

# Comparative Study of Some Engineering Properties of Shea Kernel from Different Ecological Zones of Ghana

Emmanuel Amomba Seweh, Samuel Apuri, Isaac Gibberson Dukuh, Osei Tutu Isaac

**Abstract**—The engineering properties of grains and nuts do not only differ in variety, crop to crop and moisture content, but also the growth conditions, climate and ecological zone of production. In this study, variations in engineering properties of the shea kernel in respect to ecological zone are determined. Six samples were collected from six different locations of the three regions of the north of Ghana where the crop grows. The engineering properties investigated included the geometric, gravimetric and frictional properties. The geometric properties (Length, (L), Width, (W), Thickness, (T), Arithmetic diameter, (Da), Geometric Diameter (DgM), Sphericity, ( $\epsilon$ ), Aspect ratio, (Ra), Surface area, (As), Volume, (V) for the Northern; Upper East and West regions were: (2.54±0.20cm, 1.81 ±0.14cm, 1.56 ±0.18cm, 1.92±0.12cm, 1.97±0.11cm, 71.54±6.9%, 75.82±5.18%, 11.64±1.41cm<sup>2</sup>, 3.76±0.69cm<sup>3</sup>), (2.53±0.22cm, 1.77±0.16cm, 1.58±0.15cm, 1.92± 0.13cm, 1.96 ±0.13cm, 71.15±7.42%, 77.03±4.29%, 11.97±0.92cm<sup>2</sup>, 3.92±0.45cm<sup>3</sup>) and (2.54±0.19cm, 1.80±0.14cm, 1.54±0.15cm, 1.91±0.11cm, 1.96±0.11cm, 71.15±7.42%, 75.45±4.79%, 11.52±1.26cm<sup>2</sup>, 3.70±0.61cm<sup>3</sup>) respectively. Results of the gravimetric properties (1000-kernel mass, True density, Bulk density and Porosity) for the three regions were (4110.7±686.00g, 1.20±0.09g/cm<sup>3</sup>, 0.68±0.01 g/cm<sup>3</sup>, 37.60±4.47%), (4146.87±718g, 1.11±0.01g/cm<sup>3</sup>, 0.67±0.01g/cm<sup>3</sup>, 38.61±4.62%) and (4121.4±583g, 1.13±0.16g/cm<sup>3</sup>, 0.68±0.02g/cm<sup>3</sup>, 38.52±6.99%) respectively while the frictional properties (Angle of Repose ( $\phi$ ) and static co-efficient of friction on: Glass, Plywood, Mild steel, Galvanized steel, Stainless steel) were (34.24±3.28, 0.19±0.01, 0.42±0.03, 0.41±0.02, 0.24±0.02, 0.31±0.05), (35.40±4.58, 0.15±0.02, 0.53±0.02, 0.39±0.02, 0.22±0.02, 0.28±0.01) and (34.82±3.93, 0.17±0.01, 0.43±0.01, 0.35±0.01, 0.26±0.01, 0.26±0.02) respectively. The moisture contents on dry basis (d.b) of the kernels were 6.54%, 6.48%, and 7.27% respectively. Though there were slight variations in the means of the engineering properties investigated among kernel from the different locations, they were not statistically significant when analysed with one-way Analysis of variance (ANOVA) at P<0.05. These values are similar to values obtained by some Nigerian and Cameroonian researchers. The results are therefore adequate, and can be used to design equipment and machinery to process shea kernel not only from Ghana but the entire West African shea region.

**Key words:** Aspect ratio, Engineering properties, Geometric Diameter, Shea kernel, Static co-efficient of friction, Sphericity, Surface area, Variation, Volume.

## Introduction

Shea butter is a vegetable fat obtained from the sheanut tree (*Vitellaria paradoxa*). The shea tree grows wild in twenty African countries, stretching from Senegal in the West to Ethiopia in the East. This region is known as the “Shea belt”. The Northern, Upper East and West regions of Ghana fall within this belt. Throughout the “Shea belt”, the trees are highly valued by the local communities not only for the economic and dietary value of the cooking oil, but also for the fruit pulp, bark, roots and leaves, which are used in traditional medicines [1]. The shea fruit contains one large oval to slightly round, red brown to dark brown seed, which is usually referred to as the “shea nut” [2]. The shell of this nut is shiny, smooth, and fragile. This seed comprises about 50%

of the weight of the fresh fruit, and is the part used in shea butter production [2].

Almost all agricultural materials require some degree of processing in order to add value to them. During handling and processing, agricultural materials behave differently based on their properties. The ever increasing importance of agricultural products together with the complexity of modern technology for their production, processing and storage need a better knowledge of their engineering properties so that machines, processes and handling operations can be designed for maximum efficiency and the highest quality of the final end products [3]. In Ghana, shea butter is largely processed by the traditional method, which is not only time consuming but arduous. It is

imperative to understand the properties that may affect the design of machines to handle their processing. This study was conducted to determine the variations in some engineering properties of shea kernel in Ghana in order to facilitate the design of some machines for its processing.

### Engineering applications of physical properties

The size and shape are important in the electrostatic separation grains from undesirable materials and in the development of sizing and grading machinery [4]. The study of size is essential for uniformity and packing in standard material. Shape and physical dimensions, such as length, width and thickness, unit mass, sizes of seeds determines the size of holes to permit grains to pass through. Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer during aeration and drying; they are also useful in containerization, transportation and separation systems [5]; [6]. Grains with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans. Grain densities have been of interest in breakage susceptibility and hardness studies. Density can be used to determine the difference in quality of fruits, grains and seeds. Bulk and true density of agricultural materials play an important role in drying and storage, design of silos and storage bins, separation seeds from undesirable materials, and grading [7]; [6] Porosity and surface area affect the resistance to airflow through the bulk material and help in designing dryers.

Airflow resistance affects the performance of systems designed for forced convection drying of bulk solids and aeration systems used to control the temperature of stored bulk solids. Porosity allows air and liquids to flow through a mass of particles in aeration, drying, heating and cooling operations. One thousand seed mass is useful in determining the equivalent diameter that can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces. It is also important in storage and machinery design. The theories used to predict the pressures and loads on storage structures ([8]; [6] require information on bulk density. Also the design of grain hoppers for processing machinery requires data on bulk density. This study was conducted to investigate some engineering properties of the shea kernel.

## MATERIALS AND METHOD

### Sample Selection and preparation

Fresh ripen shea fruits which have fallen off the tree were collected from six different trees and from six different high shea producer villages (Foo and Tantua, both in the Northern region, Pusunamongu and Doba in the Upper East region and Kpongo and Jonga in the Upper West region) during the peak harvesting period in June, 2015. The fruits were then de-pulped after fermentation. The resultant sheanuts were parboiled and dried. After five days sun-drying, the nuts were cracked to release the kernel. All impurities and broken kernel were removed. All samples were given the same treatment. 100 kernels each were randomly selected for the study.

### Size and shape

In the determination of axial dimensions, 100 shea kernels were randomly selected and length (L), width (W) and thickness (T) were measured using a digital caliper with a resolution of 0.01mm. The diameter was calculated by using the arithmetic means diameter (Da) and geometric mean diameter (DgM) of the three axial dimensions. The arithmetic mean diameter, (Da), and geometric mean diameter, (DgM) of the shea kernel were calculated by using equation 1 and 2 by [9]; [10] respectively while sphericity ( $\phi$ ), aspect ratio (Ra) surface area (Sa) and volume, (V) were determined using equations 3, 4, 5, and 6 by [11] [12] [13], [14] and [15] respectively were used.

$$Da = \frac{L+W+T}{3} \quad [1]$$

$$DgM = (LWX T)^{\frac{1}{3}} \quad [2]$$

$$\phi = \frac{(LWX T)^{\frac{1}{3}}}{L} \quad [3]$$

$$Ra = \frac{W}{L} \times 100 \quad [4]$$

$$As = \pi DgM^2 \quad [5]$$

$$V = \pi [LWX T] / 6 \quad [6]$$

Where: Da – arithmetic mean diameter (cm), DgM – geometric mean diameter (cm), L – length (cm), W – width (cm), T – thickness (cm);  $\phi$  – sphericity, Ra – aspect ratio, Sa – surface area and V – volume.

**1000-kernel Mass**

The 1000 kernel mass was determined using precision electronic balance to an accuracy of 0.01g. 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 10 replications.

**True density, Bulk density and Porosity**

The true density ( $\rho_t$ ) was determined as the ratio of the unit mass and unit volume of kernel and calculated using equation 7. Bulk density was also determined from equation 8. From the values of particle density ( $\rho_t$ ) and bulk density ( $\rho_b$ ), porosity was calculated from equation 9. These procedures were replicated five times and the average values recorded.

$$\rho_t = M_i/V_i \quad [7]$$

$$\rho_b = Mb/Vb \quad [8]$$

$$\varepsilon = \frac{[\rho_t - \rho_b]}{\rho_t} \times 100 \quad [9]$$

Where: ( $\rho_t$ ) – true density ( $\text{g/cm}^3$ ),  $M_i$  – mass of individual kernel (g),  $V_i$  – volume of individual kernel ( $\text{cm}^3$ ),  $\rho_b$  is the Bulk density ( $\text{g/m}^3$ ),  $Mb$  – Weight of the sample in g,  $Vb$  – Volume occupied by the sample in  $\text{cm}^3$ ,  $\varepsilon$  – porosity in (%),  $\rho_b$  – bulk density in  $\text{g/cm}^3$  and  $\rho_t$  – true density in  $\text{g/cm}^3$ .

The filling angle of repose ( $\theta_f$ ) was determined using a topless 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 and was filled with shea kernels. The cylinder was raised slowly until the kernel 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 10 by [16]; [17] while the static co-efficient of friction was determined on five structural surfaces, using the tilting plate method. Using equation 11, the tangent of the angle of internal friction or tilt ( $\theta$ ) gave the static co-efficient of friction.

$$\theta_f = \tan^{-1}[2H/D] = \tan^{-1}[2H/20] \quad [10]$$

$$\mu_s = \tan\theta \quad [11]$$

Where:  $\theta_f$  – filling angle of repose, H is the height of the heap and D is a known diameter [20cm] of the circular plate,  $\mu_s$  – static co-efficient of friction and  $\theta$  – angle of internal friction or tilt.

**Determination of Moisture Content**

The standard method of moisture determination was used to determine the moisture content of the kernel. In this method, the three different samples were put in an oven (DIN EN 60529-IP 20 Schutzart,

Germany) at 105 °C for 72 hrs. The measurements 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 [18] recommended method and using the following equation 12:

$$MCdb = [Ww - Wd]/Wd \times 100 \quad [12]$$

Where: MCdb – Moisture content (dry basis),  $Ww$  – Weight of materials before oven drying;  $Wd$  – Weight of material after oven drying.

**RESULTS AND DISCUSSION**

From table 1, the range and mean values of length of

Table 1: Summary of geometric properties of shea kernel from the different shea growing regions in Ghana.

Location	Northern Region			Upper East Region			Upper West Region		
	Min.	Max.	Mean± S.D.	Min.	Max.	Mean± S.D.	Min.	Max.	Mean± S.D.
Length, (cm)	2.595	2.602	2.54±0.20a	1.88	3.226	2.53±0.22a	1.936	3.091	2.54±0.19a
Width, (cm)	1.444	2.164	1.81±0.14b	1.001	2.280	1.77±0.16b	1.441	2.222	1.80±0.14b
Arith. Mean dia., (cm)	1.638	2.226	1.92±0.12d	1.602	2.175	1.92±0.13d	1.59	2.18	1.91±0.11d
Geo. Mean Dia, (cm)	1.699	2.287	1.97±0.11e	1.639	2.303	1.96 ±0.13e	1.616	2.225	1.96±0.11e
Sphericity, (%)	50.59	86.198	71.54±6.9f	37.198	95.519	71.15±7.42f	52.055	89.139	71.15±7.42f
Aspect ratio, (%)	65.973	88.032	75.82±5.18g	59.539	90.631	77.03±4.29g	62.077	85.242	75.45±4.79g
Surface area, (cm <sup>2</sup> )	8.43	15.564	11.64±1.41h	8.064	14.868	11.97±0.92h	7.942	14.925	11.52±1.26h
Volume, (cm <sup>3</sup> )	2.305	5.788	3.76±0.69i	1.57	5.403	3.92±0.45i	2.108	5.434	3.70±0.61i

Mean values in the same rows followed by the same letter (a-i) are not significantly different at P<0.05.

kernel from the Northern, Upper East and Upper West regions were 2.595-2.602cm and 2.54±0.20cm, 1.88-3.226cm and 2.53±0.22cm and 1.936-3.091cm and 2.54±0.19 respectively. While the corresponding values for the width and thickness were (1.444-2.164cm and 1.81±0.14cm; 1.001-2.28cm and 1.77±0.14cm, 1.441-2.222cm and 1.80±0.14cm) and (1.057-2.009cm and 1.56±0.18cm; 1.167-1.89 and 1.58±0.15, 1.21-1.54023cm and 1.54±0.15cm) respectively. Statistical analysis using one tail ANOVA revealed that at P<0.05, there was no significant differences in the axial dimensions investigated. The arithmetic mean diameter ranged between 1.638-2.226cm, 1.602-2.175cm, and 1.59-2.18 cm with mean values of 1.92±0.12 cm, 1.92±0.13 cm and 1.91±0.11cm for the Northern, Upper East and Upper West regions respectively. While for the geometric mean diameter, the mean values and ranges were 1.97±0.11cm, 1.96±0.13cm and 1.96±0.11cm and 1.699-2.287cm, 1.639-2.303cm and 1.616-2.225 cm respectively. The values suggest that kernel from the Northern and Upper East regions are marginally larger than those from the Upper West.

However, there was no significant difference in the means at P<0.05.

Sphericity ranged from 50.59-86.198%, 37.198-95.519% and 52.055-89.139% and the mean values are 71.54±6.91%, 71.15±7.42% and 71.15±7.42% for the three regions respectively. Though there is no significant differences in the means at p<0.05, the results showed marginally that, kernel from the Northern region are rounder than those from the Upper East and West regions. The aspect ratio also ranged between 65.973-88.032%, 59.539-90.631% and 62.077-85.242% with mean values of 75.82±5.18%, 77.03±4.29% and 75.45±4.79%. The results indicate that kernel from Upper East region can roll or slide in all directions more easily than those from the Northern and Upper West region. Statistically, there was no significant difference in the means. Mean values for surface area and volume were 11.64±1.41 cm<sup>2</sup>, 11.52±1.26cm<sup>2</sup>, 11.97±0.92cm<sup>2</sup> and 3.76±0.69cm<sup>3</sup>, 3.92±0.45cm<sup>3</sup>, 3.70±0.61 cm<sup>3</sup> and ranged between 8.43-15.564cm<sup>2</sup>, 8.064-14.868 cm<sup>2</sup>, 7.942-14.925cm<sup>2</sup> and 2.305-5.788cm<sup>3</sup>, 2.157-5.403cm<sup>3</sup>, 2.108-5.434cm<sup>3</sup> respectively. Kernels from the Upper West region have a higher surface area than those from the Northern and Upper East regions. The relationship drawn from this results is that, the smaller the size of the kernel, the larger the surface area. Surface area affects the velocity of air stream that can be used in

other to separate the seed from unwanted material in pneumatic separator or to convey seed in pneumatic conveying [19]. Marginally, kernel from the Upper East region had a higher volume followed by those from Northern and Upper West regions in that order. Volume of food materials and agricultural products play an important role in the design of silos and storage bins [20] Statistically, there were no differences in the surface area and volume of kernel from all the regions at P<0.05.

Summary of all gravimetric properties determined are shown in table 2. The range for the mass of 1000-kernel were 2780-6460g, 2660-5880g, 2570-5720g with mean values of 4110.7±686.00g, 4121.4±583.45g and 4146.87±718.27g for the Northern, Upper East and West regions respectively. The mean true densities of the kernel were 1.20±0.09g/cm<sup>3</sup>, 1.11±0.01g/cm<sup>3</sup>, 1.13±0.16g/cm<sup>3</sup> and ranged between 0.88-1.85g/cm<sup>3</sup>, 1.10-1.13g/cm<sup>3</sup>, and 0.83-2.14g/cm<sup>3</sup>. These values are very similar to values obtained by [21]. The values showed a slightly higher true density of kernel from the Northern region with the least from the Upper East. However, they all had values greater than that of water and so will sink in water during cleaning. The bulk density measures the weight of the produce including the inter-granular air. The mean bulk densities and ranges for the three regions were 0.68±0.01g/cm<sup>3</sup> 0.67-0.70g/cm<sup>3</sup> and, 0.67±0.01g/cm<sup>3</sup> and 0.68-0.71g/cm<sup>3</sup> and 0.68±0.02 g/cm<sup>3</sup> and 0.66-0.70g/cm<sup>3</sup> for the Northern, Upper East and West regions respectively. Porosity is an index of the degree of pore spaces within grains held in bulk. The larger the particle size, the larger the porosity. The corresponding mean values and ranges of porosity for the three regions were 37.60±4.47 and 22.66-63.10, 38.61±4.62 and 23.60-66.50, 38.52±6.99 and 17.48-51.29 respectively. The porosity values were quite large, an indication that, bulk shea kernel is very porous. Marginally, kernel from the Upper East region had a higher value followed by those from Upper West and finally, Northern region. The mean values of 1000 kernel mass, true density, bulk density and porosity were statistically indifferent at P<0.05.

Table 2: Summary of gravimetric properties of shea kernel from the different shea growing regions

Property	Northern Region			Upper East Region			Upper West Region		
	Min.	Max.	Mean±S.D.	Min.	Max.	Mean±S.D.	Min.	Max.	Mean±S.D.
1000-kernel mass, (g)	2780	6460	4110.7±686.0a	2660	5880	4146.87±718.a	2570	5720	4121.4±583a
True density, (g/cm <sup>3</sup> )	0.88	1.85	1.20±0.09b	1.10	1.13	1.11±0.01b	0.83	2.14	1.13±0.16b
Bulk density, (g/cm <sup>3</sup> )	0.67	0.70	0.68±0.01c	0.68	0.71	0.67±0.01c	0.66	0.70	0.68±0.02c
Porosity (%)	22.66	63.10	37.60±4.47d	23.6	66.50	38.61±4.62d	17.48	51.29	38.52±6.99d

Mean values in the same rows followed by the same letters (a-d) are not significantly different at P<0.05

Results of frictional properties determined are tabulated in table 3. The filling angle of repose ( $\theta_f$ ) was used to determine the angle of repose. The mean angles of repose for kernels from the three regions were  $34.24\pm 3.28^\circ$ ,  $34.82\pm 3.93^\circ$  and  $35.40\pm 4.58^\circ$  respectively and ranged between  $27.02$ - $38.66^\circ$ ,  $27.47$ - $41.99^\circ$  and  $27.25$ - $40.33^\circ$  respectively. Kernels from the Upper West region had the highest angle of repose, followed by kernels from the Upper East and finally kernel from the Northern region. This parameter is important when designing machine hoppers for grain processing. The static co-efficient of friction was determined on five structural surfaces which are mainly used in the manufacture of

It is realize that kernel from the Northern Region had the highest resistance to motion on glass ( $0.19\pm 0.01$ ) while kernel from the Upper East region had the least resistance to motion ( $0.15\pm 0.02$ ).

On plywood, kernel from the Upper East had the highest resistance to motion ( $0.53\pm 0.02$ ) while northern region had the least ( $0.42\pm 0.03$ ). On mild steel, Northern Region was highest ( $0.41\pm 0.02$ ) and Upper West was the least ( $0.35\pm 0.01$ ). On galvanise steel, kernel from the Upper West had the highest resistance ( $0.26\pm 0.01$ ) and those from Upper East had

Table 3: Summary of frictional properties of shea kernel from the different shea growing regions

Property	Northern Region			Upper East Region			Upper West Region		
	Min.	Max.	Mean±S.D.	Min.	Max.	Mean±S.D.	Min.	Max.	Mean±S.D.
Filling angle of repose (°)	27.02	38.66	34.24±3.28a	27.47	41.99	35.40±4.58a	27.25	40.33	34.82±3.93a
Co-efficient of static friction on:									
Glass	0.17	0.20	0.19±0.01b	0.12	0.17	0.15±0.02b	0.16	0.18	0.17±0.01b
Plywood	0.38	0.46	0.42±0.03c	0.51	0.55	0.53±0.02c	0.41	0.45	0.43±0.01c
Mild steel	0.38	0.42	0.41±0.02d	0.36	0.41	0.39±0.02d	0.34	0.36	0.35±0.01d
Galvanized steel	0.22	0.25	0.24±0.02e	0.19	0.24	0.22±0.02e	0.25	0.27	0.26±0.01e
Stainless steel	0.27	0.40	0.31±0.05f	0.26	0.29	0.28±0.01f	0.26	0.29	0.26±0.02f

Mean values in the same rows followed by the same letter (a-f) are not significantly different at P<0.05.

Agricultural processing equipment. They are Glass, Plywood, Mild steel, Galvanized steel and Stainless steel.

The corresponding ranges of static co-efficient of friction of the surfaces are 0.17-0.20, 0.12-0.17, 0.16-0.18; 0.38-0.46, 0.51-0.55, 0.41-0.45; 0.38-0.42, 0.36-0.41, 0.34-0.36; 0.22-0.25, 0.19-0.24, 0.25-0.27 and 0.27- 0.40, 0.26-0.29, 0.26-0.29 for the Northern, Upper East and Upper West regions respectively while the mean static coefficient of friction were  $0.19\pm 0.01$ ,  $0.17\pm 0.01$ ,  $0.15\pm 0.02$ ;  $0.43\pm 0.01$ ,  $0.53\pm 0.02$ ,  $0.42\pm 0.03$ ;  $0.41\pm 0.02$ ,  $0.35\pm 0.01$ ,  $0.39\pm 0.02$ ;  $0.24\pm 0.02$ ,  $0.22\pm 0.02$ ,  $0.26\pm 0.01$  and  $0.31\pm 0.05$ ,  $0.26\pm 0.02$ ,  $0.28\pm 0.01$  respectively.

the least resistance ( $0.22\pm 0.02$ ). On stainless steel, Northern Region had the highest static co-efficient of friction ( $0.31\pm 0.05$ ) while Upper West had the least ( $0.26\pm 0.02$ ). It is realized that the rougher the surface of the test material, the higher the static co-efficient of friction. Plywood had the highest static co-efficient of friction in all the experiments. Conversely, glass had the least static co-efficient of friction in all experiments as it had the smoothest surface. The test materials are ranked according to their resistance to motion of the contact kernel in descending order as: Plywood, mild steel, stainless steel, galvanise steel and glass.

of machinery for processing shea kernel across West Africa.

## Conclusions

The following conclusions are made after the study:

- i. The average values for the geometric properties (Length, (L), Width, (W), Thickness, (T), Arithmetic diameter, (Da), Geometric Diameter (DgM), Sphericity, ( $\epsilon$ ), Aspect ratio, (Ra), Surface area,(As), Volume, (V) for the Northern; Upper East and West regions are: (2.54±0.20cm, 1.81±0.14cm, 1.56±0.18cm 1.92±0.12cm, 1.97±0.11cm, 71.54±6.9%, 75.82±5.18%, 11.64±1.41cm<sup>2</sup>,3.76±0.69cm<sup>3</sup>), (2.53±0.22cm,1.77±0.16cm,1.58±0.15cm 1.92±0.13cm, 1.96±0.13cm, 71.15±7.42%, 77.03±4.29%,11.97±0.92cm<sup>2</sup>,3.92±0.45cm<sup>3</sup>) and (2.54±0.19cm,1.80±0.14cm, 1.54±0.15cm, 1.91±0.11cm, 1.96±0.11cm, 71.15±7.42%,75.45±4.79%, 11.52±1.26cm<sup>2</sup>,3.70±0.61cm<sup>3</sup>) respectively.
- ii. The mean values for the gravimetric properties studied (1000-kernel mass, True density, Bulk density, Porosity) are 4110.7±686.00g, 1.20±0.09g/cm<sup>3</sup>, 0.68±0.01g/cm<sup>3</sup>, 37.60±4.47%; 4146.87±718.27g, 1.11±0.01g/cm<sup>3</sup>, 0.67±0.01g/m<sup>3</sup>, 38.61±4.62% and 4121.4±583.45g, 1.13±0.16g/cm<sup>3</sup>, 0.68±0.02g/cm<sup>3</sup>, 38.52±6.99% respectively.
- iii. The results of frictional properties studied (Filling angle of repose ( $^{\circ}$ ) and Co-efficient of static friction ( $\mu_s$ ) on: Glass, Plywood, Mild steel, Galvanized steel, Stainless steel) are (34.24±3.28, 0.19±0.01, 0.42±0.03, 0.41±0.02, 0.24±0.02, 0.31±0.05), (35.40±4.58, 0.15±0.02, 0.53±0.02, 0.39±0.02, 0.22±0.02, 0.28±0.01) and 34.82±3.93, 0.17±0.01, 0.43±0.01, 0.35±0.01, 0.26±0.01, 0.26±0.02) respectively.
- iv. At a confidence level of 95%, there are no significant differences in the geometric, gravimetric and frictional properties of shea kernel from Ghana and that of the rest of the West African shea region.
- v. Results from this work are a good source of data for consideration in engineering design

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**About the authors:**

Emmanuel Amomba Seweh, Lecturer, Department of Agricultural Engineering, School of Engineering, Bolgatanga Polytechnic, Bolgatanga, Ghana,

Samuel Apuri, Lecturer, Department of Ecological Agriculture, School of Art and Applied Sciences, Bolgatanga Polytechnic, Ghana.

Isaac Gibberson Dukuh, Senior Lecturer, Department of Agricultural Engineering, School of Engineering, Bolgatanga Polytechnic, Bolgatanga, Ghana

Osei Tutu Isaac, Mphil, Student, Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana