of *H. barteri* and filbert nut in comparison to these other nuts.

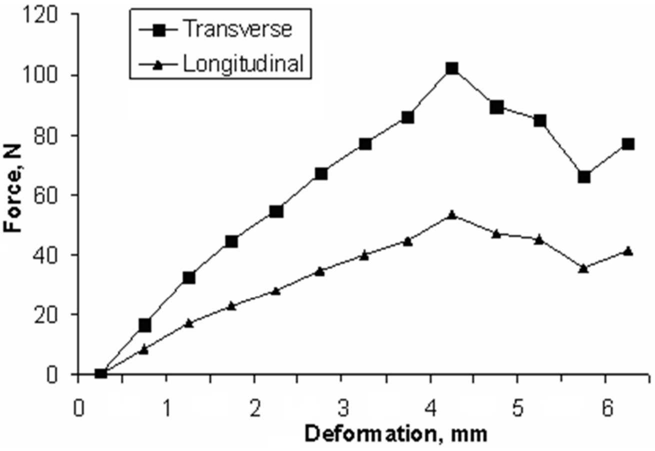

Fig. 5: Force-Deformation of kariya nuts under quasi-static compression

Table 5: Some strength characteristics of kariya nuts during quasi-static loading

Quantity	Orientation of load application	
	longitudinal axis	transverse axis
Stiffness, N/mm	29.71	13.53
Maximum elastic deformation, mm	3.39	4.18
Load at nutshell rupture, N	91.65	104.87

4. CONCLUSIONS

The following conclusions can be drawn from this study:

i. *Kariya* though an underutilized seed is rich in protein (17.54%) and crude fat (37.45%). The fatty acids profile indicates an almost equal amount of myristic, palmitic, stearic and linolenic acids.
ii. The average values of length, width, thickness, equivalent diameter and mass were 14.06, 10.2, 9.57, 11.10 mm and 0.47 g for the nut and 10.16, 7.20, 7.16, 8.05 mm and 0.35 g for the kernel respectively. The volume, surface area, sphericity and aspect ratio were 719.81 mm^3, 387.13 mm^2, 79.26 and 73.78% for the nut and 324.28 mm^3, 203.60 mm^2, 80.45 and 71.33% for the kernel respectively.
iii. The true and bulk density, density ratio and porosity were 787.17, 375.39 kg/m^3, 56.42 and 47.69%, for the nuts and 1058.02, 508.02 kg/m^3, 45.37 and 51.98% for the kernel respectively.
iv. The angle of repose and coefficient of friction on wood, aluminium and galvanized steel surfaces were 38.22°, 0.32, 0.34 and 0.35 for the nut and 33.37°, 0.23, 0.30, 0.31 for the kernel.
v. The average compressive force required to cause nut rupture during longitudinal loading (91.65 N) was less than during transverse loading (104.87 N). The average maximum deformations of kariya nuts at nutshell rupture were 3.39 and 4.18 mm and the corresponding values for stiffness were 29.71 and 13.53 N/mm.

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