Effect of Air-Drying on Physical Properties of Shea Kernel

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Abstract

In order to design postharvest processing equipment for shea kernel, it is necessary to evaluate its physical and engineering properties. In this study, the physical properties of shea kernel were investigated at five moisture levels for two size categories of large size kernel (LSK) and small size kernel (SSK) as the kernels were air-dried from an initial high moisture content. As the SSK dry from moisture content of 73.38 to 6.58% (db), major, intermediate and minor diameters decreased from 30.80 to 23.32mm, 21.63 to 15.76 mm and 19.42 to 13.36 mm, respectively. The geometric mean diameter also decreased from 19.96 to 19.54 mm while sphericity and surface area also decreased from 0.76 to 0.73 and 17.31 to 9.08cm^2, respectively. The mass and volume as well decreased from 6.82 to 3.14 g, 6.8 to 2.59 cm^3 while kernel density increased from 1.04 to 1.26 g/cm^2 as the moisture content decreased. The static coefficient of friction on galvanized iron, wood and steel decreased from 0.68 to 0.39, 0.76 to 0.45 and 0.57 to 0.42 respectively. The angle of repose however increased from 23.4 to 30.5 degrees. Corresponding values were also observed for LSK categories. Regression equations were utilized to model the relationship between moisture content and the physical attributes for the shea kernel.

Keywords*: Postharvest processing, engineering property, regression models, kernel size, coefficient of friction.*

Introduction

Shea butter tree (*Vitellaria paradoxa*) is a medium-sized deciduous tree belonging to the family Sapotaceae. It is believed that it is native to the West-African savannas and Central Africa (Purseglove 1974). The shea tree has a rough and corky bark that is deeply cracked. It is usually characterized by milky latex in the stems and branches. The shea tree produces greenish yellow fruits, called shear fruit, which is of great economic importance (Purseglove 1974). In Nigeria, it grows widely in the North, some parts of West and East of Nigeria. One of the most important characteristics of biological materials is their moisture content. According to Sitkei (1986), the moisture content of agricultural materials affects their physical and mechanical properties. Moisture content also affects the storability, handling and processing of biomaterials.

Many researchers have studied and reported the relationship between moisture content of biomaterials and their other properties. These are, for examples, locust been seed (Ogunjimi *et al*. 2002), arigo seed (Davies 2010), Simarouba fruit and kernel (Dash *et al*. 2008), shea nut (Aviara *et al*. 2005; Olaniyan and Oje 2002). The physical properties of biomaterials are essential in the design and development of specific equipment and structures for transporting, handling, processing and storage and also for assessing the behaviour of product quality (Kashaninejad *et al*. 2005; Razavi *et al*. 2007).

Physical properties of shea kernel are essential in the design of items of equipment for decortication, drying, cleaning, grading, storage and oil extraction. Moisture content is useful information in the dry process. Dimensions and shape are important in designing separating, harvesting, sizing and grinding machines (Dash *et al*. 2008).

The aim of this study was to further investigate some physical properties of shea kernel in addition to previous studies (Manuwa and Muhammad 2010, 2011). The parameters studied include: dimensions, sphericity, kernel density, angle of repose, coefficient of static friction on structural surfaces.

Materials and Methods

Sample Preparation

Fresh shea butter fruits were procured from the local market. The pulp was removed by hand to release the nuts. These were left on the open floor for some days to dry for easy detachment of the kernels from the nuts. The kernels were released from the nuts manually using stones. Thereafter the kernels were graded into two category sizes; large size kernel (LSK) and small size kernel (SSK). Experiments were carried out to determine some design related physical properties of shea butter kernel at five moisture levels.

Physical Properties

The physical properties determined were linear dimensions, surface area, volume, kernel density, mass of grain, coefficient of static friction on structural surfaces and angle of repose. Experiments were conducted at five levels of moisture content in the range of 79.95 to 7.47% (db) for LSK and 73.38 to 6.58% (db) for small size kernel.

Linear Dimensions and Geometric Mean Diameter

To determine the sizes of the kernel, 100 kernels in each category were taken and their three linear dimensions namely, length (L), width (W) and thickness (T) were measured with a vernier callipers having accuracy of 0.01 mm. The geometric mean diameter (D_{GM}) of a kernel was calculated by using the following relationship (Sharma *et al*. 1985):

$$D_{GM} = (LWT)^{1/3} . \qquad (1)$$

Mass

The masses of both LSK and SSK were determined using a sensitive electrical weighing machine with accuracy of 0.01 g. One hundred replicates each were used for both LSK and SSK at the five moisture levels.

Kernel Seed Density

The kernel seed density was determined by the liquid displacement method to determine the seed volume similarly to that reported by Deshpande and Ali (1988) and Tabatabaeefar (2003).

Sphericity: According to Mohsenin (1970), sphericity ϕ was calculated using the formula:

$$\phi = \frac{(LWT)^{1/3}}{L} . \qquad (2)$$

Angle of Repose:

The emptying angle of repose θ was determined at five moisture levels using the pipe method (Henderson and Perry 1976, Jha 1999). A pipe of 40 cm height and 106 mm internal diameter was kept on the floor vertically and filled with the sample; tapping during filling was done to obtain uniform packing. The tube was slowly raised above the floor so that the whole material could slide and form a heap. The height above the floor H and the diameter of the heap D at its base were measured with a measuring scale and the angle of repose, θ, of shea kernel was computed using the following equation:

$$\theta = Arc\tan(2H / D) . \qquad (3)$$

Surface Area

The surface area of a kernel was found by analogy with a sphere of geometric mean diameter for the different levels as given by McCabe *et al*. (1986):

$$S = \pi D_{GM}^2 . \qquad (4)$$

Coefficient of Static Friction

The coefficient of static friction for shea kernel was determined against three structural surfaces namely: wood (WD), steel (ST) and galvanized steel (GST). A bottomless wooden box of 150 mm x 150 mm x 40 mm was constructed for this purpose. This procedure was similar to that reported by Oje (1994). The box was filled with shea kernel on an adjustable tilting surface. The surface was raised gradually using a screw device until the box started to slide down and the angle of inclination read on a graduated scale.

Results and Discussion

The physical properties of shea kernel (LSK) at different moisture contents are shown in Table 1. The physical properties of shea kernel (SSK) at different moisture contents are shown in Table 2.

Kernel Dimensions

The moisture content varied from 79.95 to 7.47% (db), for LSK and 73.38 to 6.58% (db) for small size kernel, SSK. The range of length, width, thickness and geometric mean diameter are as presented in Tables 1 and 2. These properties decreased as moisture decreased through air drying and the relationships are presented in Table 3.

Seed Density

The seed density at different moisture levels varied from 1.00 g/cm^3 to 1.44 g/cm^3 an increase of 44% for LSK, and 1.04 to 1.26 g/cm3 an increase of 21.1% for SSK. The seed density was found to bear the relationship with moisture content shown in Eqs. (5) and (6):

$\rho_{sSSK} = 1.271 - 0.003\, MC$ ($R^2 = 0.9542$), (5)

$\rho_{sLSK} = 1.164 - 0.002\, MC$ ($R^2 = 0.9843$). (6)

Sphericity

The values of sphericity at different moisture levels varied from 0.74 to 0.70 a decrease of 5.4% for LSK, and 0.76 to 0.73 a decrease of 3.9% for SSK. The linear relationship with moisture content is presented in Eqs. (7) and (8):

$\Phi_{SSK} = 0.692 + 0.0002\, MC$ ($R^2 = 0.8982$), (7)

$\Phi_{LSK} = 0.696 + 0.0001\, MC$ ($R^2 = 0.9673$). (8)

Table 1. Physical properties of shea kernel (LSK) at different moisture contents.

S/N	Properties	Replications	Moisture content, % (db)				
			79.95	67.88	28.01	18.18	7.47
1	Length (mm)	100	38.99 (2.10)	34.64 (1.96)	30.98 (1.77)	30.01 ((1.44)	29.4 (1.2)
2	Width (mm)	100	26.51 (2.03)	23.30 (1.83)	20.45 (1.74)	19.57 (1.30)	19.28 (1.53)
3	Thickness (mm)	100	23.30 (2.84)	20.08 (2.34)	18.00 (1.72)	16.98 (1.15)	15.67 (1.88)
4	Geometric diameter (mm)	100	28.80 (1.47)	25.24 (1.29)	22.46 (1.19)	21.53 (0.94)	20.66 (1.23)
5	Sphericity	100	0.74 (0.05)	0.73 (0.05)	0.73 (0.05)	0.72 (0.03)	0.70 (0.05)
6	Surface area (cm^2)	100	26.13 (2.67)	20.07 (2.05)	15.90 (1.68)	14.59 (1.30)	13.46 (1.59)
7	Main mass (gm)	100	12.32 (2.00)	8.72 (1.25)	6.59 (0.81)	5.94 (0.55)	5.25 (0.78)
8	Volume (cm^3)	100	12.60 (1.93)	8.48 (1.29)	5.98 (0.95)	5.25 (0.72)	4.66 (0.82)
9	Kernel density, g/cm^3	100	1.00 (0.21)	1.03 (0.08)	1.12 (0.14)	1.14 (0.11)	1.44 (0.17)
10	Coeff. of static friction on:						
i	Galvanised steel	10	0.71 (0.028)	0.61 (0.02)	0.52 (0.019)	0.44 (0.008)	0.40 (0.01)
ii	Wood	10	0.68 (0.043)	0.67 (0.026)	0.56 (0.024)	0.39 (0.014)	0.35 (0.01)
iii	Steel	10	0.54 (0.032)	0.53 (0.021)	0.52 (0.017)	0.40 (0.016)	0.36 (0.011)
11	Angle of Repose, degree	10	23.60 (1.44)	26.1 (1.52)	29.5 (1.40)	30.1 (0.26)	30.7 (1.49)

Note: Figures in parenthesis are standard deviation.

Table 2. Physical properties of shea kernel (SSK) at different moisture contents.

S/N	Properties	Replications	Moisture Content, % (db)				
			73.38	60.59	38.46	20.02	6.58
1	Length (mm)	100	30.80 (2.23)	29.56 (2.34)	27.14 (1.55)	26.93 (2.36)	23.32 (1.74)
2	Width (mm)	100	21.63 (1.02) (1.93)	19.77 (1.84) (1.84)	18.09 (1.23) (1.23)	17.75 (1.79) (1.79)	15.76 (1.79) (1.79)
3	Thickness (mm)	100	19.42 (2.09) (2.09)	16.99 (2.11) (2.11)	15.25 (1.22) (1.22)	14.70 (2.55) (2.51)	13.36 (1.59) (1.19)
4	Geometric diameter (mm)	100	19.54 (1.46) (1.46)	21.44 (1.60) (1.60)	19.54 (1.09) (1.09)	19.09 (1.61) (1.61)	19.96 (1.10) (1.10)
5	Sphericity	100	0.76 (0.05) (0.05)	0.73 (0.05) (0.05)	0.72 (0.03) (0.03)	0.71 (0.04) (0.05)	0.73 (0.04) (0.04)
6	Surface area (cm^2)	100	17.31 (2.15) (2.15)	14.53 (2.10) (2.10)	12.04 (1.32) (1.32)	11.54 (1.91) (1.91)	9.08 (1.20) (1.20)
7	Main mass (g)	100	6.82 (1.19) (1.19)	5.42 (1.150 (1.15)	4.62 (0.80) (0.80)	4.32 (0.95) (0.95)	3.14 (0.42) (0.42)
8	Volume (cm^3)	100	6.80 (1.26) (1.26)	5.24 (1.10) (1.10)	3.94 (0.64) (0.64)	3.72 (0.91) (0.91)	2.59 (0.52) (0.52)
9	Kernel density, g/cm^3	100	1.04 (0.27) (0.27)	1.04 (0.11) (0.11)	1.18 (0.11) (0.11)	1.16 (0.20) (0.20)	1.26 (0.27) (0.27)
10	Coeff. of static friction on:						
i	Galvanised iron	10	0.68 (0.03) (0.03)	0.62 (0.03) (0.03)	0.45 (0.01) (0.012)	0.41 (0.37) (0.037)	0.39 (0.03) (0.033)
ii	Wood	10	0.76 (0.26) (0.026)	0.72 (0.02) (0.023)	0.51 (0.02) (0.016)	0.49 (0.05) (0.050)	0.45 (0.03) (0.027)
iii	Steel	10	0.57 (0.03) (0.032)	0.54 (0.03) (0.030)	0.49 (0.02) (0.016)	0.45 (0.02) (0.020)	0.42 (0.04) (0.037)
11	Angle of Repose, degree	10	23.42 (2.76) (2.76)	28.2 (1.31) (1.31)	29.3 (0.66) (0.66)	30.1 (0.68) (0.68)	30.5 (0.66) (0.66)

Note: Figures in parenthesis are standard deviation.

Table 3 Models of the effect of moisture content on dimensions of shea kernel.

Parameter	SSK	R^2	LSK	R^2
L	23.55 + 0.100 MC	0.9171	24.11 + 0.064 MC	0.8770
W	15.55 + 0.076 MC	0.9442	15.95 + 0.066 MC	0.9230
D_{GM}	19.48 + 0.010 MC	0.0960	19.45 + 0.011 MC	0.0154

The experimental shea kernels can be regarded as spherical since the sphericity is greater than 0.70 (Dutta *et al*. 1988). In this study, the shea kernel is treated as an equivalent sphere for calculation of the surface area. The decrease in sphericity with moisture content is probably due to the greatest contraction along its length rather than along its thickness as was reported (Deshpande *et al*. 1993) for 'JS-7244' soybean.

Kernel Mass

The shea kernel mass varied from 12.32 to 5.25 g, a decrease of 5.7% for LSK, and 6.82g to 3.14g a decrease of 5.39% for SSK in the moisture content ranges. The following relationships, Eqs. (9) and (10), were fitted to the data:

$M_{SSK} = 2.935 + 0.047\ MC\ (R^2 = 0.9292)$, (9)

$M_{LSK} = 3.196 + 0.040\ MC\ (R^2 = 0.8941)$. (10)

The models would be very good for the prediction of these properties since the correlation coefficients are greater than 0.7 in each case.

Volume of Kernel

The average volume of shea kernel decreased as the moisture content decreased through air-drying from 12.60 to 4.66 cm^3 a decrease of 63.0% for LSK and 6.8 to 2.59 cm^3, a decrease of 61.2% for SSK in the moisture content ranges. The relationships were given by Eqs. (11) and (12):

$V_{SSK} = 2.21 + 0.056\ MC\ (R^2 = 0.9271)$, (11)

$V_{LSK} = 2.47 + 0.048\ MC\ (R^2 = 0.9321)$. (12)

Angle of Repose

The angle of repose of shea kernel increased from 23.6 to 30.7 degrees, an increase of 30% for LSK and 23.42 to 30.5 degrees, an increase of 30.2% for SSK in the moisture content ranges. The mathematical relationships are presented in Eqs. (13) and (14):

$\Theta_{SSK} = 31.90 - 0.090\ MC\ (R^2 = 0.756)$, (13)

$\Theta_{LSK} = 31.49 - 0.079\ MC\ (R^2 = 0.770)$. (14)

Surface Area

The surface area of the kernel decreased from 26.13 to 13.46 cm^2, a decrease of 48.48% for LSK in the moisture range (Table 1) and 17.31 to 9.08 cm^2 a decrease of 47.5% for SSK in the moisture content range (Table 2) while Eqs. (15) and (16) describe the relationships:

$S_{SSK} = 8.501 + 0.109\ MC\ (R^2 = 0.9442)$, (15)

$S_{LSK} = 9.046 + 0.095\ MC\ (R^2 = 0.936)$. (16)

Static Coefficient of Friction

It was found that the static coefficient of friction for shea kernel decreased with decrease in moisture content on the structural materials of steel (ST), galvanized steel (GST), and wood (WD). The percentage decreases were 33.3, 38.0 and 48.5% for ST, GST and WD respectively in the LSK category. Furthermore, the percentage decreases were 26.3, 42.6 and 40.7% for ST, GST and WD, respectively, in the SSK category. The relationships between static coefficient of friction (μ) and moisture content for the shea kernel derived from experimental data are presented in Table 4.

Conclusion

The following conclusion can be drawn from this study:

- As the kernels dried, the dimensions of length, width, thickness and geometric mean diameter decreased linearly as the moisture content decreased.
- The surface area, mass, volume and sphericity of shea kernel also decreased linearly as the moisture content decreased.

Table 4. Models of the effect of moisture content on coefficient static friction of shea kernel.

Parameter	SSK	R^2	LSK	R^2
μ_{WD}	0.388 + 0.005 *MC*	0.9181	0.405 + 0.004 *MC*	0.9912
μ_{GST}	0.327 + 0.004 *MC*	0.9342	0.344 + 0.004 *MC*	0.9933
μ_{ST}	0.404 + 0.002 *MC*	0.9999	0.417 + 0.001 *MC*	0.9631

Note: μ_{WD}, μ_{GST}, and μ_{ST} are coefficients of static friction on wood, galvanized steel and steel, respectively; R^2 = coefficient of determination.

- However, the kernel density and angle of repose increased as the moisture content decreased.
- Similarly, the static coefficient of friction of shea kernel decreased linearly on the structural surfaces as the moisture content decreased.

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