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

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ABSTRACT

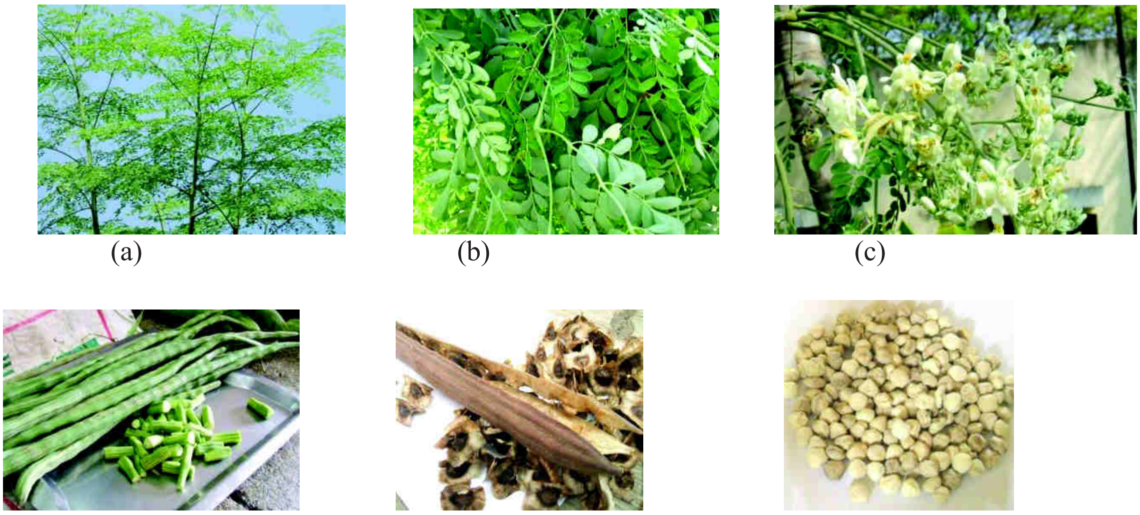
Some engineering properties of drumstick seeds were determined following standard methods in the literature. The results show that the mean values of 100 measurements for length, width, thickness and mass of drumstick seeds at a moisture content of 4.64% (w.b) were: 10.96, 10.83, 10.24 mm and 0.35 g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

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

1. INTRODUCTION

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

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



(a) (b) (c)

(d) (e) (f)

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

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

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

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

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

2. MATERIALS AND METHODS

2.1 Samples

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

2.2 Physical and Mechanical Properties

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

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

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

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

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

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

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

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

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

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

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

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

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

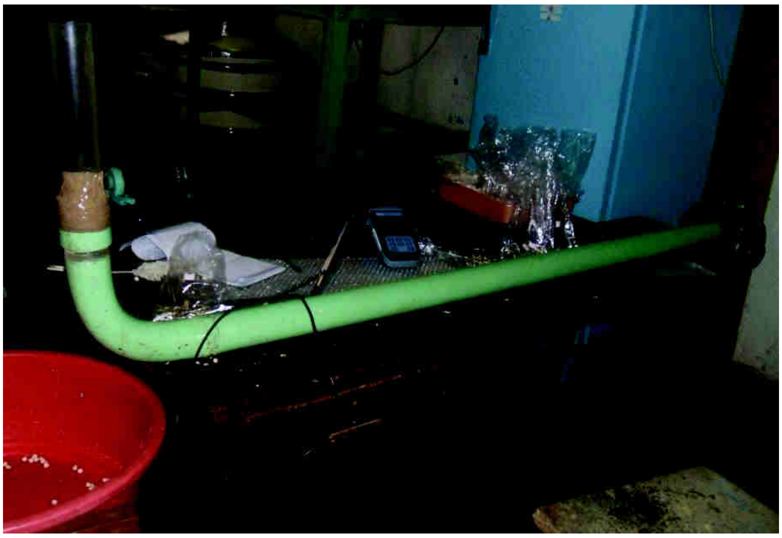


Fig. 2. Experimental set for measuring terminal velocity of drumstick seeds

2.3 Water Uptake Properties

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

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

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

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

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

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

2.4 Cooking Properties

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

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

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

3. RESULTS AND DISCUSSION

3.1 Axial Dimensions, Mass and Dimensional Relationships

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

Table 1. Physico-mechanical properties of drumstick seeds

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

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

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

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

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

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

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

and for the kernels:

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

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

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

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

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

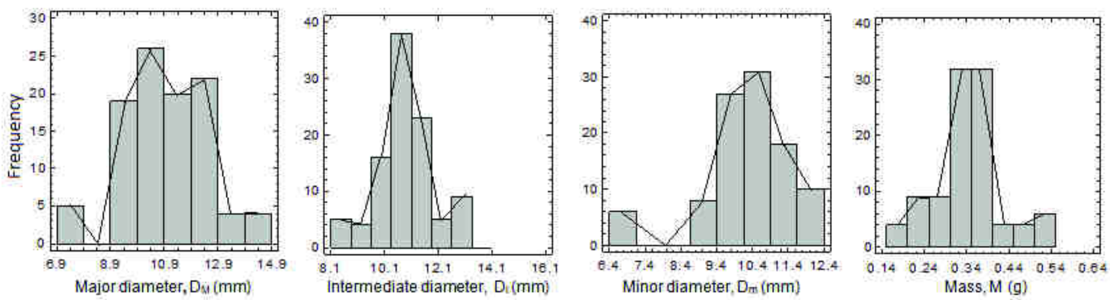


Fig. 3 a. Frequency distribution of drumstick nuts

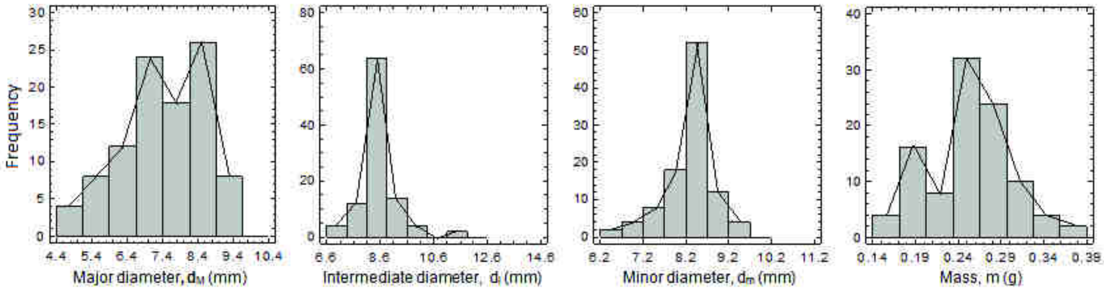


Fig. 3 b. Frequency distribution of *Drumstick* kernels

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

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

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

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

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

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

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

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

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

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

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

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

4. CONCLUSIONS

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

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

ACKNOWLEDGEMENTS

This research was carried out under the fellowship of the United Nations University, Tokyo, Japan at Central Food Technological Research Institute (CFTRI), Mysore, India. Special thanks to Dr V. Prakash, Dr A.G. Appu Rao, Srinivas, Zatyendra Rao, Lokesh, Gopal and Chikaswamy for their countless support.

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