Effect of moisture content on some engineering properties of mahogany (*Khaya senegalensis*) seed and kernel

N.A. Aviara, A.A. Lawal, H.M. Mshelia, D. Musa

Department of Agricultural and Environmental Resources Engineering, Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria

Abstract

Aviara N.A., Lawal A.A., Mshelia H.M., Musa D., 2014. **Effect of moisture content on some engineering properties of mahogany (*Khaya senegalensis*) seed and kernel**. Res. Agr. Eng., *60*: 30–36.

Some engineering properties of mahogany seed and kernel were investigated and expressed as a function of moisture content. In the moisture ranges of 7.1–32% and 5.3–22% (d.b.), respectively, the seed and kernel length, width and thickness increased with increase in moisture content. One thousand seed and kernel weight increased linearly with moisture content. True density, bulk density, porosity and angle of repose of seed and kernel also increased with increase in moisture content. Static and kinetic coefficients of friction increased linearly with moisture content and varied with structural surfaces. Specific heat increased with increase in both moisture content and temperature. Regression equations were used to express the relationships existing between the engineering properties and seed and kernel moisture contents.

Keywords: *Khaya senegalensis*; physical properties; frictional properties; thermal properties; specific heat; Nigeria

Dry-zone mahogany (*Khaya senegalensis*) is an oil rich tree crop that grows well in Sub-Saharan Africa. Its round woody capsular fruit has four to five valves in which up to 6–18 seeds are embedded. The tree's importance lies mainly on its seed (Fig. 1a), which contains a kernel (Fig. 1b) with oil content of 67%. The seed oil known as "mayin daci" is used for cooking and in the manufacture of cosmetics and pharmaceutical products in West Africa.

The present methods of handling and processing the mahogany seed involve operations that are not only slow and full of drudgery but also wasteful. Improved methods of handling and processing the seed using suitable machines and equipment could be developed if the engineering properties are known. Several researchers (Owolarafe et al. 2005; Dash et al. 2008; Naderiboldaji et al. 2008) studied the physical properties of different agricultural products for the above purpose. These researchers determined the size and shape of the investigated products by measuring the three principal axial dimensions. The volume of seed was calculated from the arithmetic mean, geometric mean and equivalent sphere effective diameters (Dutta et al. 1988a). Water displacement method was used by a number of investigators (Oje, Ugbor 1991; Joshi et al. 1993) in determining true density. Bulk density was determined using AOAC (1980) recommended method. Porosity of grains was expressed with the mathematical relationship between true density and bulk density stated by Mohsenin (1986). The inclined plane method (Aviara et al. 2005a,b) was commonly used by investigators in studying the coefficient of friction of agricultural products on different structural surfaces. Dutta et al. (1988a) and Aviara et al. (1999) used a specially constructed box with removable front panel to determine the angle of repose of gram and guna seeds. The commonly used method of determining the specific heat of agricultural products was the method of mixtures (Dutta et al. 1988b; Yang et al. 2002). Most

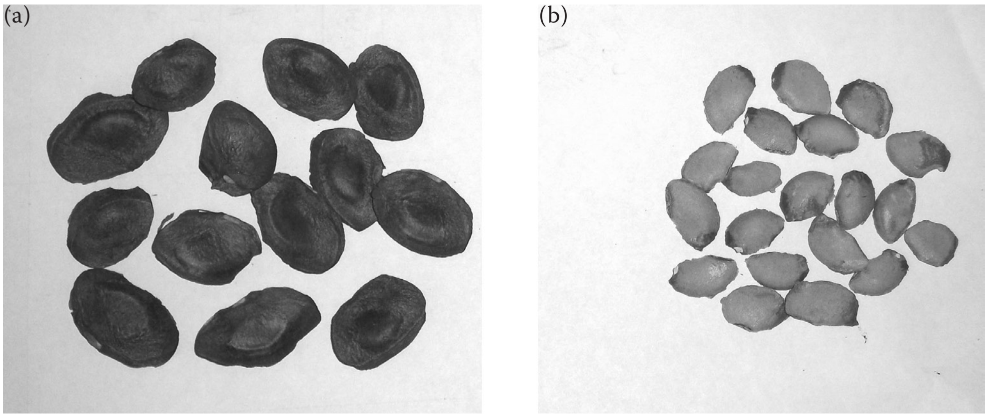

Fig. 1. Mahogany (a) seeds and (b) kernels

of the investigations show that the physical properties of agricultural products are moisture dependent. No work however, appears to have been carried out on the moisture dependence of engineering properties of this important oil seed.

The objective of this work was to investigate some engineering properties of dry-zone mahogany seed and kernel and express them as a function of moisture content.

MATERIAL AND METHODS

Sample collection and conditioning. A bulk quantity of mahogany seed and kernel was obtained from the College of Agriculture, Maiduguri, Borno State, Nigeria. The samples were cleaned, sorted manually to remove all foreign materials and stored in a jute bags under ambient condition for 24 h to attain stable moisture content. Four moisture levels were used to investigate the effect of moisture content on the engineering properties. These moisture content levels were obtained by conditioning seed and kernel samples using the method reported by Olajide et al. (2002) with modification.

Determination of physical properties. Since the seed is oil yielding, the moisture content was determined using the ASAE (1983) standard method. 100 seeds and kernels from each of four moisture levels were randomly selected following a similar method to that employed by Dutta et al. (1988a). The three principal axial dimensions namely length (L), width (W), and thickness (T) of each seed and kernel were measured using a digital vernier caliper (Hangzhou Hengfa Tools Co., Hangzhou, China) and digital micrometer screw gauge (Harrisons Pharma Machinery Private, Delhi, India). The arithmetic mean D_a and geometric mean D_g diameters of the seed and kernel were evaluated using the following relationships (Mohsenin 1986):

$$D_a = (L + W + T)/3 \quad (1)$$

$$D_g = (LWT)^{1/3} \quad (2)$$

Bulk density was determined using the method employed by Aviara et al. (2005a). True density was determined by water displacement method as described by Ogunjimi et al. (2002). Porosity of mahogany seed and kernel was determined using the method of Mohsenin (1986) as follows:

$$\varepsilon = (1 - \rho_b/\rho_t) \times 100 \quad (3)$$

where:

ε – porosity (%)

ρ_b – bulk density (kg/m^3)

ρ_t – true density (kg/m^3)

One thousand seed and kernel weights were obtained using an electronic balance weighing to 0.001 g.

Determination of frictional properties. The angles of repose of mahogany seed and kernel were determined using an open ended box made of plywood 150 × 150 × 150 mm in size with a removable front panel and following the method described by Aviara et al. (1999).

The static coefficient of friction of seed and kernel samples was evaluated on six structural surfaces, namely metal sheet, formica, plywood with wood fibres perpendicular and parallel to the direction of movement, glass and hessian bag. The inclined plane method described by Mohsenin (1986) and Dutta et al. (1988a) was used.

Kinetic coefficient of friction was determined using the box and structural surfaces utilized in evaluating the static coefficient of friction following the method of Aviara et al. (2000). The kinetic coefficient of friction was calculated using the following expression:

$$f = \frac{\text{weight of pan} + \text{weight added}}{\text{weight of box} + \text{sample}} \quad (4)$$

Determination of thermal property. The specific heat of mahogany seed and kernel was determined using a copper calorimeter placed inside a flask, using the method of mixtures. The calorimeter was calibrated following the procedure described by Aviara and Haque (2001). At equilibrium, the final temperature was noted and the specific heat was calculated using the following equation (Aviara et al. 2003).

$$C_s = \frac{(m_c C_c + m_w C_w)\left[T_w - (T_e + t'R')\right]}{m_s\left[(T_e + t'R') - T_s\right]} \quad (5)$$

where:

C_s – specific heat of sample (J/kg.K)
C_c – specific heat of calorimeter (J/kg.K)
C_w – specific heat of water (J/kg.K)
m_c – mass of calorimeter (kg)
m_w – mass of water (kg)
m_s – mass of sample (kg)
T_w – initial temperature of water (K)
T_e – equilibrium temperature of sample and water mixture (K)
T_s – initial temperature of sample (K)
R' – rate of temperature fall after equilibrium (K/s)
t' – time taken for the sample to come to equilibrium (s) (Dutta et al. 1988b)

The terms t' and R' accounted for the heat of hydration and heat exchange with the surrounding. At each moisture level employed, four initial temperatures of the samples were used to investigate the effect of temperature on the specific heat.

All experiments were replicated three times and the average values were recorded.

RESULT AND DISCUSSIONS

Seed and kernel moisture contents

The moisture contents at which the mahogany seeds and kernels were purchased were 7.1 ± 0.36% and 5.3 ± 0.29% (d.b.), respectively. The three moisture contents of the seed and kernel after conditioning were 20.6 ± 1.17, 21 ± 0.89, 32 ± 1.3 and 15.3 ± 0.94, 16.3 ± 1.05, 22 ± 1.16% (d.b.), respectively. Investigations were conducted at the above moisture levels to determine the effect of moisture content on the engineering properties of mahogany seed and kernel.

Seed and kernel size

The results of mahogany seed and kernel sizes measurements at the moisture levels of 7.1–32.0% (d.b.) and 5.3–22.0% (d.b.), respectively, are presented in Table 1. This table shows that the length, width and thickness increased from 29.58 to 30.6 mm, 18.75 to 19.8 mm and 1.85 to 2.06 mm, respectively for seed, and 19.6 to 20.25 mm, 12.19 to 13.1mm and 1.81 to 2.04 mm, respectively for kernel as the moisture contents increased within the above ranges. The arithmetic mean and geometric mean diameters as well as the aspect ratio of the seed and kernel increased with increase in moisture content (Table 1) with the arithmetic mean diameter had the highest values.

Bulk and true densities and porosity of seed and kernel

The bulk density of mahogany seed and kernel increased from 164 to 310 kg/m^3 and 384 to 456 kg/m^3 as their moisture contents increased from 7.1 to 32.0 and 5.3 to 22.0% (d.b.), respectively. The variation of seed and kernel bulk density with moisture content is shown in Table 1. From this table, it can be seen that the bulk density of the seed is lower than that of kernel within a similar moisture range. The relationship existing between seed and kernel bulk density and moisture content can be expressed with the following equations:

$$\rho_{bs} = 0.059M + 0.127 \qquad R^2 = 0.99 \quad (6)$$

$$\rho_{bk} = 0.0041M + 0.3561 \qquad R^2 = 0.88 \quad (7)$$

where:

ρ_{bs}, ρ_{bk} – bulk densities (kg/m^3) of seed and kernel, respectively
M – moisture content (%)

The variations of true density with seed and kernel moisture contents are shown in Table 1. The true density increased from 325 to 465 kg/m^3 and as the moisture increased from 7.1 to 32.0% (d.b.) for seed and from 321 to 705 kg/m^3 for kernel the moisture content increased from 5.3 to 22.0% (d.b.). The rela-

Table 1. Some physical properties of mahogany seed and kernel at different moisture contents

Properties	Moisture content (%, d.b.)							
	seed				kernel			
	7.10	20.10	21	32	5.30	15.40	16.30	22
Length (mm)	29.58 (2.40)	30.10 (2.70)	30.30 (2.80)	30.60 (2.90)	19.60 (2.03)	19.90 (1.80)	20.03 (1.20)	20.25 (1.56)
Width (mm)	18.75 (2.30)	18.80 (1.70)	19.50 (1.70)	19.8 (2.13)	12.19 (1.49)	12.70 (1.60)	12.90 (1.31)	13.10 (2.04)
Thickness (mm)	1.85 (0.25)	1.94 (0.21)	1.96 (0.23)	2.06 (0.19)	1.81 (0.25)	1.90 (0.32)	1.91 (0.40)	2.04 (0.42)
Arithmetic mean (mm)	1.67	1.70	1.73	1.75	1.12	1.15	1.16	1.18
Geometric mean (mm)	1.001	1.032	1.050	1.073	0.762	0.783	0.790	0.816
Bulk density (kg/m^3)	164 (12)	250 (9)	260 (17)	310 (20)	384 (27)	405 (22)	422 (34)	456 (27)
True density (kg/m^3)	325 (24)	375 (18)	398 (21)	465 (31)	321 (11)	466 (33)	606 (36)	705 (43)
Porosity (%)	44.80 (1.40)	55.20 (1.42)	57.80 (2.11)	60.00 (2)	20.50 (1.10)	22.90 (1.40)	25.70 (1.31)	26.80 (1.20)
Repose angle (°)	33 (3.20)	34.90 (4.10)	35.85 (3.80)	36.55 (2.90)	29.80 (3.00)	31.20 (2.60)	31.90 (3.10)	33.40 (4.10)
Weight of 1,000 (kg)	0.28 (0.01)	0.30 (0.02)	0.31 (0.02)	0.35 (0.03)	0.20 (0.01)	0.24 (0.02)	0.27 (0.02)	0.29 (0.04)

numbers in parentheses are standard deviations

tionship existing between seed and kernel true density and moisture content was found to be linear and can be expressed by the following equations:

$$\rho_{ts} = 0.0056M + 0.02783 \qquad R^2 = 0.96 \qquad (8)$$

$$\rho_{tk} = 0.0229M + 0.1861 \qquad R^2 = 0.91 \qquad (9)$$

where:

ρ_{ts},ρ_{tk} – true densities (kg/m^3) of seed and kernel, respectively

M – moisture content (%)

The porosities of mahogany seed and kernel were found to increase from 44.8 to 60.0% and 20.5 to 26.8% within the moisture content ranges of 7.1 to 32.0% and 5.3 to 22.0% (d.b.), respectively. The effect of moisture content on the seed and kernel porosity as can be seen from Table 1 shows that the relationship existing between porosity and moisture content was linear and can be expressed using the following equations:

$$\varepsilon_s = 0.0063M + 0.4183 \qquad R^2 = 0.90 \qquad (10)$$

$$\varepsilon_k = 0.0038M + 0.1834 \qquad R^2 = 0.88 \qquad (11)$$

where:

ε_s, ε_k – porosities (%) of seed and kernel, respectively

M – moisture content (%)

One thousand seed and kernel weight

The variation of one thousand seed and kernel weights with moisture content is presented in Table 1. This table shows that the one thousand seed weight increased from 0.28 to 0.35kg in the moisture range of 7.1 to 32.0% (d.b.), while that of the kernel increased from 0.202 to 0.294kg in the moisture range of 5.3 to 22.0% (d.b.). A linear relationship between one thousand weight, and moisture content, was obtained and can be expressed using the equations:

$$W_{1000s} = 0.028M + 0.2549 \qquad R^2 = 0.94 \qquad (12)$$

$$W_{1000k} = 0.0055M + 0.1695 \qquad R^2 = 0.90 \qquad (13)$$

where:

W_{1000s}, W_{1000k} – one thousand seed and kernel weights, respectively

M – moisture content (%)

Angle of repose

The variation of angle of repose with moisture content as seen from Table 1 shows that the angle of repose of mahogany seed increased from 33.0 to 36.6° in the moisture range of 7.1 to 32.0% (d.b.),

Table 2. Static and kinetic coefficients of friction of mahogany seed and kernel at different moisture contents and on various structural surfaces

Property	Structural surface	Moisture content (%, d.b.)							
		seed				kernel			
		7.10	20.60	21	32	5.30	15.40	16.30	22
Static coefficient of friction	formica	0.207	0.325	0.333	0.364	0.200	0.299	0.410	0.481
	glass	0.330	0.390	0.343	0.549	0.213	0.317	0.329	0.331
	galvanized metal sheet	0.344	0.481	0.539	0.559	0.372	0.377	0.434	0.593
	plywood with grains parallel	0.371	0.481	0.547	0.577	0.452	0.495	0.554	0.610
	plywood with grains perpendicular	0.451	0.547	0.577	0.601	0.524	0.539	0.570	0.585
	hessian bag	0.431	0.502	0.577	0.593	0.337	0.524	0.546	0.562
Kinetic coefficient of friction	formica	0.259	0.333	0.349	0.410	0.320	0.360	0.370	0.400
	glass	0.342	0.374	0.378	0.412	0.337	0.367	0.410	0.467
	galvanized metal sheet	0.448	0.458	0.500	0.525	0.441	0.476	0.515	0.537
	plywood with grains parallel	0.444	0.483	0.500	0.528	0.427	0.461	0.526	0.543
	plywood with grains perpendicular	0.500	0.533	0.550	0.574	0.450	0.550	0.605	0.660
	hessian bag	0.603	0.667	0.682	0.697	0.535	0.548	0.556	0.578

while that of the kernel increased from 29.8 to 33.4° in the moisture range of 5.3 to 22.0% (d.b.). The relationship existing between seed and kernel angle of repose and moisture content was linear and can be expressed using the following equations:

$$\Theta_s = 0.1453M + 32.142 \qquad R^2 = 0.92 \qquad (14)$$

$$\Theta_k = 0.209M + 28.49 \qquad R^2 = 0.94 \qquad (15)$$

where:

Θ_s, Θ_k – angles of repose of seed and kernel, respectively

M – moisture content (%)

Static and kinetic coefficients of friction

The static coefficient of friction of mahogany seed and kernel increased with moisture content and varied with structural surface in the moisture range of 7.1 to 32.0% (d.b.) for seed and 5.3 to 22.0% (d.b.) for kernel (Table 2). The relationship existing between the static coefficient of friction and moisture content was linear and can be expressed for different structural surfaces using the following equations:

For seed:

$$\mu_{fs} = 0.0065M + 0.1771 \qquad R^2 = 0.99 \qquad (16)$$

$$\mu_{gls} = 0.052M + 0.2987 \qquad R^2 = 0.99 \qquad (17)$$

$$\mu_{gms} = 0.0031M + 0.4208 \qquad R^2 = 0.80 \qquad (18)$$

$$\mu_{pls} = 0.02M + 0.4548 \qquad R^2 = 0.84 \qquad (19)$$

$$\mu_{pps} = 0.003M + 0.479 \qquad R^2 = 0.96 \qquad (20)$$

$$\mu_{hbs} = 0.0054M + 0.5632 \qquad R^2 = 0.99 \qquad (21)$$

where:

μ_{fs}, μ_{gls}, μ_{gms}, μ_{pls}, μ_{pps}, μ_{hbs} – static coefficients of friction of seed on formica, glass, galvanized metal sheet, plywood with grains parallel, plywood with grain perpendicular and hessian bag, respectively

M – moisture content (%)

For kernel:

$\mu_{fk} = 0.064M + 0.1767 \quad R^2 = 0.92 \quad (22)$

$\mu_{glk} = 0.052M + 0.2965 \quad R^2 = 0.91 \quad (23)$

$\mu_{gmk} = 0.0066M + 0.392 \quad R^2 = 0.90 \quad (24)$

$\mu_{plk} = 0.093M + 0.2963 \quad R^2 = 0.99 \quad (25)$

$\mu_{ppk} = 0.084M + 0.3239 \quad R^2 = 0.91 \quad (26)$

$\mu_{hbk} = 0.061M + 0.4209 \quad R^2 = 0.88 \quad (27)$

where:

μ_{fk}, μ_{glk}, μ_{gmk}, μ_{plk}, μ_{ppk}, μ_{hbk} – static coefficients of friction for kernel on formica, glass, galvanized sheet, plywood with grain parallel, plywood with grain perpendicular and hessian bag, respectively

M – moisture content (%)

The kinetic coefficients of friction of mahogany seed and kernel increased with increase in moisture content and varied with structural surface (Table 2). The relationship existing between the kinetic coefficients of friction of seed and kernel and moisture content was linear and can be represented by the following equations:

For seed:

$f_{fs} = 0.061M + 0.2153 \quad R^2 = 0.99 \quad (28)$

$f_{gls} = 0.0027M + 0.3312 \quad R^2 = 0.99 \quad (29)$

$f_{gms} = 0.0031M + 0.4208 \quad R^2 = 0.80 \quad (30)$

$f_{pls} = 0.02M + 0.4548 \quad R^2 = 0.84 \quad (31)$

$f_{pps} = 0.003M + 0.479 \quad R^2 = 0.96 \quad (32)$

$f_{hbs} = 0.0054M + 0.5632 \quad R^2 = 0.99 \quad (33)$

where:

f_{fs}, f_{gls}, f_{gms}, f_{pls}, f_{pps}, f_{hbs} – kinetic coefficients of friction of seed on formica, glass, galvanized sheet, plywood parallel, plywood perpendicular and hessian bag, respectively

M – moisture content (%)

For kernel:

$f_{fk} = 0.0047M + 0.291 \quad R^2 = 0.93 \quad (34)$

$f_{glk} = 0.0071M + 0.2891 \quad R^2 = 0.84 \quad (35)$

$f_{gmk} = 0.0071M + 0.3884 \quad R^2 = 0.88 \quad (36)$

$f_{plk} = 0.069M + 0.3944 \quad R^2 = 0.89 \quad (37)$

$f_{ppk} = 0.0093M + 0.4401 \quad R^2 = 0.89 \quad (38)$

$f_{hbk} = 0.0024M + 0.5183 \quad R^2 = 0.88 \quad (39)$

where:

f_{fk}, f_{glk}, f_{gmk}, f_{plk}, f_{ppk}, f_{hbk} – kinetic coefficients of friction of kernel on formica, glass, galvanized sheet, plywood parallel, plywood perpendicular and hessian bag, respectively

M – moisture content (%)

Specific heat

The specific heat of mahogany seed and kernel at different moisture contents and temperatures are presented in Table 3. From this table, it can be seen that the specific heat of the seed and kernel increased linearly with moisture content at the indicated temperatures. The following regression equations governed the relationship existing between the specific heat of mahogany seed and kernel and moisture content at each temperature.

For seed:

323K: $C_{ss} = 29.56M + 1406.8 \quad R^2 = 0.93 \quad (40)$

333K: $C_{ss} = 33.106M + 1588.2 \quad R^2 = 0.92 \quad (41)$

343K: $C_{ss} = 32.286M + 2134.5 \quad R^2 = 0.91 \quad (42)$

Table 3. Values of specific heat of mahogany seed and kernel at different moisture contents and temperatures

Property	Temperature (K)	Moisture content (%, d.b.)							
		seed				kernel			
		7.10	20.60	21	32	5.30	15.40	16.30	22
Specific heat (J/kg.K)	323	1,606.5	1,927.8	2,144.2	2,336.7	1,063.6	1,235.8	1,343.4	1,557.8
	333	1,836	2,141	2,388.6	2,659	1,606.5	1,836	2,045.4	2,215.9
	343	2,440.3	2,662.1	2,781.8	3,295.4	1,797.5	1,977.2	2,193.8	2,536.6
	353	2,677	2,841	3,156.6	3,342.3	2,205.7	2,421	2,524.1	2,794

353K: $C_{ss} = 26.737M + 2464.8 \quad R^2 = 0.82$ (43)

For kernel:

323K: $C_{sk} = 28.534M + 879.27 \quad R^2 = 0.92$ (44)

333K: $C_{sk} = 36.268M + 1391 \quad R^2 = 0.91$ (45)

343K: $C_{sk} = 42.087M + 1505.5 \quad R^2 = 0.85$ (46)

353K: $C_{sk} = 33.888M + 1987.1 \quad R^2 = 0.93$ (47)

where:

C_{ss}, C_{sk} – specific heat of seed and kernel, respectively

M – moisture content (%)

CONCLUSIONS

In the moisture ranges of 7.1–32.0% and 5.3–22.0% (d.b.) for mahogany seed and kernel, respectively, the principal axial dimensions, arithmetic mean and geometric mean diameters, bulk density, true density, porosity, 1,000 seed and kernel weight, angle of repose, static and kinetic coefficients of friction as well as the specific heat of the seed and kernel increased linearly with increase in moisture content. Static and kinetic coefficients of friction varied with structural surface in the specified ranges of seed and kernel moisture content. Specific heat increased with increase in seed and kernel temperature.

References

AOAC, 1980. Official Methods of Analysis. Washington, Association of Official Analytical Chemists Press.

ASAE, 1983. Moisture measurement, grain and seed: Agricultural Engineer Yearbook of Standards. St. Joseph ASAE.

Aviara N.A., Gwandzang M.I, Haque M.A., 1999. Physical properties of guna seeds. Journal of Agricultural Engineering Research, *73*: 105–111.

Aviara N.A., Haque M.A., 2001. Moisture dependence of thermal properties of sheanut kernel. Journal of Food Engineering, *47*: 109–113.

Aviara N.A., Haque M.A., Izge I.A., 2000. Physical and frictional properties of sheanut. AgroScience, *2*: 19–34.

Aviara N.A., Ajibola O.O., Oni S.A., 2003. Effect of moisture content and temperature on the specific heat of soyabean TGX 1440-1E. In: Proceedings from the 4th International Conference of the Nigerian Institution of Agricultural Engineers. Damaturu, *25*: 183–191.

Aviara N.A., Mamman E., Umar B., 2005a. Some physical properties of *Balanites Aegyptiaca* nuts. Biosytems Engineering, *93*: 325–334.

Aviara N.A., Oluwole F.A., Haque M.A., 2005b. Effect of moisture content on some physical properties of sheanut (*Butyrospernum Paradoxum*). International Agrophysics, *19*: 193–198.

Dash A.K., Pradhan R.C., Das L.M., Naik S.N., 2008. Some physical properties of simarouba fruit and kernel. International Agrophysics, *22*: 111–116.

Dutta S.K., Nema V.K., Bhardwaj R.K., 1988a. Physical properties of gram. Journal of Agricultural Engineering Research, *39*: 259–268.

Dutta S.K., Nema V.K., Bhardwaj R.K., 1988b. Thermal properties of gram. Journal of Agricultural Engineering Research, *39*: 269–275.

Joshi D.C., Das S.K., Mukherjee R.K., 1993. Some physical properties of pumpkin seed. Journal of Agricultural Engineering Research, *54*: 219–229.

Mohsenin N.N., 1986. Physical Properties of Plant and Animal Materials, 2nd Ed. New York, Gordon and Breach Science Publishers.

Naderiboldaji M., Khadivikhub A., Tabatabaeefar A., Ghasemi V.M., Zamani Z., 2008. Some physical properties of sweet cherry *(Prunus avium* L.*)* fruit. American-Eurasian Journal of Agricultural and Environmental Sciences, *3*: 513–520.

Ogunjimi L.A.O., Aviara N.A., Aregbesola O.A., 2002. Some engineering properties of locust bean seed. Journal of Food Engineering, *55*: 95–99.

Oje K., Ugbor E.C., 1991. Some physical properties of oil bean seed. Journal of Agricultural Engineering Research, *50*: 305–313.

Olajide J.O., Ade-Omowaye B.I.O., Otunla E.T., 2002. Some physical properties of shea kernel. Journal of Agricultural Engineering Research, *76*: 419–421

Owolarafe O.K., Olabige M.T., Faborode M.O., 2005. Physical and mechanical properties of two varieties of fresh oil palm fruit. Journal of Food Engineering, *78*: 1228–1232.

Yang W., Sokhansanj J.S., Tang J., Winter P., 2002. Determination of thermal conductivity, specific heat and thermal diffusivity of borage seed. Biosystem Engineering, *82*: 167–176.

Received for publication February 2, 2012
Accepted after corrections September 3, 2012

Corresponding author:

Dr. Ndubisi A. Aviara, University of Maiduguri, Faculty of Engineering, Department of Agricultural and Environmental Resources Engineering, Bama Road, P.M.B 1069, Maiduguri, Nigeria
phone: + 234 803 492 2425, e-mail: nddyaviara@yahoo.com