© 2016 IJSRSET | Volume 2 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN: 2394-4099
Themed Section: Science and Technology

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

E. A. Seweh[1*], S. Apuri[2], J. O., Darko[3] A. Addo[3], P. A. Asagadunga[1], and S. D. Agyegelone[1]

[1]Department of Agricultural Engineering, School of Engineering, Bolgatanga Polytechnic, Bolgatanga, Ghana
[2]Department of Ecological Agriculture, School of Applied Science and Arts, Bolgatanga Polytechnic, Bolgatanga, Ghana.
[3]Department of Agricultural Engineering, Kwame Nkrumah, University of Science and Technology, Kumasi, Ghana.

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/cm^3 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±145.83mm^2, 3.63±0.15 to 11.20±0.60kg, 1.46±0.28 to 8.95±0.13cm^3 and 35.47 to 40.89^0 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/cm^3. 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).

$$MCdb = 100 \times (Ww - Wd)/(Wd) \qquad (1)$$

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]:

$$Q = Wi \times (Wf - Wi)/(100 - Wf) \qquad (2)$$

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 (∅), 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.

$$Da = (a + b + c)/3 \qquad (3)$$
$$Dg = (abc)^{0.333} \qquad (4)$$
$$\emptyset = (Dg/a) \times 100 \qquad (5)$$
$$Ra = (b/a) \times 100 \qquad (6)$$
$$As = \pi(Dg)^2 \qquad (7)$$
$$V = \frac{4}{3}\pi(abc) \qquad (8)$$

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; ∅ is sphericity in %, Ra is aspect ratio in %, As is surface area in mm^2 and V is volume in cm^3.

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 (ρ_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 (ρ_t) and bulk density (ρ_b), porosity was calculated using

Equation (11). These procedures were replicated three times and the average values recorded.

$$\rho t = (Mi/Vi) \quad (9)$$
$$\rho b = (Mb/Vb) \quad (10)$$
$$\varepsilon = 100 \times (\rho t - \rho b)/\rho t \quad (11)$$

Where,
(ρt) is true density in g/cm^3, M_i is mass of individual kernel in g, V_i is volume of individual kernel in cm^3, ρb is the bulk density in g/m^3, Mb is weight of the sample in g, Vb is volume occupied by the sample in cm^3, ε is porosity in %, ρb is bulk density in g/cm^3 and ρt is true density in g/cm^3.

The filling angle of repose (θ_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 (θ_f) was calculated using Equation (12) by [18]; [19]. The static co-efficient of friction was determined on four structural surfaces, using Equation (13).

$$\theta f = Tan^{-1}(2H/D) = Tan^{-1}(2H/20) \quad (12)$$
$$\mu s = tan\theta \quad (13)$$

Where,
θf is Filling angle of repose, H is height of the heap in cm and D is known diameter [20cm] of the circular plate, μs is static co-efficient of friction and θ is angle of internal friction or tilt in ^{0}.

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).

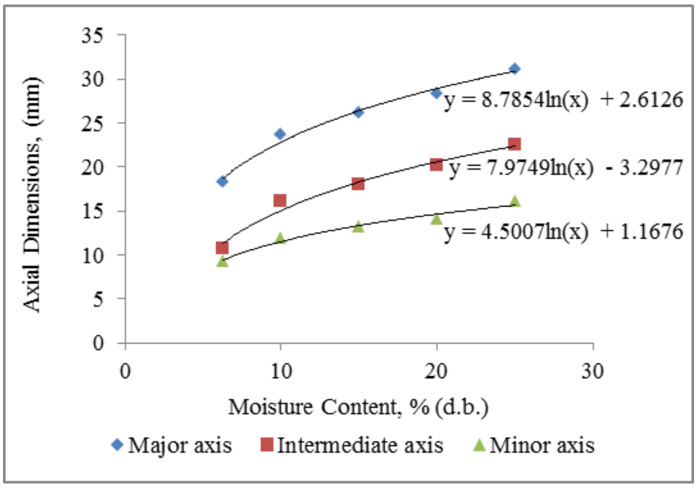

Fig. 1 Effect of moisture content on triaxial dimensions of shea kernel

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.

Table 1 Mathematical models of the effect of moisture content on the axial dimensions of shea kernel

Axial Dimension	Mathematical Model	Coefficient of determination (R^2)
Major dia., mm	D_{mj}=8.7854ln(Mc)+2.6126	0.9872
Intermediate dia., mm	D_{int}=7.9749ln(Mc)-3.2977	0.9792
Minor dia., mm	D_{mn}=4.5007ln(Mc)+1.1676	0.9681

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.

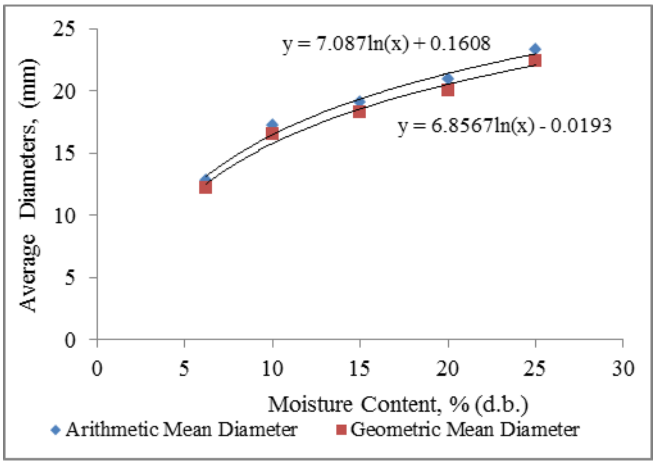

Fig. 2. Effect of moisture content on average diameters of shea kernel

Table 2 Models of the effect of moisture content on average diameters of shea kernel

Parameter	Mathematical Model	Coefficient of determination (R^2)
Arithmetic dia., mm	$Da = 7.087\ln(Mc) + 0.1608$	0.9828
Geometric mean dia., mm	$Dg = 6.8567\ln(Mc) - 0.0193$	0.9810

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).

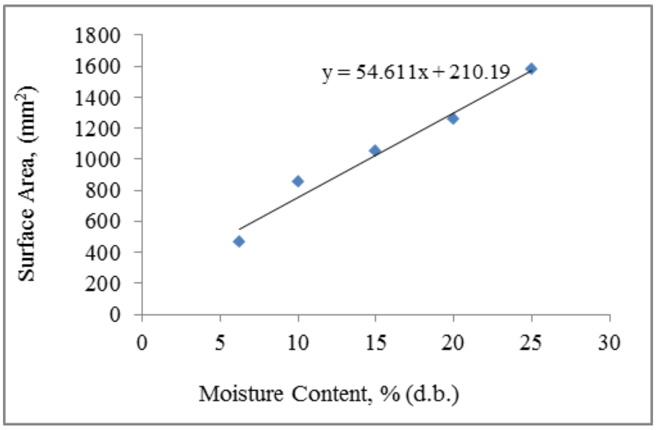

Fig. 3 Effect of moisture content on surface area of shea kernel

Similar trends were reported by [29] for beniseed and [30] for maize. The function of moisture content (Mc) on the surface area of shea kernel (As) can be expressed mathematically as presented in Table 3:

Table 3 Models of the effect of moisture content on surface area of shea kernel

Parameter	Mathematical Model	Coefficient of determination (R^2)
Surface area, mm^2	$As = 54.611Mc + 210.19$	0.9722

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.

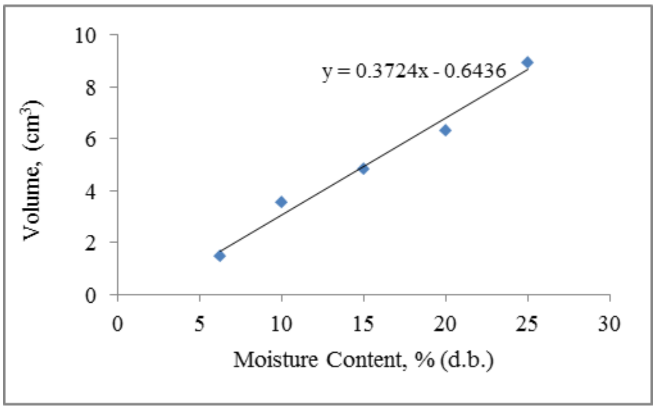

Fig. 4 Effect of moisture content on Volume of shea kernel

Table 4 Models of the effect of moisture content on average diameters of shea kernel

Parameter	Mathematical Model	Coefficient of determination (R^2)
Volume, cm^3	$V_S = 0.3724Mc - 0.6436$	0.9815

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 inversed 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].

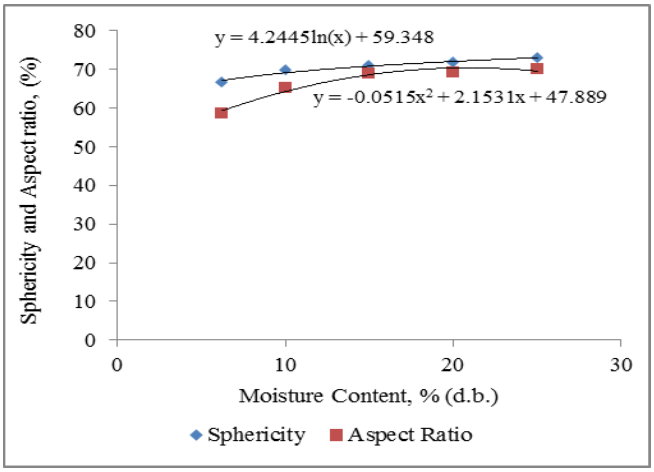

Fig. 5 Effect of moisture content on sphericity and aspect ratio of shea kernel

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 (Øsk) and aspect ratio (Rak) of kernel and are presented in Table 5.

Table 5 Models of the effect of moisture content on shape of shea kernel.

Parameter	Mathematical Model	Co-efficient of determination (R^2)
Sphericity, %	$Ø_{Sk}$=4.2445ln(Mc) + 59.348	0.9685
Aspect ratio, %	Ra_k= -0.0515Mc^2 + 2.1531Mc + 47.889	0.9669

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 1000kernel mass between 6.24 and 10% 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.

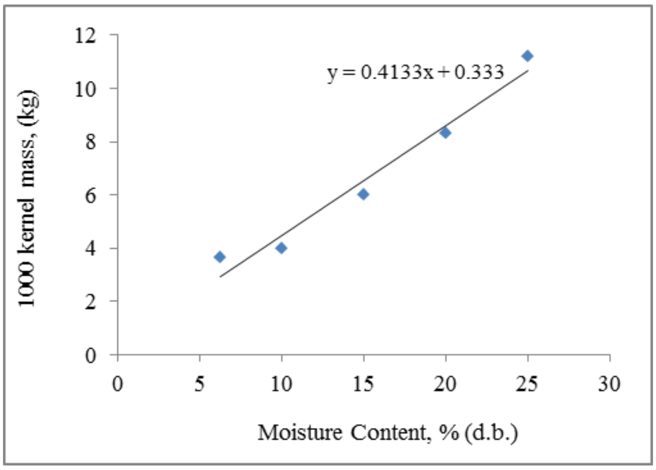

Fig. 6 Effect of moisture content on 1000 kernel mass of shea kernel

Table 6 Models of the effect of moisture content on average diameters of shea kernel

Parameter	Mathematical Model	Coefficient of determination (R^2)
Thousand kernel mass, kg	1000kmSk= 413.28Mc + 333.02	0.9652

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.

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 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 and10% but not different at 15, 20 and 25% moisture content (P=0.05).

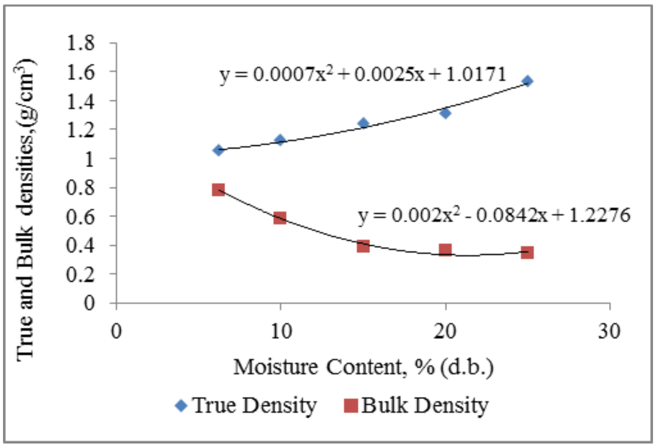

Fig. 7 Effect of moisture content on true and bulk density of shea kernel

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 (ρtSk) and its bulk density (ρbSk) with moisture content (Mc) and are presented in Table 7.

Table 7 Models of the effect of moisture content on true and bulk densities of shea kernel

Parameter	Mathematical Model	Coefficient of determination (R^2)
True density, g/cm^3	$\rho_{tSk} = 0.0007Mc^2 + 0.0025Mc + 1.0171$	0.9816
Bulk density, g/cm^3	$\rho_{bSk} = 0.002Mc^2 - 0.0842Mc + 1.2276$	0.9911

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 (εsk) and moisture content (Mc) is represented by the equation in Table 8.

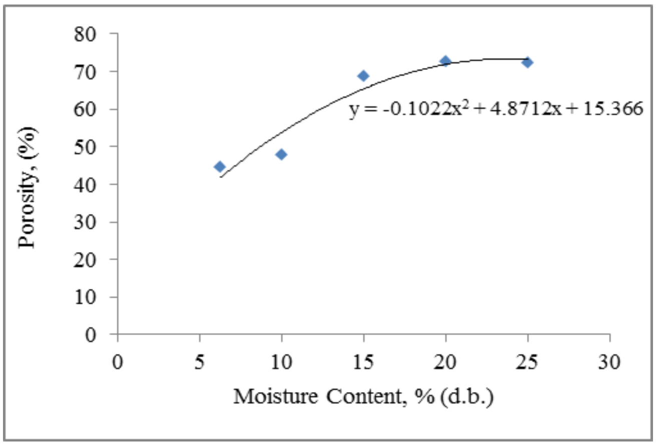

Fig. 8 Effect of moisture content on shea kernel's porosity

Table 8 Models of the effect of moisture content on porosity of bulk shea kernel

Parameter	Mathematical Model	Coefficient of determination (R^2)
Porosity, %	$\varepsilon_{Sk} = -0.1022Mc^2 + 4.8712Mc + 15.366$	0.9245

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 (θfSk) and moisture content (Mc) determined is represented in Table 9.

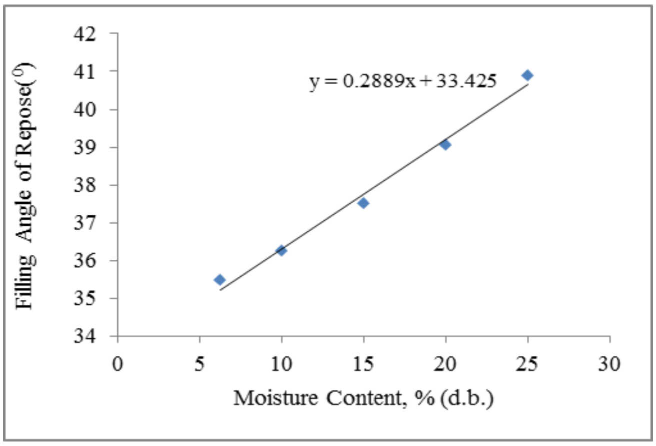

Fig. 9 Effect of moisture content on filling angle of repose of shea kernels

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

Parameter	Mathematical Model	Coefficient of determination (R^2)
Filling angle of repose,^{0}	θfSk=0.2889Mc+33.425	0.9889

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).

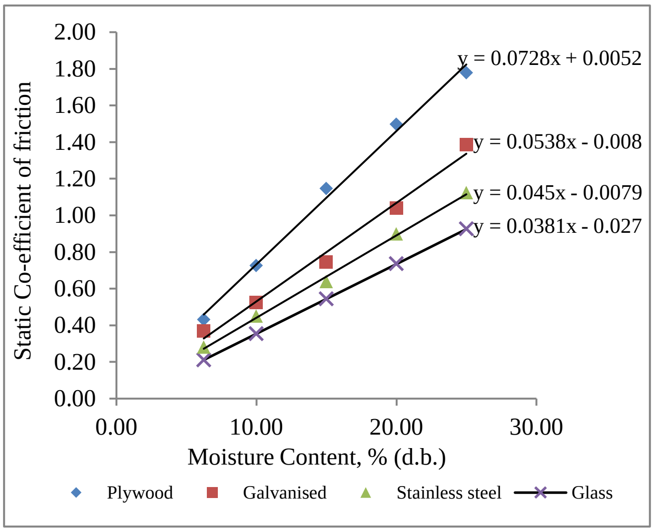

Fig. 10 Effect of moisture content on static co-efficient of friction of shea kernel

Regression analysis were used to obtain the relationships between moisture content (Mc) and variations of static co-efficient of friction on plywood (µsSkply), galvanise steel (µsSkGalSt), stainless steel (µsSkSSt) 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

Parameter	Mathematical Model	Coefficient of determination (R^2)
Plywood	µplywood = 0.0728Mc + 0.0052	0.9943
Galvanise steel	µgalsteel= 0.0538Mc - 0.008	0.9882
Stainless steel	µstainless= 0.045Mc- 0.0079	0.9977
Glass	µglass = 0.0381Mc - 0.027	1.000

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

Authors wish to thank Mr. Sebastian Achibase and Emmanuel Kwarafoge both of the Department of Agricultural Engineering, Bolgatanga Polytechnic for their assistance during the laboratory experiments.

VI. REFERENCES

[1] Maydell H., von.(1990). *Butyrospermum parkii* (G.Don) Kotschy 202-207. Trees and shrubs of the Sahel: Their characteristics and uses. English text revised J. Brase. Eschborn, Germany: Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ).

[2] Maranz, S. and Weisman, Z. (2003). Evidence of indigenous selection and distribution of the shea trees (*Vitellaria paradoxa*) and is important significance to prevailing parkland savanna tree patterns in Sub Saharan Africa north of equator. *Journal of Biogeography 30: 1505-1516.*

[3] Afonso Junior P. C., (2001). Aspectos físicos, fisiológicose de qualidade do café em função da secageme do armazenamento (Coffee physical, physiological aspects and coffee quality in function of drying and storage). Doctorate Thesis in Agricultural Engineering, Agricultural Engineering Department, Federal University of Viçosa, Viçosa, MG, Brazil. 351.

[4] Ghadge P. N., Vairagar, P. R. and Prasad K (2008a). Some physical properties of chickpea split (*Cicer Aretino* L.). *Agricultural Engineering International: the CIGR Ejournal.* Manuscript FP 07 039 6:1-9

[5] 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.

[6] Bart-Plange A., Addo, A., Akowuah, J. O. and Ampah, J. (2012). Some moisture dependent compressive properties of shea kernel (*Vitellaria paradoxa* L). *Canadian Journal of Pure and Applied Sciences* 6(3):2113-2119.

[7] Seweh E.A., S. Apuri, I. G. Dukuh and I. Osei Tutu (2015). Some Engineering Properties of Shea kernel in Ghana, *International Journal of Scientific & Engineering Research*, 6 (8):1717-1727.

[8] Seweh E. A., S., Apuri, I. G. Dukuh and I. Osei Tutu (2015b). Comparative Study of Some Engineering Properties of Shea Kernel from Different Ecological Zones of Ghana, *International Journal of Scientific & Engineering Research*, 6 (9):1686-1693.

[9] AOAC. (1984). Official methods of analysis. 14th edition. Association of Official Analytical Chemists, Washington D.C.

[10] Balasubramanian S., and Viswanathan, R. (2010). Influence of moisture content on physical properties of minor millets. Journal of Food Science and Technology. 47(3): 279–284.

[11] Davies R. M., and El-Okene A.M. (2009). Moisture-dependent physical of Soybeans. *International. Agrophysics*, 23: 299-303.

[12] Singh K. K., and Goswami, T. K. (1996). Physical properties of cumin seed. *Journal of Agricultural Engineering Research (*64): 93-98.

[13] Galedar M.N., Jafari, A.and Tabatabaeefa, A. (2008). Some physical properties of wild pistachio nut and kernel as a function of moisture content. *Journal of Physics and Environmental and Agricultural Sciences* 22: 117-124.

[14] Mohsenin N. N., (1980). Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York. 51-87.

[15] Koocheki A., S.M.A. Razavi, E. Milani, T.M. Moghadan, M. Abedini, Alamatiyan, S. and Izadikhah, S. (2007). Physical properties of watermelon seed as a function of moisture content and variety. *International Agrophysics* 21: 349-359.

[16] Maduako J.N., and. Faborode, M. O. (1990). Some physical properties of cocoa pods in relation to primary processing. *Ife Journal of Technology*, 2: 1-7.

[17] Arthur M. A., (2009). Moisture-Dependent Physical Properties of Cowpea. Unpublished B.Sc. Thesis, Department of Agricultural and Environmental Engineering, Niger Delta University, Bayelsa State. 64pp.

[18] Stroshine, R. (1998). Physical Properties of Agricultural Materials and Food Products. Course Manual, Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, Indiana.

[19] Kaleemullah, S. and Gunasekar, J.J. (2002). Moisture dependent physical properties of arecanut kernels. *Biosystems. Engineering.* 52:331-338.

[20] Davies R. M, & Zibokere D S. (2011). Effect of moisture content on some physical and mechanical properties of three varieties of cowpea (*Vigna unguiculata* (L) Walp*). Agricultural Engineering International: CIGR Journal*, Manuscript No.1700. Vol. 13(1):1-16.

[21] Ampah J., Bart-Plange, A. and Dzisi, K. A. (2012). Effect of rewetting on selected physical properties of ‘Asontem’ cowpea variety, *ARPN Journal of Engineering and Applied Sciences* 7 (4): 389-395.

[22] Tavakoli H., Rajabipour A. and Mohtasebi S. S. (2009). Moisture-dependent some engineering properties of Soybean Grains”. *Agricultural Engineering International: the CIGR Ejournal.* Manuscript 1110. Vol. 11(2):1-14.

[23] Deshpande S. D., Bal S. and Ojha T. P. 1993. Physical properties of soybean. *Journal of Agricultural Engineering Research*. (56): 89-98.

[24] Altuntas E. and Yildiz M. (2007). Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. Journal of Food Engineering, 78: 174-183.

[25] Sayed H. P., Fatemeh R. A. Iraj B. and Mohammad R. A. (2011). Effect of moisture content on some engineering properties of peanut varieties. *Journal of Food, Agriculture & Environment* 9 (3&4): 326-331.

[26] Theertha D.P., J.Alice.R.P.Sujeetha, C.V.Kavitha Abirami and K. Alagusundaram (2014). Effect of moisture content on physical and gravimetric properties of black gram (*Vigna mungo l*.) *International Journal of Advancements in Research & Technology*, 3, (3): 97-104.

[27] Wang, B., Li, D., Wang, L. J., Huang, Z. G., Zhang, L., Chen, X. D., & Mao, Z. H. (2007). Effect of moisture content on the physical properties of fibered flaxseed. Int. J. Food Eng., 3(5):1-11.

[28] Ozturk I., Kara M., Elkoca E. and Ercisli S. (2009). Physico-chemical grain properties of new common bean cv. ‘Elkoca 05’ *Scientific Research and Essay*. 4(2): 88-93.

[29] Tunde-Akintunde T.Y. and Akintunde B.O. (2007). Effect of moisture content and variety on selected properties of beniseed: *Agricultural Engineering International: CIGR E-Journal* 9: 1-13.

[30] Bart-Plange A. Addo A. and Dzisi K. A. (2006). Effects of Drying and Rewetting on Some Dimensional and Mass Properties of ‘Dorke’ Maize Variety. *Journal of Ghana Science Association.* 8(1): 89-96.

[31] Igbozulike A. O. and Aremu A. K. (2009). Moisture dependent physical properties of Garcinia kola seeds. *Journal of Agricultural Technology*. 5(2): 239-248.

[32] Gharibzahedi S. M. T., Mousavi, S. M., Moayedi A., Garavand, A. T. and Alizadeh S. M. (2010). Moisture dependent engineering properties of black cumin (*Nigella sativa* L.) seed. *Agricultural Engineering International: CIGR*. 12(1): 194－202.

[33] Mohsenin N. N., (1970). Plant and Animal Materials (physical characteristics). Gordon and Breach Science Publisher, New York. 51-83.

[34] Nimkar P. M. and Chattopadhyay, P. K. (2001). Some physical properties of green gram. *Journal of Agricultural Engineering Research* 80: 183–189.

[35] Aydin C. (2006). Some engineering properties of peanut and kernel. *Journal of Food Engineering* 79: 810–816.

[36] Özarslan C. (2002). Some physical properties of cotton seed. *Biosystems Engineering* 83: 169–174.

[37] Adejumo O. I.. Alfa, A. A. and Mohammed. A. (2007).Physical properties of Kano white variety of Bambara groundnut. *Nigerian Academic Forum* 12(1): 68-77.

[38] Al-Mahasneh M. A., and Rababah, T. M. (2007). Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering*.79: 1467–1473.

[39] Seifi M R and Alimardani R (2010) Comparison of moisture dependent physical and mechanical properties of two varieties of corn (Sc 704 and Dc 370). *Australian Journal of Agricultural Engineering* 1: 170-178.

[40] Kasap A., and Altuntaş, E. (2006). Physical properties of monogerm sugarbeet (*Beta vulgaris var. altissima*) seeds. New *Zealand Journal of Crop Horticulture Science* 34: 311–318.

[41] Pradhan R.C., S.N. Naik, N. Bhatnagar, and S.K. Swain (2008). Moisture-dependent physical properties of Karanja (*Pongamia pinnata*) kernel. Industrial Crops and Products 28(2): 155-161.

[42] Garnayak, D. K., Pradhan, R. C., Naik, S. N., & Bhatnagar, N. (2008). Moisture-dependent physical properties of Jatropha seed (*Jatropha curcas* L.). *Indian Journal of CropProducts., 27*: 123-129.

[43] Yalçin İ., C. Özarsalan, and T. Akbaş. (2007). Physical properties of pea (*Pisum sativum*) seed. *Journal of Food Engineering,* 79(2): 731-735.

[44] Altuntaş, E. and H. Demirtola (2000). Effect of moisture content on physical properties of some grain legume seeds.

[45] Baumler E., Cuniberti, A. Nolasco, S. M. and Riccobene, I. C. (2006). Moisture dependent physical and compression properties of safflower seed. *Journal of Food Engineering.* 72:134-140.

[46] Olalusi Bolaji A.P., O.T and Adebayo S.S. (2009). Some Engineering Properties of Tiger Nut. Journal of 3rd International Conference of WASAE and 9th International Conference of NIAE. 244-248.

[47] McCabe, W.L., J.C. Smith and P. Harriot, 1986. Unit Operations of Chemical Engineering. New York: McGraw-Hill.

[48] Karimi M. K., Kheiralipour, A. Tabatabaeefar, G.M. Khoubakht, M. Naderi and K. Heidarbeigi (2009). The Effect of Moisture Content on Physical Properties of Wheat, *Pakistan Journal Journal of Nutrition,* 8 (1):90-95.