Int. Agrophysics, 2005, 19, 193-198

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Effect of moisture content on some physical properties of sheanut (*Butyrospernum Paradoxum*)

N.A. Aviara[1]*, *F.A. Oluwole*[2], *and M.A. Haque*[1]

[1]Department of Agricultural Engineering, University of Maiduguri, Maiduguri, Nigeria
[2]Department of Mechanical Engineering, Ramat Polytechnic, Maiduguri, Nigeria

Received November 2, 2004; accepted May 4, 2005

A b s t r a c t. The effect of moisture content on the physical properties of sheanut (*Butyrospernum paradoxum*) was determined to explore the possibility of developing its bulk handling and processing equipment. In the moisture range of 6 to 27.9% (d.b.), the major, intermediate and minor axes of the nut increased from 37 to 39.4, 26.8-28.3 and 25.9-26.8 mm, respectively. The arithmetic mean, geometric mean and equivalent sphere effective diameters determined at the same moisture level were significantly different from each other, with the arithmetic mean diameter being of the highest value and the equivalent sphere effective diameter yielding the volume that is closest to the experimentally determined value.

In the above moisture range, one thousand nut weight and volume increased linearly with moisture content from 7.8 to 10.6 kg and 12 360 to 14 030 mm^3, respectively. Particle density, bulk density and angle of repose increased logarithmically with moisture content from 643 to 782 g cm^{-3}, 291.3-356.2 g cm^{-3}, and 24.7-25.1°, respectively, while porosity increased with increase in moisture content to a maxi- mum value of 56.5% at the moisture content of 22.7% (d.b.), and thereafter decreased to a value of 54.5% at the moisture content of 27.9% (d.b.). Static coefficient of friction increased linearly with moisture content from 0.300 to 0.394 in the above moisture range, and varied with structural surface. The maximum static coefficient of friction was on plywood with wood grains perpendicular to the direction of movement, while the minimum value was on formica (*papreg*).

Regression equations that could be used to express the relationships existing between the physical properties and nut moisture content were established.

K e y w o r d s: sheanut, moisture content, physical properties

INTRODUCTION

Sheanut (*Butyrospernum Paradoxum*) is an oil rich tropical tree crop which is indigenous to the West African Savannah Zone. Its fruit contains one or two nuts which are brown and shiny. The fruit pulp is eaten, but the tree is mainly important for its nut (Fig. 1) which contains a kernel with an oil content ranging from 45 to 60% (Opeke, 1992). The oil, known as shea butter, is used in the manufacture of soap, candles, cosmetics, pharmaceutical products and butter substitutes. The kernel is obtained from the nut by cracking with stones, mortar and pestle. In the traditional process of extracting the oil, the kernel is subjected to a series of operations which include steeping, roasting, pounding or grinding, and boiling.

The present methods of carrying out these operations, which involve manual labour, are not only labour- and time-consuming but also wasteful. Improved methods of processing the nut using suitable machines and equipment can be developed if the physical properties are known.

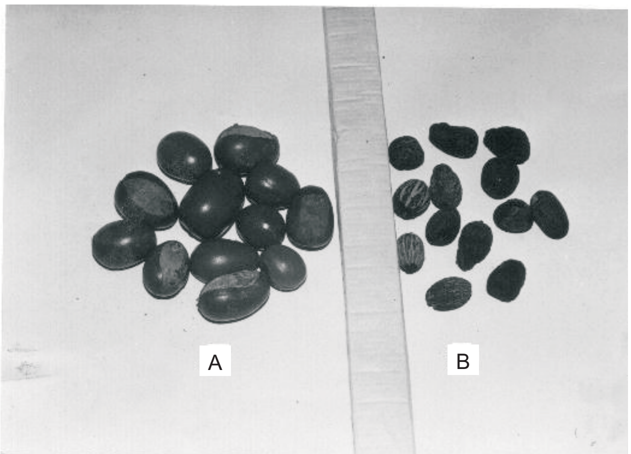

Fig. 1. Sheanut and kernel, A – nut, B – kernel.

*Corresponding author's e-mail: nddyaviara@yahoo.com

Researchers (Dutta *et al.*, 1988; Deshpande *et al.*, 1993; Oje, 1993; Omobuwaju *et al.*, 1999; Baryeh, 2001; Ogunjimi *et al.*, 2002) have investigated the physical properties of several agricultural products for a similar purpose. These investigators determined the size of various grains and seeds by measuring their principal axial dimensions. Kaleemullah (1992), Deshpande *et al.* (1993) and Aviara *et al.* (1999) investigated the variation of these dimensions with moisture content for groundnut kernel, soybean and guna seed, respectively. Dutta *et al.* (1988) employed the arithmetic mean, geometric mean and equivalent sphere effective diameters of the three principal axes of weight in calculating the volume of the seed. The results reported showed that these diameters approximately predicted the experimentally determined values. Aviara *et al.* (1999), in a similar work on guna seeds, reported that it was the geometric diameter that gave the closest values to the experimentally determined volume of guna seeds.

Two methods of determining the particle density of agricultural materials have been utilized by investigators. These include the gas displacement method (Thompson and Isaacs, 1967; Nelson, 1980; Joshi *et al.*, 1993; and Suthar and Das, 1996,) and the water displacement method (Shepherd and Bhardwaj, 1986; Dutta *et al.*, 1988; Oje and Ugbor, 1991; Oje, 1994; and Aviara *et al.*, 1999). Bulk density has been determined using the AOAC (1980) recommended method. The relationship between porosity, particle density and bulk density as stated by Mohsenin (1986) has been used to calculate the porosity of grains and seeds. Different methods have been used in studying the coefficient of friction of agricultural products on different structural surfaces. These include moving a given surface against the material (Lawton, 1980), tilting an inclined plane (Dutta *et al.*, 1988; Aviara *et al.*, 1999; Mohsenin, 1986) to the shear box equipment (Osunade and Lasisi, 1994). The structural surfaces employed are galvanized steel sheet and plywood. Investigators (Fraser *et al.*, 1978; Dutta *et al.*, 1988; Aviara *et al.*, 1999), using a specially constructed box with removable front panel, have conducted studies on the angle of repose of grains and seeds. Most of the investigations show that the physical properties of agricultural products are moisture dependent. Olajide *et al.* (2000) studied some physical properties of shea nut kernel, but they did not include those of the nut. Also, the effect of moisture content on the physical properties of shea nut kernel was not considered. Aviara *et al.* (2000) investigated the effect of moisture content on some physical properties of sheanut kernel and only determined those of the nut at a moisture content of 3.8% (d.b.), but Aviara *et al.* (1999) noted that the moisture dependent characteristics of physical properties have an effect on the adjustment and performance of agricultural product processing machines. They further noted that a range of moisture content usually exists within which the optimum performance of the machine could be achieved. Therefore, the effect of moisture on the physical properties of sheanut is of important consideration in the design of its handling, processing and storage facilities. The objective of this work was to determine the effect of moisture content on the physical properties of sheanut, namely principal axial dimensions, volume, one thousand nut weight, particle and bulk densities, porosity, static coefficient of friction on different structural surfaces, and angle of repose. The methods employed were selected on the basis of simplicity, accuracy of results, and wide acceptability.

MATERIALS AND METHODS

For this work, a bulk quantity of dried sheanut was obtained from Michika in Michika Local Government Area of Adamawa State, Nigeria. The nuts were cleaned and sampled for experiments using a multi-slot riffle box divider.

Since the nut is oil yielding, the moisture content was determined using the method reported by Ajibola *et al.* (1990) and Oje (1993). This involved oven drying of nut samples at 130°C with weight loss monitored on hourly basis to give an idea of the time at which the weight began to remain constant. Weight of samples was found to remain constant after oven drying for a period of about 4 h. Four moisture levels were used to investigate the effect of moisture content on the physical properties. Nut samples of desired moisture content levels were prepared by conditioning the samples using the method of Ezeike (1986). This involved the soaking of different bulk samples in clean water for a period of one to four hours, followed by spreading out in a thin layer to dry in natural air for about eight hours. After this, the samples were sealed in polyethylene bags and stored in that condition for a further 24 h. This enabled stable and uniform moisture content of the samples to be achieved.

To determine the nut size, 100 nuts were randomly selected, following a method similar to that employed by Dutta *et al.* (1988). For each nut, the three principal axial dimension, namely the major, intermediate and minor axes, were measured using a vernier calliper reading to 0.05 mm. One thousand nut weight was obtained using an electronic balance reading to 0.001 g.

Particle density was determined by the water displacement method. Thirty nuts, each coated with very thin layer of epoxy resin to prevent the absorption of water during the experiment, were used. Increase in nut weight due to the adhesive was negligible (less than 2%). Bulk density was determined using the AOAC (1980) method. This involved the filling of a 1500 ml cylinder with nuts from a height of 15 cm and weighing the contents. Porosity was calculated from the particle and bulk densities using the relationship given by Mohsenin (1986).

The static coefficient of friction was evaluated on four structural surfaces, namely metal sheet, formica (generally known as *papreg*), plywood with wood fibres parallel to the direction of movement, and plywood with wood fibres perpendicular to the direction of movement. The inclined plane method was used (Dutta *et al.*, 1988; Mohsenin, 1986). This involved the placing of an open-ended box on an adjustable tilting surface which was formed with a structural surface. The box was filled with nuts and the structural surface with the box and its content on top was gradually raised with a screw device until the box just started to slide down. The angle of tilt was read from a graduated scale and the tangent of this angle was taken as the static coefficient of friction. In determining the angle of repose, a specially constructed open-ended box made of plywood and 150 x 150 x 150 mm in size, with a removable front panel, was used. The box was placed on a table and filled with nuts. The front panel was quickly removed to allow the material to slide and assume its natural slope in bulk. The angle of repose was calculated from the depth of the free surface of the product, measured at two known horizontal distances from one end of the box. All the experiments were repeated five times and the average values are reported.

RESULTS AND DISCUSSION

Nut moisture content

The initial moisture content of the nut was found to be 6±0.38% (d.b.). The three other moisture levels obtained after conditioning the nuts were 13±1.27, 22.7±0.92 and 27.9±1.05% (d.b.), respectively. The investigations were carried out at the above moisture levels to determine the effect of moisture content on the physical properties of sheanut.

Nut size

The results of the sheanut size measured at different moisture content levels are presented in Table 1. The table shows that the three axial dimensions increased with moisture content in the moisture range of 6-27.9% (d.b.). The major axis increased from 37 to 39.4 mm, the intermediate axis from 26.8 to 28.3 mm, and the minor axis from 25.9 to 26.8 mm. The arithmetic mean of the three principal axes, their geometric mean and the equivalent sphere effective diameter of the nut at different moisture contents, also presented in Table 1, increased with increase in moisture content. The arithmetic mean diameter had higher values than the geometric and equivalent sphere effective diameters of the nut. These could be of important consideration in the theoretical determination of the nut volume at different moisture contents.

One thousand nut weight

The variation of one thousand nut weight, W_{1000}, with moisture content is presented in Fig. 2. This shows that the one thousand nut weight increased from 7.8 to 10.6 kg in the moisture range of 6-27.9% (d.b.). A linear relationship between W_{1000} and moisture content M was obtained and can be expressed using the equation:

$$W_{1000} = 0.1287M + 7.158, \tag{1}$$

with a coefficient of determination $R^2 = 0.986$, where: W_{1000} is one thousand nut weight (kg), M is moisture content, % (d.b.).

Nut volume, particle density and bulk density

The nut volume determined by the water displacement method and used to calculate the particle density was found

T a b l e 1. Axial dimensions of sheanut at different moisture contents

Moisture content (%, d.b.)	Axis: Major (a)	Axis: Intermediate (b)	Axis: Minor (c)	Arithmetic mean diameter $\left(\frac{a+b+c}{3}\right)$	Geometric mean diameter $(abc)^{\frac{1}{3}}$	Equivalent sphere effective diameter $\left(\frac{6W_{1000}}{1000\rho_t\pi}\right)$
	(mm)					
6.0	37.00 (4.20)*	26.80 (2.81)	25.90 (2.86)	29.90	29.50	28.50
13.0	37.20 (4.05)	27.60 (3.10)	26.30 (2.76)	30.37	30.00	28.71
22.7	38.60 (3.84)	27.90 (2.45)	26.50 (2.79)	31.00	30.56	29.17
27.9	39.40 (3.70)	28.30 (2.59)	26.80 (2.44)	31.50	31.03	29.53

*Numbers in parentheses are standard deviations.

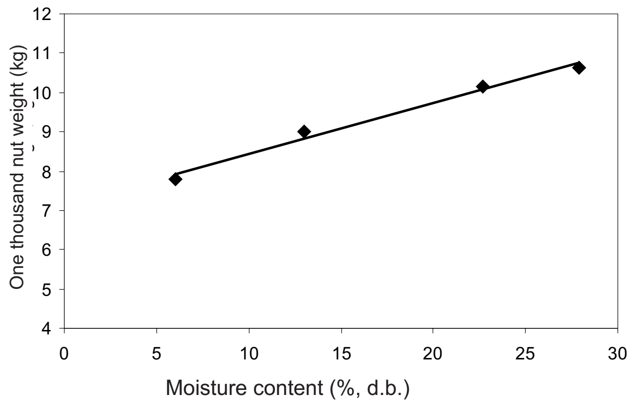

Fig. 2. Effect of moisture content on the one thousand nut weight.

to increase from 12 360 to 14 030 mm^3 as the moisture content increased from 6 to 27.9% (d.b.). The variation of nut volume with moisture content is presented in Fig. 3. This figure shows that the relationship existing between the volume and moisture content was linear and can be expressed with the following equation:

$$V = 76.09M + 11866, \tag{2}$$

with a coefficient of determination $R^2 = 0.997$, where V is volume (mm^3).

The volume of nut calculated using the arithmetic mean, geometric mean and equivalent sphere effective diameters showed that the equivalent sphere effective diameter gave the closest value to the experimentally determined volume at each moisture level in the above range. Sheanut could therefore be treated as a sphere in the theoretical determination of its volume.

The particle density obtained was found to be a function of moisture content. The effect of moisture content on the particle density of sheanut is presented in Fig. 4. This shows that particle density increased from 643 to 789 kg m^{-3} as the moisture content increased from 6 to 27.9% (d.b.). The relationship existing between particle density and moisture content was found to be logarithmic and can be represented by the following equation:

$$\rho_t = 92.776 \mathrm{Ln} M + 486.58, \tag{3}$$

with a coefficient of determination $R^2 = 0.950$, where ρ_t is particle density (kg m^{-3}).

The bulk density of sheanut increased from 291.3 to 356.2 kg m^{-3} in the above moisture range and was found to have a similar relationship with moisture content as the particle density. The variation of nut bulk density with moisture content is shown in Fig. 5. The relationship existing between bulk density and the nut moisture content can be expressed with the following equation:

$$\rho_b = 38.559 \mathrm{Ln} M + 223.84, \tag{4}$$

with a coefficient of determination $R^2 = 0.953$, where ρ_b is bulk density (kg m^{-3}).

Porosity

The porosity of sheanut was found to increase from 54.7% at the moisture content of 6% (d.b.) to a maximum

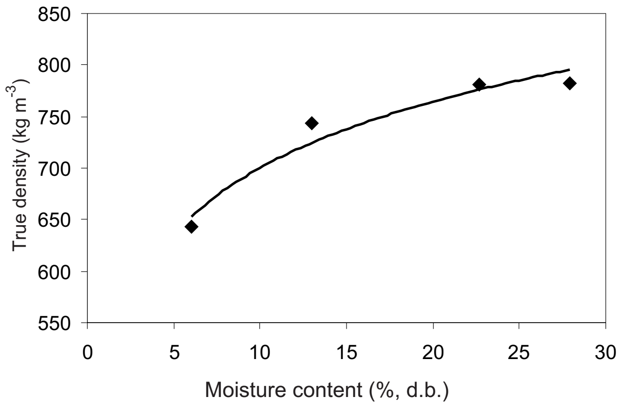

Fig. 4. Variation of the true density of sheanut wit moisture content.

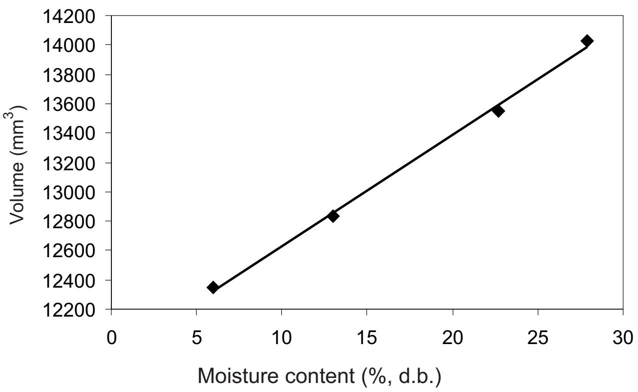

Fig. 3. Variation of the volume of sheanut with moisture content.

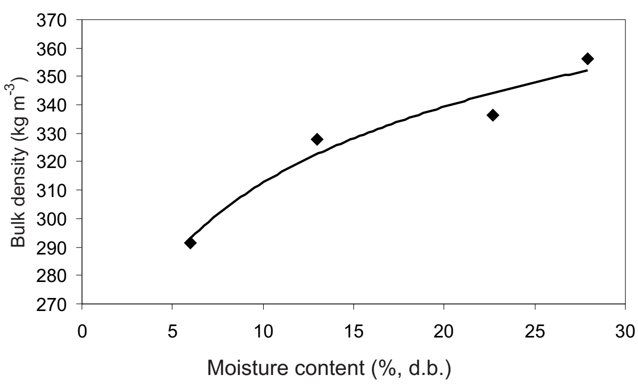

Fig. 5. Variation of the bulk density of sheanut with moisture content.

value of 56.9% at the moisture content of 22.7% (d.b.), after which it decreased with further increase in moisture content. The effect of moisture content on the nut porosity is presented in Fig. 6. The relationship existing between porosity and moisture content was found to be parabolic and can be expressed using the following equation:

$$P = - 0.0139M^2 + 0.497M + 52.131, \quad (5)$$

with a coefficient of determination $R^2 = 0.926$, where P is porosity (%).

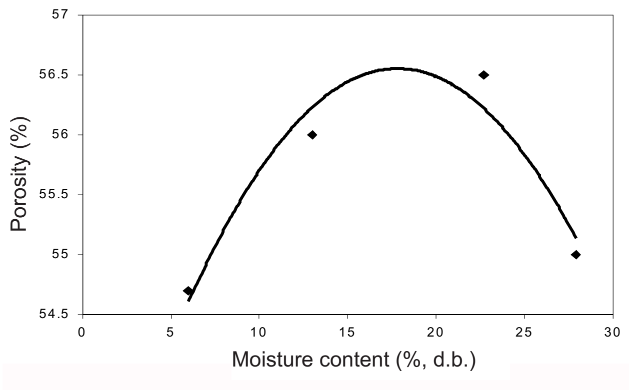

Fig. 6. Variation of the porosity of sheanut with moisture content.

Static coefficient of friction

The static coefficient of friction of sheanut increased linearly with moisture content and varied with structural surface in the moisture range of 6-27.9% (d.b.) (Fig. 7). The maximum value of 0.394 was obtained on the surface of plywood with wood grains perpendicular to the direction of movement and the minimum value of 0.3 was on formica (*papreg*). The relationship existing between the static coefficient of friction and moisture content can be expressed for different structural surfaces using the following equations:

$$f_s = 0.0002M + 0.3024, \quad (6)$$

$$f_f = 0.0001M + 0.2993, \quad (7)$$

$$f_{pr} = 0.0003M + 0.3665, \quad (8)$$

$$f_{pd} = 0.0003M + 0.3865, \quad (9)$$

with coefficients of determination R^2 of 0.965, 0.968, 0.979 and 0.970, respectively, where f_s, f_f, f_{pr} and f_{pd} are the static coefficients of friction of sheanut on metal sheet, formica (*papreg*), plywood with wood grains parallel to the direction of movement, and plywood with wood grains perpendicular to the direction of movement, respectively.

Angle of repose

The variation of the angle of repose of sheanut with moisture content is shown in Fig. 8. From this figure, it can be seen that the angle of repose increased logarithmically with moisture content from 24.7 to 25.1° in the moisture range of 6-27.9% (d.b.). The relationship existing between angle of repose and moisture content can be expressed using the equation:

$$\theta = 0.269 \text{Ln} M + 24.244, \quad (10)$$

with coefficient of determination $R^2 = 0.982$, where θ is angle of repose in degrees.

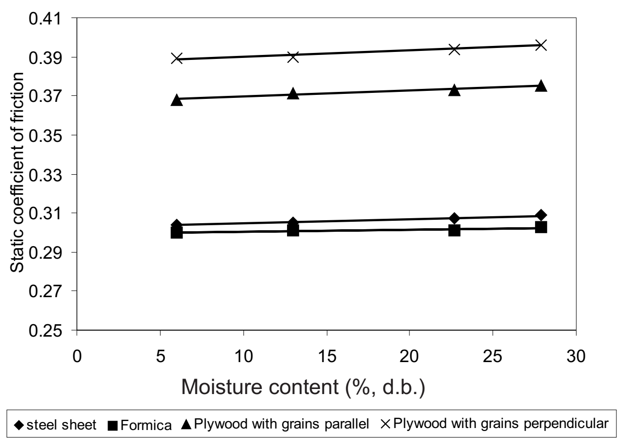

Fig. 7. Variation of the static coefficient of friction of sheanut with structural and moisture content.

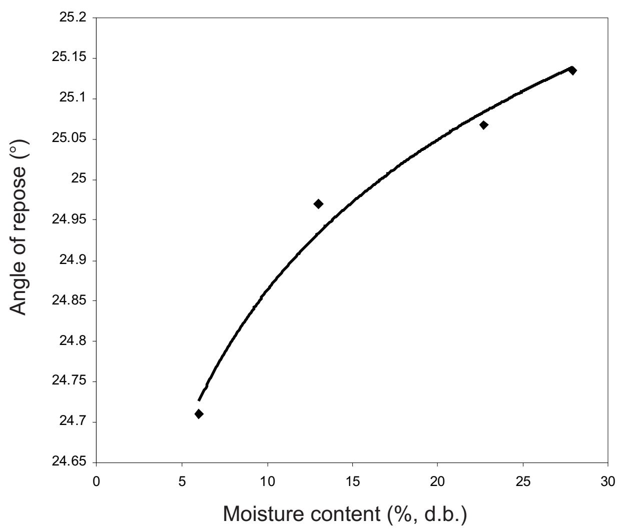

Fig. 8. Effect of moisture content on the angle of repose of sheanut.

CONCLUSIONS

1. In the moisture range of 6-27.9% (d.b.), the major, intermediate and minor axes of the nut increased from 37 to 39.4, 26.8-28.3 and 25.9-26.8 mm, respectively.

2. One thousand nut weight, nut volume, and static coefficient of friction on different structural surfaces increased linearly, while particle density, bulk density, and angle of repose increased logarithmically and porosity increased parabolically, all with moisture content in the above moisture range.

REFERENCES

Ajibola O.O., Eniyemo S.E., Fasina O.O., and Adeeko K.A., 1990. Mechanical expression of oil from melon seeds. J. Agric. Eng. Res., 45, 45-53.

AOAC, **1980.** Official methods of analysis. 13th edition. Association of Official Analytical Chemists, Washington D.C.

Aviara N.A., Gwandzang M.I., and Haque M.A., 1999. Physical properties of guna seeds. J. Agric. Eng. Res., 73, 105-111.

Aviara N.A., Haque M.A., and Izge I.A., 2000. Physical and frictional properties of sheanut. AgroSci., 2(1), 19-34,

Baryeh E.A., 2001. Physical properties of bambara groundnuts. J. Food Eng., 47, 321-326.

Deshpande S.D., Bal S., and Ojha T.P., 1993. Physical properties of soybean. J. Agric. Eng. Res., 56, 89-98.

Dutta S.K., Nema V.K., and Bhardwaj R.K., 1988. Physical properties of gram. J. Agric. Eng. Res., 39, 259-268.

Ezeike G.O.I., 1986. Quasi-static hardness and elastic properties of some tropical seed grains and tomato fruit. Int. Agrophysics, 2,15-29.

Fraser B.M., Verma S.S., and Muir W.E., 1978. Some physical properties of fababeans. J. Agric. Eng. Res., 23, 53-57.

Joshi D.C., Das S.K., and Mukherjee R.K., 1993. Some physical properties of pumpkin seed. J. Agric. Eng. Res., 54, 219-229.

Kaleemullah S., 1992. The effect of moisture contents on the physical properties of groundnut kernels. Tropical Sci., 32, 129-136.

Lawton P.J., 1980. Coefficient of friction between cereal grain and various silo wall materials. J. Agric. Eng. Res., 25, 75-86.

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

Nelson S.O., 1980. Moisture dependent kernel and bulk density relationship for wheat and corn. Transactions of the ASAE, 23, 139-143.

Ogunjimi L.A.O., Aviara N.A., and Aregbesola O.A., 2002. Some engineering properties of locust bean seed. J. Food Eng., 55(2), 95-99.

Oje K., 1993. Some engineering properties of the vetianut. J. Agric. Eng. and Technol., 1, 38-45.

Oje K., 1994. Moisture dependence of some physical properties of cowpea. Ife, J. Technol., 4, 23-27.

Oje K. and Ugbor E.C., 1991. Some physical properties of oil bean seed. J. Agric. Eng. Res., 50, 305-313.

Olajide J.O., Ade-Omowaye B.I.O., and Otunola E.T., 2000. Some physical properties of shea kernel. J. Agric. Eng. Res., 76(4), 419-421.

Omobuwaju T.O., Akande E.A., and Sanni L.A., 1999. Selected physical, mechanical and aerodynamic properties of African breadfruit (*Treculia africana*) seeds. J. Food Eng., 40, 241-246.

Opeke L.K., 1994. Tropical Tree Crops. Spectrum Books, Ibadan.

Osunade J.A. and Lasisi F., 1994. Coefficient of friction of maize and sorghum grains on laterized concrete wall. NSE Technical Transaction, 29, 50-57.

Shepherd H. and Bhardwaj R.K., 1986. Moisture dependent physical properties of pigeon pea. J. Agric. Eng. Res., 35, 227-234.

Suthar S.H. and Das S.K., 1996. Some physical properties of karingda seed. J. Agric. Eng. Res., 54, 219-229.

Thompson R.A. and Isaacs G.W., 1967. Porosity determination of grains and seeds with air comparison pycnometer. Transactions of the ASAE, 10, 693-696.