Effect of Moisture on Some Physical Properties of Shea (Vitellaria Paradoxa L) Kernels

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ABSTRACT

Moisture-dependent engineering properties of seeds are important in the design of postharvest equipment for their handling and processing. In this study, the physical properties of shea kernels were determined as a function of moisture content in the range of 6.24 to 25% (d.b.) using standard techniques. The results showed that with increasing moisture content, the major, intermediate, minor, arithmetic mean diameter, geometric mean diameter, sphericity, aspect ratio, true density and porosity all increased non-linearly from 18.33±0.81 to 31.20±1.21, 10.77±1.07 to 22.50±0.87 and 9.33±0.81 to 16.17±1.07mm, 12.81±0.73 to 23.29±1.00mm, 12.22±0.81 to 22.40±1.02mm, 66.68±4.10 to 71.79±1.51%, 58.73±5.24 to 70.07±1.51%, 1.04±0.10 to 1.54g/cm³ and 44.67 to 72.37% respectively as moisture content increased from 6.24 to 25%. Surface area, 1000-kernel mass, volume and filling angle of repose all increased linearly from 470.47±61.64 to 1578.53±145.83mm², 3.63±0.15 to 11.20±0.60kg, 1.46±0.28 to 8.95±0.13cm³ and 35.47 to 40.89° respectively at the same moisture range. Also, static co-efficient of friction on plywood, galvanise steel, stainless steel and glass increased linearly from 0.43±0.01 to 1.78±0.02, 0.37±0.01 to 1.39±0.03, 0.28±0.03 to 1.12±0.01 and 0.21±0.01 to 0.93±0.01 respectively. Finally, bulk density decreased non-linearly from 0.78±0.01 to 0.35±0.06g/cm³. Data was analysed using SPSS (Version 16) and Microsoft Excel (2010). Analysis of Variance (ANOVA) was carried out to assess the variation of each parameter within the moisture range. Differences in the means were compared using Duncan Multiple Range Test (P=0.05). Regression analyses were conducted to establish the relationship between the physical properties of shea kernel and moisture content. Differences in the means of most parameters determined were statistically significant within the moisture range investigated.

Keywords: aspect ratio, bulk density, angle of repose, coefficient of friction, moisture content, porosity, shea kernel, sphericity.

I. INTRODUCTION

The shea tree (Vitellaria paradoxa L) is a member of the sapotaceae family. It is a deciduous tree of medium size, with a spherical crown. It often reaches heights of 10 to 15 m, with rare recorded occasions of up to 25 m [1]. It is a light demanding, slow growing tree, with a thick and rough bark. The flowers, which appear from December to March, are greenish yellow and occur in terminal groups of approximately 30 to 40. It is insect pollinated and, as such, is often associated with bees [2]. Shea butter, an important vegetable fat is obtained from the kernel of this plant. Designing equipment for processing of shea kernel requires knowledge of its engineering parameters and the effect of moisture on them. The knowledge of the physical properties of agricultural materials is important during the harvesting of grains, transporting, design and dimensioning of correct storage procedures, manufacturing and operating different equipment used in post harvesting processing operations of these products [3]; [4]. Moisture content
is the most vital factor influencing physical properties of grains. Studies have been published on effects of moisture content on some physical and mechanical properties of some agricultural materials. [5] studied the effect of moisture content on some physical properties of sheanuts in Nigeria. [6] also studied the effect of moisture content on mechanical properties of shea kernel in Ghana. [7], [8] studied some engineering properties of shea kernel and comparative study of some engineering properties of shea kernel in Ghana respectively. However, their studies did not investigate the effect of moisture on the physical properties of the kernel. This study was therefore conducted to investigate the effect of moisture content on the physical properties of shea kernel at a moisture content range of 6.24 to 25% (d.b).

II. METHODS AND MATERIAL

The standard method of moisture determination was used to determine the moisture content of the kernel. The measurement on each sample were replicated three times and the average moisture content taken. Weight loss on drying to a final constant weight was recorded as moisture content by [9] recommended method and percentage calculated using Equation (1).

\[ MC_{db} = 100 \times (Ww - Wd)/(Wd) \]  

Where,

\( MC_{db} \) is moisture content on dry basis, \( Ww \) is Weight of materials before oven drying; \( Wd \) is Weight of material after oven drying.

The other levels of moisture content were attained by conditioning the samples through a process of rewetting in which calculated amount of distilled water was added, thorough mixing and then sealing in separate polyethylene bags. From an initial moisture content of 6.24% (d.b.), the samples were conditioned to the desired moisture contents of 10, 15, 20 and 25%, (d.b.). The amounts of distilled water added to the samples were obtained using Equation (2) as described by [10]:

\[ Q = Wi \times (Wf - Wi)/(100 - Wf) \]  

Where,

\( Q \) is mass of distilled water to be added in g, \( Wi \) is initial mass of sample to be conditioned in g, \( Mi \) is initial moisture content of sample in % (db) and \( Mf \) is final moisture content in % (db).

The samples were then placed into a refrigerator for one week at a temperature of 5°C in order to ensure uniform distribution of moisture within the samples [11]. The morning before the start of the experiment, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to room temperature for about 2 hours [12]. To determine the size and shape, 100 kernels were randomly selected and the principal dimensions (major, intermediate, and minor) measured using a digital calliper, (Model Mecanic, Type 6911 VWR Scientific, Switzerland) with an accuracy of 0.01 mm. The arithmetic mean diameter (\( Da \)) and geometric mean diameter (\( Dg \)) were calculated using Equations (3) and (4) by [13] and [14] respectively. Theoretically, sphericity (\( \Phi \)), aspect ratio (\( Ra \)), surface area (\( As \)) and volume (\( V \)) were determined using Equations (5), (6), (7), and (8) by [15]; [16]; [17] and [18] respectively.

\[ Da = (a + b + c)/3 \]  
\[ Dg = (abc)^{0.333} \]  
\[ \Phi = (Dg/a) \times 100 \]  
\[ Ra = (b/a) \times 100 \]  
\[ As = \pi(Dg)^2 \]  
\[ V = \frac{4}{3}\pi(abc) \]  

Where,

\( Da \) is arithmetic mean diameter in mm, \( Dg \) is geometric mean diameter in mm, \( a \) is major diameter in mm, \( b \) is intermediate diameter in mm, \( c \) is minor diameter in mm; \( \Phi \) is sphericity in %, \( Ra \) is aspect ratio in %, \( As \) is surface area in mm² and \( V \) is volume in cm³.

The 1000-kernel mass was determined using a precision electronic (Yamato, model HB 3000, Japan) reading to 0.01g accuracy. To evaluate the 1000 kernel mass, 50 randomly selected samples were weighed and multiplied by 20 to get the 1000-kernel mass. The reported value was a mean of three replications. The true density (\( \rho_t \)) was determined as the ratio of the unit mass and unit volume of kernel and calculated using Equation (9). Bulk density was also determined from Equation (10). From the values of particle density (\( \rho_p \)) and bulk density (\( \rho_b \)), porosity was calculated using
Equation (11). These procedures were replicated three times and the average values recorded.

\[ \rho_t = (M_t / V_t) \]  
(9)

\[ \rho_b = (M_b / V_b) \]  
(10)

\[ \varepsilon = 100 \times (\rho_t - \rho_b) / \rho_t \]  
(11)

Where,

(\( \rho_t \)) is true density in g/cm\(^3\), \( M_t \) is mass of individual kernel in g, \( V_t \) is volume of individual kernel in cm\(^3\), \( \rho_b \) is the bulk density in g/m\(^3\), \( M_b \) is weight of the sample in g, \( V_b \) is volume occupied by the sample in cm\(^3\), \( \varepsilon \) is porosity in %, \( \rho_b \) is bulk density in g/cm\(^3\) and \( \rho_t \) is true density in g/cm\(^3\).

The filling angle of repose (\( \theta_f \)) was determined using a top and bottomless cylinder of 12 cm diameter and 25 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 20 cm (specifically constructed for this purpose) and was filled with shea kernels. The cylinder was raised slowly until the kernel poured out and formed a conical heap on the circular plate. The height of the heap was measured and the filling angle of repose (\( \theta_f \)) was calculated using Equation (12) by [18]; [19]. The static co-efficient of friction was determined on four structural surfaces, using Equation (13).

\[ \theta_f = \tan^{-1}(2H/D) = \tan^{-1}(2H/20) \]  
(12)

\[ \mu_s = \tan \theta \]  
(13)

Where,

\( \theta_f \) is Filling angle of repose, \( H \) is height of the heap in cm and \( D \) is known diameter [20cm] of the circular plate, \( \mu_s \) is static co-efficient of friction and \( \theta \) is angle of internal friction or tilt in °.

Data was analysed using Microsoft Office Excel (2010) and SPSS (version 16) and summarised into means and standard deviations. Analysis of Variance (ANOVA) was carried out to assess the variations of each parameter within the moisture range. All analyses were carried out in triplicates. Duncan’s Multiple Range Test was used to compare mean variance. Significance was accepted at 5% level of probability.

III. RESULTS AND DISCUSSION

3.1 Axial dimensions

From Fig. 1, it was realized that as moisture content increased from 6.24 to 25% (d.b.), the major, intermediate and minor diameters increased non-linearly from 18.33±0.81 to 31.20±1.21, 10.77±1.07 to 22.50±0.87 and 9.33±0.81 to 16.17±1.07mm, an increase of 70.18, 108.98 and 73.21% respectively. This implied that as the shea kernel absorbed moisture; it expanded volumetrically. Very high coefficients of determination were observed between the three principal dimensions within the moisture range investigated. Similar trends were observed by [20]; [21] for cowpea, [22]; [23] for soybean, [24] for faba beans. Significant differences existed in the major and intermediate diameters at the moisture range studied, but no difference in the minor diameter at moisture range 10 to 15% (P=0.05).

Regression analyses were used to obtain the relationship between moisture content (Mc) and major diameter (Dmj), intermediate diameter (Dint) and minor diameter (Dmn) and are presented in Table 1.

![Fig. 1 Effect of moisture content on triaxial dimensions of shea kernel](image)

3.2 Average diameters

The arithmetic and geometric mean diameters increased logarithmically with increased moisture content (Fig. 2) and the values ranged from 12.81±0.73 to 23.29±1.00mm and 12.22±0.81 to 22.40±1.02mm, an increase of 81.79 and 83.31%
respectively within moisture range of 6.24 to 25% (d.b.). This trend was also observed by [25] for peanut and [26] for black gram beans. [27] and [28] also found the geometric mean diameter to increase with increasing moisture content for flaxseed and common beans respectively. There were significant differences in the means of both the arithmetic and geometric mean diameters as moisture varied (P=0.05). The mathematical models that best describes the relationship between the variations in arithmetic and geometric mean diameters as function of moisture are expressed in Table 2.

**3.3 Surface Area**

From Fig. 3, the surface area of shea kernel increased linearly from 470.46±61.64 to 1578.53±145.83mm$^2$, an increase of 235.53% with moisture content range of 6.24 to 25% (d.b.). This is because it is dependent on the three axial dimensions, which increased as moisture increased. Statistically the difference in the means are significant (P=0.05).

**3.4 Volume**

From Fig. 4, the volume of the kernel increased linearly from 1456.47±282.54 to 8947.93±1252.40mm$^3$, an increase of 514.36% as moisture increased from 6.24 to 25% (d.b.). The volumetric expansion observed may be attributed to moisture absorption, which increased the axial dimensions of the kernels. The variation in the mean volume was statistically important (P=0.05). This trend is very similar to those observed by [10] for soybeans [31] for Garcinia kola seeds and [32] for black cumin (Nigella sativa L.) seeds. The relationship between moisture content (Mc) and volume of shea kernel (VSk) is given in Table 4.

**3.5 Sphericity and aspect ratio**

Sphericity expresses the characteristic shape of a solid object relative to that of a sphere of the same volume [32]. There was a 9.37% logarithmic increase in sphericity from 66.68±4.10 to 71.79±1.51percentage, at a moisture range of 6.24 to 25% (d.b.) (Fig. 5). This is because; sphericity is dependent on the triaxial dimensions, which were increased as moisture increased. There were no significant differences in sphericity at the moisture range studied (P=0.05). Similar trends have been reported by [22] for soybean seed, [33] for green gram, [34] for Turkish mahaleb, and [35] for cottonseeds respectively. However, some
researches have observed an inverse relationship between increased moisture content and its effect on sphericity. Notable among them are [36] for Kano white variety of bambara groundnut, and [23] for faba bean. Knowledge of grain shape is important during modeling of grain drying, aeration, heating and cooling [37].

Aspect ratio is the ratio of the intermediate diameter and the major diameter. This property determines the ability of grains to slide or roll on a surface. Aspect ratio increased by 19.31% from 58.73±5.24 to 70.07±1.53 to % in the moisture range 6.24 to 25% (d.b.) (Fig. 5). There was a marginal increase in the kernel intermediate diameter than the major diameter. Statistically, there were significant differences in means values of aspect ratio at the moisture range studied except within 10 to 15% where no significant difference existed (P=0.05). This statistic showed that, kernels assumed spherical shape as they absorbed moisture. This means that at higher moisture level, kernel will tend to roll rather than slide on inclined surfaces. This trend was observed by [38] for maize. Regression analyses were conducted to determine the relationship between moisture content (Mc) and sphericity (Sk) and aspect ratio (Rak) of kernel and are presented in Table 5.

3.6 1000-kernel mass
The thousand kernel mass of shea kernel increased linearly by 208.72% from 3.63±0.15 to 11.20±0.60kg as moisture content increased from 6.24 to 25% (d.b.) as seen in Fig. 6. There were no differences in 1000 kernel mass between 6.24 and 15% moisture content, but significant differences existed at 15, 20 and 25% moisture contents. The relationship between thousand-kernel mass (1000kmSk) and the moisture content (Mc) can be represented by the equation in Table 6.

3.7 True and bulk densities
The true density increased non-linearly by 46.31% as the moisture content increased from 6.24 to 25% (d.b.) (Fig. 7). The values ranged from 1.04±0.10 to 1.54g/cm$^3$ in the moisture range studied. This was because an increase in mass of kernel owing to moisture absorption was higher than its accompanying volumetric expansion. This property can be very useful in the design of cleaning and separation equipment. The true density for all the moisture contents investigated were greater than the density of water (1g/cm$^3$), implying that shea kernel will sink during cleaning in water. There were no significant differences in true density at moisture content 10, 15 and 25%, but significant differences existed at 6.24% and 20% (P=0.05). The trend agreed with those

![Fig. 5 Effect of moisture content on sphericity and aspect ratio of shea kernel](image)

![Fig. 6 Effect of moisture content on 1000 kernel mass of shea kernel](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mathematical Model</th>
<th>Co-efficient of determination (R$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphericity, %</td>
<td>$S_k = 4.2445ln(Mc) + 59.348$</td>
<td>0.9685</td>
</tr>
<tr>
<td>Aspect ratio, %</td>
<td>$R_{ak} = -0.0515M_x^2 + 2.1531M_x + 47.889$</td>
<td>0.9669</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mathematical Model</th>
<th>Co-efficient of determination (R$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thousand kernel mass, kg</td>
<td>$1000kmSk = 413.28M_x + 333.02$</td>
<td>0.9652</td>
</tr>
</tbody>
</table>

Similar increasing trends were reported by [39] for corn, [23] for soya bean grains, and [40] for monogerm sugarbeet seeds, [41] for karanja (Pongamia pinnata) kernels.
reported by [23] for soya bean grains, [42] for jatropha seed and [40] for karanja kernel. In contrast, there was a negative correlation between increased moisture content and bulk density of shea kernel. Bulk density decreased by 55.69% from 0.78±0.01 to 0.35±0.06g/cm$^3$, as moisture content increased from 6.24 to 25% (d.b.) (Fig. 7). This was because an increase in mass of kernels owing to the moisture absorption was lower than accompanying volumetric expansion. The difference in bulk density with respect to moisture content were significant at 6.24 and 10% but not different at 15, 20 and 25% moisture content (P=0.05).

![Fig. 7 Effect of moisture content on true and bulk density of shea kernel](image)

Similar decreasing trends in bulk density have been reported by [43] for pea seeds, [44] for some legumes seeds, [42] for jatropha seed and [40] for monogerm sugarbeet (Beta vulgaris var. altissima) seeds. Regression analyses were used to obtain the relationships of shea kernel’s true density ($\rho_tSk$) and its bulk density ($\rho_bSk$) with moisture content ($Mc$) and are presented in Table 7.

![Table 7 Models of the effect of moisture content on porosity of bulk shea kernel](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mathematical Model</th>
<th>Coefficient of determination ($R^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>True density, g/cm$^3$</td>
<td>$\rho_tSk = 0.0007Mc^2 + 0.0025Mc + 1.0171$</td>
<td>0.9816</td>
</tr>
<tr>
<td>Bulk density, g/cm$^3$</td>
<td>$\rho_bSk = 0.002Mc^2 - 0.0842Mc + 1.2276$</td>
<td>0.9911</td>
</tr>
</tbody>
</table>

### 3.8 Porosity

The porosity of shea kernel increased polynomially by 62.03% from 44.67 to 72.37% with increased moisture content from 6.24 to 25% (d.b.) (Fig. 8). At a 5% level of probability, there were no differences in porosity values as affected my moisture except at 10% moisture content where significant difference existed. [45] reported similar trend for safflower. The relationship between porosity ($\varepsilon_sk$) and moisture content ($Mc$) is represented by the equation in Table 8.

![Fig. 8 Effect of moisture content on shea kernel’s porosity](image)

$$\varepsilon_sk = -0.1022Mc^2 + 4.8712Mc + 15.366$$

### 3.9 Filling angle of repose

There was a 15.23% linear increase in the filling angle of repose from 35.47 to 40.890 as moisture content increased (Fig. 9). The increased filling angle of repose is attributable to the increase in size of the seeds as reported by [46] and [47]. The increasing trend of filling angle of repose with moisture content occurred because, surface layer of moisture surrounding the particles held the aggregate of grains together through surface tension [40]. Differences in mean porosity as affected by moisture were significant (P=0.05). [45] reported an increased filling angle of repose against moisture content variations and have evaluated the relationship between angle of repose and moisture content for safflower. [46] also reported similar trends for Tiger nuts. The relationship between shea kernel filling angle of repose ($\theta_{fSk}$) and moisture content ($Mc$) determined is represented in Table 9.

![Fig. 9 Effect of moisture content on filling angle of repose of shea kernels](image)
3.10 Static Co-efficient of friction

The effect of moisture content on the static coefficients of friction of shea kernels on the different test surfaces are presented in Fig. 10. All increased linearly from 0.43±0.01 to 1.78±0.02, 0.37±0.01 to 1.39±0.03, 0.28±0.03 to 1.12±0.01 and 0.21±0.01 to 0.93±0.01, an increase of 313.49, 276.07, 300.64 and 339.16% on plywood, galvanise steel, stainless steel and glass respectively within the moisture range of 6.24 to 25% (d.b) (Fig. 10). This is due to the increased adhesion between the kernel and the test surfaces at higher moisture values [48]. Differences in static coefficient of friction for all the test surfaces as affected by moisture were statistically significant (P=0.05).

Regression analysis were used to obtain the relationships between moisture content (Mc) and variations of static co-efficient of friction on plywood (µSkPly), galvanise steel (µSkGalSt), stainless steel (µSkSSt) and glass (µsg) and expressed respectively as equations in Table 10.

Table 9 Models of the effect of moisture content on filling angle of repose of shea kernel

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mathematical Model</th>
<th>Coefficient of determination (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling angle of reposes,°</td>
<td>0.036e-0.2889Mc+33.425</td>
<td>0.9889</td>
</tr>
</tbody>
</table>

Regression analysis were used to obtain the relationships between moisture content (Mc) and variations of static co-efficient of friction on plywood (µSkPly), galvanise steel (µSkGalSt), stainless steel (µSkSSt) and glass (µsg) and expressed respectively as equations in Table 10.

Table 10 Models of the effect of moisture content on static co-efficient of friction of shea kernel on tested surfaces

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mathematical Model</th>
<th>Coefficient of determination (R²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plywood</td>
<td>µPlywood = 0.0728Mc + 0.0052</td>
<td>0.9943</td>
</tr>
<tr>
<td>Galvanise steel</td>
<td>µGalvanise = 0.0538Mc - 0.008</td>
<td>0.9882</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>µStainless = 0.045Mc - 0.0079</td>
<td>0.9977</td>
</tr>
<tr>
<td>Glass</td>
<td>µGlass = 0.0381Mc - 0.027</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**IV. CONCLUSION**

Surface area, 1000-kernel mass, volume, filling angle of repose and static co-efficient of friction on plywood, galvanise steel, stainless steel and glass all increased linearly while bulk density decreased non-linearly. The major, intermediate, minor, arithmetic mean diameter, geometric mean diameter, sphericity, aspect ratio, true density and porosity all increased, but non-linearly. Finally, bulk density decreased non-linearly in the moisture range investigated. Statistically, not all means of parameters studied within the moisture range investigated were significantly different (P=0.05).

**V. ACKNOWLEDGEMENTS**

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**VI. REFERENCES**


