DETERMINATION OF SOME PHYSICAL PROPERTIES OF *CANARIUM SCHWEINFURTHII ENGL* NUTS FROM NIGERIA

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ABSTRACT

Physical properties of three varieties of Canarium schweinfurthii nuts (Canarium schweinfurthii short ($CSHT_S$), Canarium schweinfurthii long ($CSHT_L$) and Canarium schweinfurthii large ($CSHT_{LRG}$)) were studied at three different moisture contents (10.20%, 17.23% and 25.06%) wet basis. The values of physical parameters studied were obtained experimentally and analyzed using ANOVA at 5% alpha level. The results showed that the principal dimensions of large nuts ranged from 32.29 - 32.91 mm (major diameter), 16.07 - 16.55 mm (intermediate diameter) and 15.69 - 16.26 mm (minor diameter). The values of sphericity, mass and density of large nuts also ranged from 0.62 – 0.63, 4.32 - 4.90 g and 1.27 – 1.21 g/cm^3 respectively. The long nuts had 36.75 - 37.36 mm (major diameter), 13.67 - 13.19 mm (intermediate diameter) and 13.18 - 12.89 mm (minor diameter). The sphericity ranged from 0.50 – 0.51, mass from 2.79 - 3.14 g and density from 1.14 – 1.07 gcm^{-3}. The major diameter of the short nuts ranged from 23.26 - 23.87 mm, intermediate diameter from 10.93 - 11.24 mm and minor diameter from 10.76 - 11.04 mm. The values of sphericity ranged from 0.60 – 0.62, mass from 1.21 - 1.43 g and density from 1.14 – 1.06 gcm^{-3}. The nuts are oblong shaped with surface areas of 336.7 mm^2, 301.55 mm^2 and 164.28 mm^2 for large, long and short varieties respectively. Moisture content had no effect on the geometric dimensions but significantly (5%) affected mass, density and surfaces area. The porosity of all the nut varieties studied decreased as moisture level increased and the density values were higher than one, hence cannot be separated by floating. Rubber surface had the highest coefficient of friction than the other material surfaces studied. All physical parameters investigated had good relationship (high R^2 values) with moisture content. These results are essential in design and development of machines and equipment for processing and handling this product.

KEYWORDS: Properties, *Canarium schweinfurthii,* Nuts, Density, Shape.

1 INTRODUCTION

Canarium schweinfurthii engl. nut is one of the by-products obtained by extracting oil from *Canarium schweifurthii engl* fruit. The tree is a forest tree crop and belongs to the family of *Burseraceae* . It is mostly grown in the equatorial forest region of East, West and Central Africa (Orwa, *et al.*, 2009) and popularly called *ubemgba* in the Eastern part of Nigeria. The spindle-like stony nuts contain edible oil that are used domestically for food and industrially to make shampoo, waxes and drugs for treatment of wounds and microbial infections (Edou, *et al.*, 2012). They are also used to make musical beads, quench mud and for decoration. Like most of shelled nuts, *Canarium schweinfurthii* engl. Nuts possess great potential for generating energy when gasified, store energy in batteries (dry cells) and as a filter in sewage plants when converted to biochar. Separation of the nut from fruit mesocarp after digestion is by hand picking while kernel extraction for oil is by cracking the nut with hammer or hard stone. These practices are injurious, promotes drudgery and, low quality and quantity of extracted oil. Producing mechanical device for handling and processing of the nuts for quality end product requires adequate knowledge of the physical behaviour of the nut. For instance, moisture content affects the mechanical behavior of agricultural product during milling and flow operation (Gharib-Zahedi *et al.*, 2010). Shape and size affect the development of shape and size of product flow channels and determine the standards for design of grading, processing and packaging systems (Tabatabaeefar, and Rajabipour 2005). The volume, solid density, bulk density, porosity and static coefficient of friction are used for design of drying and aeration, conveyors and storage systems. Information on physical properties of agricultural products helps to overcome all the challenges of local practices, reduces waste and saves material and money. Researchers have studied the physical properties of agricultural nut such as palm nut (*Tenera* and *Dura*) (Akinoso and Raji, 2011), tiger nut (Abano and Amoah, 2011), dika nut (Orhevba *et al.,* 2013), ginkgo nut (Ch'ng *et al.*, 2013), cashew nut (Bart-Plange *et al.*, 2012), pistachio nut (Peyman *et al.*, 2013) and almond nut (Aydin, 2003). Literature on physical properties of *Canarium schweifurthii* engl. nuts is lacking, hence the mass, principal dimensions, surface area, volume, true density, bulk density, porosity, sphericity, and static friction of the nuts on different types of material surfaces were examined to aid in design and development of efficient systems for their processing, handling and storage.

2 MATERIALS AND METHODS

Three varieties of *Canarium schweinfurthii* nuts (*Canarium schweinfurthii short* ($CSHT_S$), *Canarium schweinfurthii long* ($CSHT_L$) and *Canarium schweinfurthii large* ($CSHT_{LRG}$)) used for this study were sourced from Ebonyi State (6º 15' N 8º 05' E) of Nigeria. The experiment was conducted in the Bioresources Engineering Department of McGill University, Macdonald campus, Canada. The nuts were extracted from the fruits after soaking the fresh fruits in warm water of 50 ^{o}C for 20 minutes. They were conditioned to three different moisture contents using oven dry method at 105 ^{o}C. Moisture content (wet basis) was determined as in Equation 1 (Jahanbakhshi, 2018):

$$M.C_{wb} = \frac{M_1 - M_2}{M_1} \; x \; 100 \qquad (1)$$

where:
$M.C._{wb}$ = moisture content wet basis,
M_1 = initial mass (g) and
M_2 = final mass (g) of the product.

2.1 Size and shape

Three characteristic dimensions; major, intermediate and minor diameters were used to determine the size and shape of the nuts as in Equations 2 - 6 (Ehiem and Simonyan, 2012; Kara, *et al.,* 2013):

$$GMD = \sqrt[3]{abc} \qquad (2)$$

$$Sphericity = \frac{\sqrt[3]{abc}}{a} \quad (3)$$

$$A.R = \frac{a}{b} \quad (4)$$

$$DES = \left(\frac{M}{\rho_s} \; x \; \frac{6}{\pi}\right)^{\frac{1}{3}} \quad (5)$$

$$RR = \frac{a}{\sqrt{bc}} \quad (6)$$

where:

a = major diameter, b = intermediate diameter,
c = minor diameter, GMD = geometric mean diameter,
A.R. = aspect ratio, RR = roundness ratio,
DES = diameter of equivalent sphere,
ρ_s= sample density, M = mass of sample

2.2 *Volume and solid density*

Volume measures the amount of space a given object or gas occupies. The volume of the nuts was determined using Equation 7 as (Kara *et al.*, 2013):

$$Volume = \frac{\pi abc}{6} \quad (cm^3) \quad (7)$$

where:

a, b and c are the principal dimensions described above.

Solid density is the ratio of mass to the volume of the product. It was determined as in Equation 8**:**

$$\boldsymbol{\rho_p} = \frac{\boldsymbol{m}}{\boldsymbol{v}} \quad (8)$$

where:

m = mass ofthe fruit in air (g)
v = volume of the fruit (cm^3)

2.3 Bulk density

Bulk density is the ratio of weight of the material to the volume of the container it occupies. It was also determined as in Equation 9 (Bhise *et al.*, 2013).

$$\rho_b = \frac{m}{v_c} \quad (9)$$

where:

ρ_s = bulk density (gcm^{-3}),
m = mass of the product (g),
V_c = volume of the container (cm^3)

2.4 Porosity
Porosity was expressed as the percentage void of the products in a bulk packed bed as in Equation 10 (Jithender *et al.*, 2017).

$$\epsilon = 1 - \frac{\rho_b}{\rho_p} x\ 100 \qquad (10)$$

where:

$\varepsilon = porosity,$
$\rho_b = bulk\ density$ (gcm^{-3}),
$\rho_p = particle\ density$ (gcm^{-3})

2.5 Surface area
This measures the total area that the surface of a given object occupies. It affects heat processing, packaging and spray coverage of agricultural products. Surface area was determined as in Equation 11(Sirisomboon *et al.*, 2007):

$$S_s = \frac{\pi d^2}{4} \qquad (11)$$

where:

d = diameter of the nut (cm)

2.6 Specific surface area
Specific surface area, S_s, (mm^2/cm^3) of nuts was determined as in Equation 12 (Sirisomboon *et al.*, 2007):

$$S_s = \frac{A_{surface}\ x\ \rho_b}{m} \qquad (12)$$

where:

m = mass (g) of unit nut.

2.8 Angle of repose
The internal angle between the surface of the nut pile and the horizontal surface was determined as described by (Hibbeler, 2007), Equation 13 – 14.

$$\mu = \frac{h}{x} \qquad (13)$$
$$\theta = tan^{-1}\,\mu \qquad (14)$$

where:

h = height of sample pile;
x = horizontal surface;
μ = coefficient of friction;
θ = angle of repose

The collected data were subjected to analysis of variance (ANOVA) using excel statistical package at 5% level of significance to show the effect of moisture content on the physical properties of the nut.

3 RESULTS AND DISCUSSION

3.1 Effect of moisture content on the principal dimensions of the nuts

Major, intermediate and minor diameters of *Canarium schweinfurthii* engl. nut varieties increased as moisture content increased from *10.20% - 25.06% wet basis* Table 1. Major, intermediate and minor diameters of the nuts increased by 1.88%, 2.90% and 3.51% respectively for $CSHT_{LRG}$, 1.63%, 3.51% and 2.20% respectively for $CSHT_L$ and 2.56%, 2.76% and 2.54% respectively for $CSHT_S$ variety. Low percentages observed in all the varieties showed that moisture content had no effect ($p<0.05$) on the principal dimensions of the nut while the differences between the varieties are significant ($p < 0.05$) as shown in Table 2. This means that the particles of the nuts are relatively not elastic. Normal distribution of the principal dimensions showed in Figure 1a-c revealed that the data concentrated about the mean for all the varieties studied. Regression equation representing the relationship between moisture content and principal dimensions are presented in Table 3 with high coefficient of determination.

Table 1: Measured physical properties of the nuts at the moisture range 10.20% - 25.06% wet basis

Moisture content (wet basis)	Physical properties	Large	Long	Short
10.20%	a mm	32.29 ± 0.88	36.75 ± 1.27	23.26 ±0.92
	b mm	16.07 ± 0.64	13.67 ± 0.46	10.93 ± 0.38
	c mm	15.69 ± 0.59	13.18 ± 0.39	10.76 ± 0.35
	Mass (g)	4.32 ± 0.35	2.79 ± 0.19)	1.21 ± 0.14
	Volume (cm^3)	3.67 ± 0.37	2.46 ± 0.19	1.07 ± 0.13
17.23%	a mm	32.66 ± 0.96	36.91 ± 1.73	23.59 ± 0.89
	b mm	16.25 ± 0.69	13.26 ± 0.37	11.18 ± 0.45
	c mm	16.45 ± 0.64	12.99 ± 0.36	10.98 ± 0.42
	Mass (g)	4.53 ± 0.37	2.86 ± 0.24	1.27 ± 0.14
	Volume (cm^3)	4.02 ± 0.42	2.61 ± 0.16	1.15 ± 0.11
25.06%	a mm	32.91 ± 0.90	37.36 ± 1.27	23.87 ± 0.92
	b mm	16.55 ± 0.64	13.19 ± 0.45	11.24 ± 0.45
	c mm	16.26 ± 0.62	12.89 ± 0.39	11.04 ± 0.43
	Mass (g)	4.90 ± 0.40	3.14 ± 0.23	1.43 ± 0.15
	Volume (cm^3)	4.55 ± 0.55	2.95 ± 0.28	1.33 ± 0.11

a mm = major diameter. b mm = intermediate diameter. c mm = minor diameter

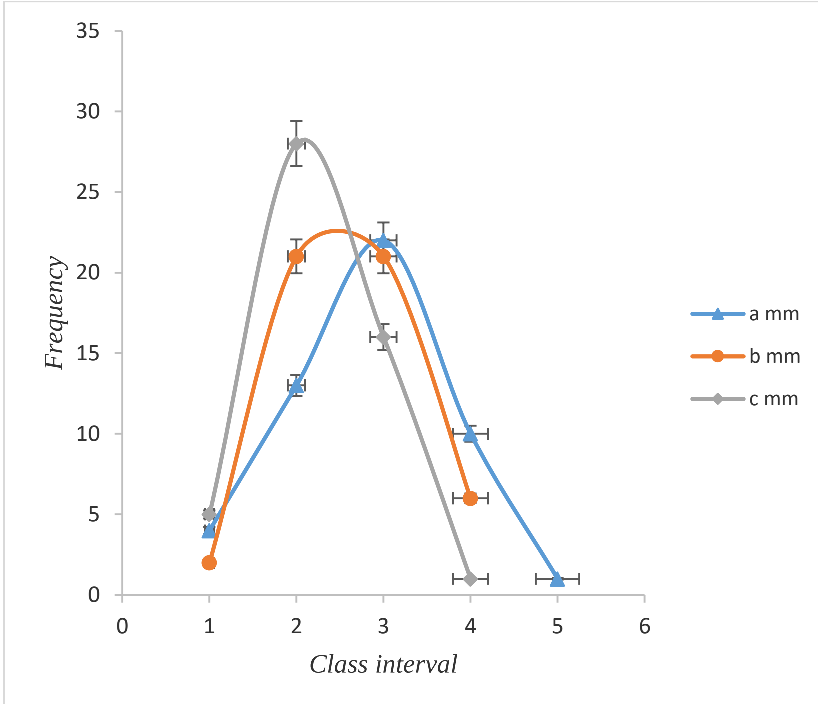
Table 2: ANOVA summary of physical parameters of *Canarium schweifurthii* nuts at moisture range of *10.2% - 25.06% wet basis* %

Source of variation	df	a (mm)	b (mm)	c (mm)	Mass (g)	GMD	Sphericity	Volume	Density	Bulk density	S. Area	5%
Samples	2	34091.78**	465.36**	28.81*	8.81*	531.01**	807.72**	255.99**	16.32*	58571.15**	1926.61**	6.94
Moisture content	2	0.6775ns	1.11ns	1.35ns	572.55**	3.30ns	0.0559ns	9.19*	13.59*	11326.73**	10.77*	6.94
Error	4	0.0165	0.1767	3.95	0.0591	0.2451	6.1E-05	0.0984	0.0018	317.51	54.67	

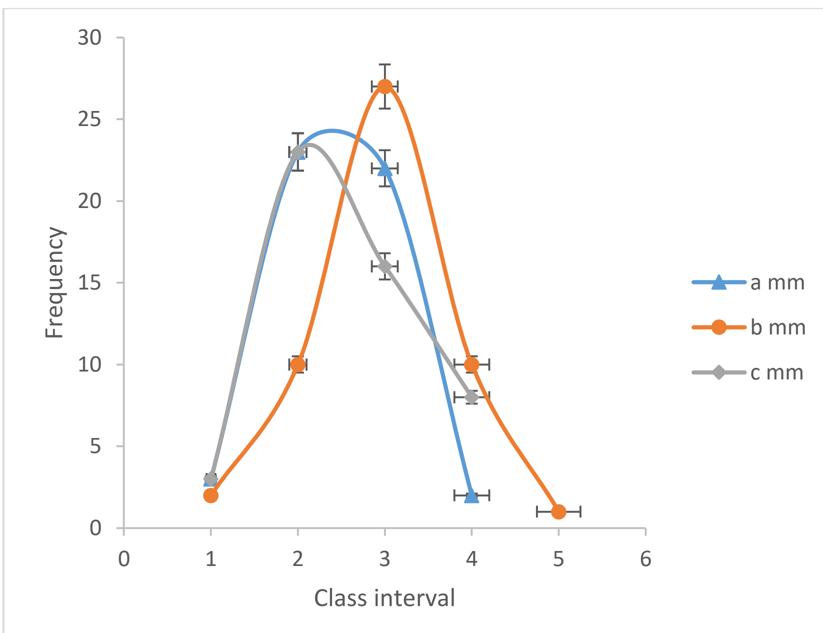
*ns = not significant, ** = highly significant, * = significant*

Tables 3: Equations representing relationship between physical parameters and moisture content wet basis

Physical Parameters	Large		Long		Short	
	Regression	R^2	Regression	R^2	Regression	R^2
a	*0.0413h +31.89*	*0.98*	*0.0412h + 36.29*	*0.94*	*0.0407h + 22.86*	*0.99*
b	*0.0291h + 15.84*	*0.83*	*0.0321h + 12.81*	*0.87*	*0.3475ln(h) + 10.15*	*0.93*
c	*0.2299h + 12.98*	*0.89*	*0.0249h + 12.56*	*0.99*	*0.3216ln(h) + 10.03*	*0.96*
Mass	*0.0455h + 3.86*	*0.99*	*0.0233h + 2.52*	*0.92*	*15.29ln(h) – 32.82*	*0.83*
GMD	*0.0379h + 19.80*	*0.85*	*0.0312h + 18.06*	*0.93*	*0.4214ln(h) + 13.02*	*0.98*
Sphericity	*0.0004h + 0.6213*	*0.48*	*0.0003h + 0.4983*	*0.94*	*0.0021ln(h) + 0.5978*	*0.64*
Volume	*0.0592h + 3.04*	*0.99*	*0.0329h + 2.09*	*0.96*	*0.0177h + 0.8696*	*0.97*
Density	*-0.0092h + 1.35*	*0.97*	*-0.0047 + 1.19*	*0.99*	*-0.0040h +1.18*	*0.99*
Surfaces Area	*1.24h + 326.35*	*0.87*	*0.9729h + 290.42*	*0.93*	*0.5937h + 158.90*	*0.94*
Bulk density	*13.33h + 590.99*	*0.91*	*11.39h + 541.18*	*0.91*	*13.24h + 571.29*	*0.89*

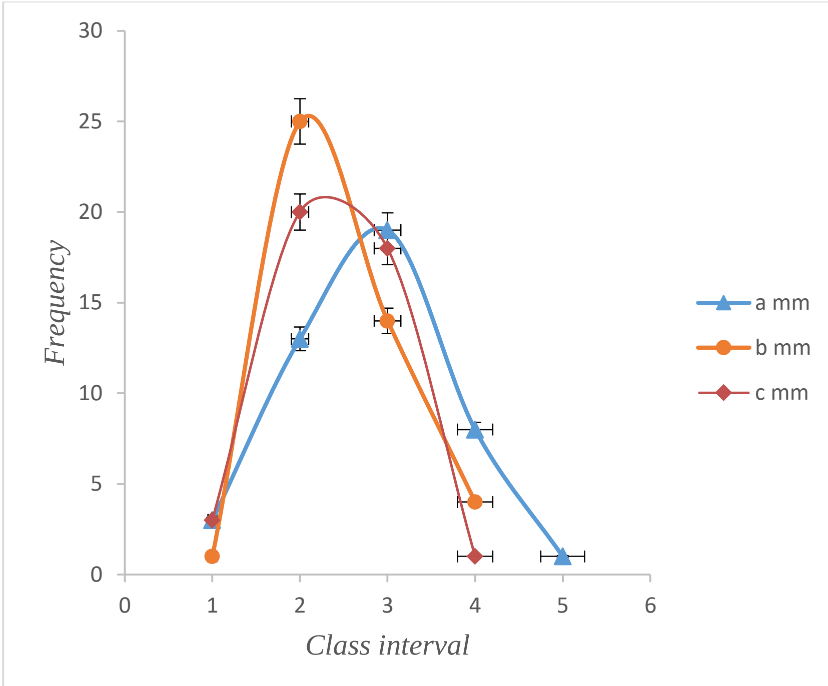


(a)



(b)

Figure 1a: Normal distribution of principal dimensions of *Canarium schweifurthii (a) large*, and *(b) long* varieties.



(c)

Figure 1b: Normal distribution of principal dimensions of *Canarium schweifurthii (c) Short* nut varieties.

3.2 Effect of moisture content on the shape of Canarium schweifurthii engl. nut

The diameter of equivalent sphere (DES), aspect ratio (AR), sphericity and roundness ration (RR) of the nuts at 10.20% moisture content wet basis ranged from 1.75 - 2.16, 1.77 – 2.18, 1.29 – 2.02 and 59% - 68% respectively for $CSHT_{LRG}$; 2.80 – 3.08, 2.8 – 3.09, 1.69 – 1.88 and 47% - 53% respectively for $CSHT_{L}$ and 1.88 – 2.28, 1.88 – 2.32, 1.20 – 1.45 and 57% - 66% respectively for $CSHT_{S}$ variety. The mean values of shape parameters shown in Table 4 reveal that AR of all the varieties are within the range for oblong shape (1.85 – 2.31) as classified by (Şehrali, 1988; Kara et al., 2013). The values of RR and DES (above one) and, sphericity being slightly higher than 50% confirmed the shape. *Canarium schweinfurhii* engl nuts had similar shape with Aras-98, Elkoca-05, Noyanbey-98 and Yakutiye-98 bean cultivars as reported by (Kara *et al.*, 2013) while Tenera and Dura palm nuts are ovate in shape (Akinoso and Raji, 2011), The sphericity of $CSHT_{LRG}$ and RR of $CSHT_{S}$ increased as moisture content increased from 10.20 – 25.06% wet basis while DES and AR of $CSHT_{LRG}$ and $CSHT_{L}$ decreased. All the shape parameters for $CSHT_{S}$ had non-linear relationship with moisture content except RR.

3.3 Effect of moisture content on the mass and volume

Mass and volume of the nut varieties increased by 11.54% and 19.34%, for $CSHT_{LRG}$, 12.10% and 16.61% for $CSHT_{L}$ and, 15.38% and 19.55% for $CSHT_{S}$ varieties as moisture content increased from 10.2% - 25.06% wet basis (Table 1). Moisture content and variety significantly ($p < 0.05$) affected mass and volume of the nuts (Table 2). Increase in mass and volume of dika nut and palm nut were reported by (Unuigbe *et al.*, 2013; Akinoso and Raji, 2011) respectively at moisture range of 8.25% - 18.98% dry basis and 5% - 11% wet basis respectively. Mass and volume of the nuts can be predicted using the regression equations shown in Table 3.

Table 4: Mean and standard deviation of shape parameters at moisture range 10.20 – 25.06% wet basis

Varieties	MC (%)	GMD	DES	Aspect Ratio	Sphericity	Roundness Ratio
	10.20	20.11 ± 0.55	1.88 ± 0.04	2.01 ± 0.03	0.62 ± 0.02	2.04 ± 0.16
CSHT$_{LFG}$	17.23	20.59 ± 0.59	1.99 ± 0.09	1.98 ± 0.09	0.63 ± 0.07	1.96 ± 0.11
	25.06	20.68 ± 0.57	1.99 ± 0.02	1.98 ± 0.01	0.63 ± 0.03	2.01 ± 0.13
`	10.20	18.73 ± 0.39	1.67 ± 0.06	2.79 ± 0.09	0.51 ± 0.01	2.82 ± 0.11
CSHT$_L$	17.23	18.52 ± 0.53	1.71 ± 0.12	2.77 ± 0.13	0.50 ± 0.02	2.80 ± 0.14
	25.06	18.89 ± 0.52	1.78 ± 0.09	2.74 ± 0.09	0.51 ± 0.01	2.78 ± 0.13
	10.20	13.93 ± 0.43	1.27 ± 0.09	2.13 ± 0.09	0.60 ± 0.02	2.15 ± 0.03
CSHT$_S$	17.23	14.25 ± 0.47	2.80 ± 0.13	2.77 ± 0.12	0.61 ± 0.02	1.71 ± 0.04
	25.06	14.36 ± 0.48	2.78 ± 0.08	2.74 ± 0.09	0.60 ± 0.02	1.78 ± 0.04

M.C. = moisture content wet basis; GMD =geometric mean diameter; DES = diameter of equivalent sphere,

3.4 Effect of moisture content on the surface area of the nuts

The mean value of surface area of the nuts shown in Table 5 revealed that surface area had linear relationship with moisture content. Akinoso and Raji (2011) observed the same trend with *Tenera* and *Dura* nuts (palm nut varieties). As expected, the surface area of CSHT$_{LRG}$ variety is higher followed by CSHT$_L$ and CSHT$_S$ varieties. Both moisture content and variety had significant effect (5%) on the surface area of the nuts. Regression equations for surface area is shown in Table 3 with low R^2 for large and high values for long and short indicating good fits.

Table 5: Calculated physical properties of the nuts at the moisture range 10.2% - 25.06% wet basis

Moisture content (wet basis)	Physical properties	Large	Long	Short
	GMD	20.11 ± 0.55	18.73 ± 0.39	13.93 ± 0.43
	Area	336.7 ± 17.22	301.55 ± 30.59	164.28 ± 10.19
	Density	1.27 ± 0.38	1.14 ± 0.09	1.14 ± 0.08
10.20%				
	Bulk density	708.23 ± 2.45	641.50 ± 12.08	685.91 ± 9.98
	Porosity	0.4423 ± 0.31	0.4373 ± 0.23	0.3983 ± 0.08
	GMD	20.59 ± 0.59	18.52 ± 0.53	14.25 ± 0.47
	Area	351.83 ± 18.98	304.88 ± 18.54	170.41 ± 10.96
	Density	1.19 ± 0.09	1.10 ± 0.07	1.11 ± 0.06
17.23%	Bulk density	856.22 ± 10.7	767..83 ± 12.95	838.12 ± 5.39
	Porosity	0.2805 ± 0.43	0.3019 ± 0.18	0.2449 ± 0.49
	GMD	20.68 ± 0.57	18.89 ± 0.52	14.36 ± 0.48
	Area	355.36 ± 18.28	315.89 ± 17.54	173.18 ± 11.45
	Density	1.21 ± 0.11	1.07 ± 0.05	1.08 ± 0.01
	Bulk density	908.23 ± 7.20	812 95 ± 7.79	884.71 ± 18.09
25.06%	Porosity	0.2494 ± 0.25	0.2406 ± 0.61	0.1808 ± 0.32

Area = mm^2, density and bulk density = gcm^{-3} GMD = mm

3.5 Moisture effect on the density, bulk density and porosity of the nut

Density and porosity decreased with increase in moisture content for all the varieties studied while bulk density increased with increase in moisture content, Table 5. This observation followed the findings of (Unuigbe *et al.,* 2007; Simoyan *et al.,* 2007) for dika nut and samara sorghum 17 grains, but showed contrary trend to the report of Simonyan *et al*. (2009) for *lablab purpureus (L)* sweet seeds and porosity of chick pea seeds. The increase in bulk density with increase in moisture content could be because the particle of the nuts are inelastic and tightly packed hence water absorbed by the nut only occupy the void space given rise to only the mass while the volume is relatively not affected. The density of all the nut varieties for all the moisture contents studied are higher than that of water hence, floating cannot be used as a method of separating it from heavier materials. The relation of density, bulk density and moisture content is presented in Table 3 with high R^2 value showing good fit.

3.6 The moisture effect on the friction of the nut on material surfaces

The angle of friction of the nuts with different material surfaces increased as moisture content increase from *10.2% - 25.06% wet basis* (Fig. 2a –c). Gezer *et al*. (2002); Isik (2007); Seifi, and Alimardani, (2010) have reported the same trend for apricot pit, round red Lentil grains, corn (Sc 704). Among five surfaces studied, acrylic plastic had the least friction angle and rubber had the highest for all the varieties studied. Ginkgo nut has also manifested the highest value of friction with rubber material than other material surfaces (Unuigbe *et al.,* 2013). The reason is because acrylic plastic has finer (smoother) grain surface while rubber had higher adhesive property than other materials. This means that rubber would produce more frictional resistance to the movement of the nuts than other surfaces. This observation is not in agreement with the report of (Bart-Plange *et al.,* 2007) for maize, cowpea and groundnut on rubber material. Varnamkhasti (2007) also reported that plywood had the highest angle of friction among other material surfaces (galvanized iron and glass) investigated. Low values of angle of friction together with low sphericity observed indicate that the nuts cannot roll and do not require agitator to slide. The difference between the angles of friction of various surfaces are significant ($p < 0.05$) except between acrylic plastic and galvanized iron sheet.

4 CONCLUSIONS

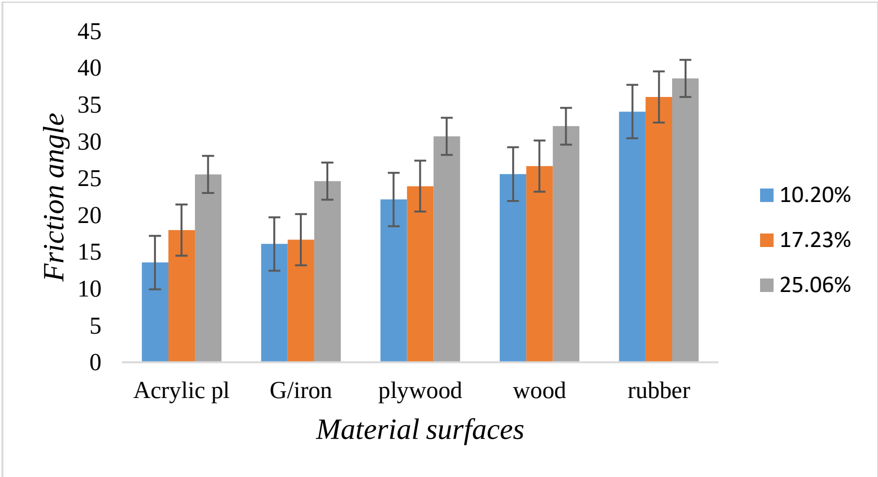
From this study, it can be concluded that:

i. The major, intermediate and minor diameters of the nut ranged from 32.29 - 32.91 mm, 16.07 - 16.55 mm and 15.69 - 16.26 mm, respectively for large; 36.75 - 37.36 mm, 13.67 - 13.19 mm, 13.18 - 12.89 mm, respectively for long and 23.26 - 23.87 mm, 10.93 - 11.24 mm, 10.76 - 11.04 mm, respectively for short variety as moisture content increased from 10.20%, - 25.06% wet basis.

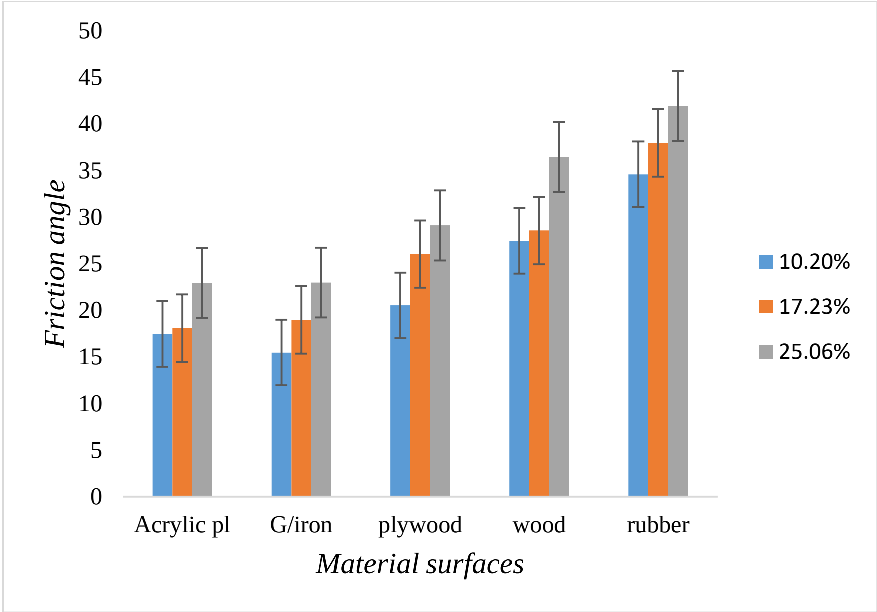
ii. The mean values of sphericity, mass and density of the nut also ranged from 0.62 – 0.63, 4.32 - 4.90 g and 1.27 – 1.21 gcm^{-3} respectively for large; and 0.50 – 0.51, 2.79 - 3.14 g and 1.14 – 1.07 gcm^{-3} respectively for long and 0.60, 1.21 - 1.43 g and 1.14 – 1.06 gcm^{-3} respectively for short variety as moisture content increased from 10.20%, - 25.06% wet basis.

iii. The principal dimensions of the nuts differ significantly ($p<0.05$) from each other and had no significant relationship with moisture content.

iv. The nut of all the varieties are oblong in shape with mean surface areas of 336.7 mm^2, 301.55 mm^2 and 164.28 mm^2 for large, long and short varieties respectively.
v. The nuts are also denser than water hence cannot be separated by floating.
vi. Rubber surface had the highest coefficient of friction than the other material surfaces studied and should not be considered during design of the handling equipment for the nuts.

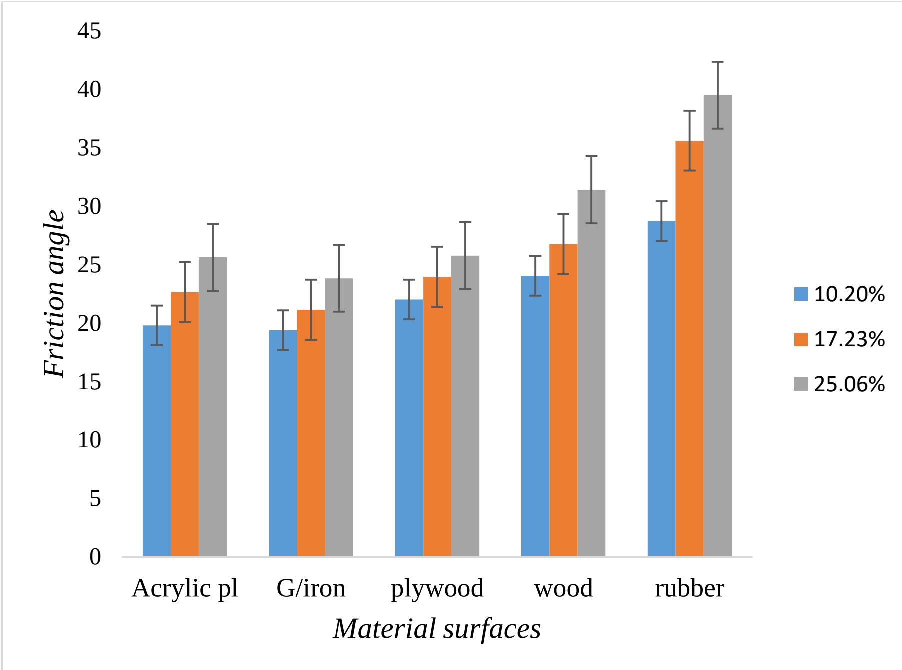


(a)



(b)

Figure 2: Frictional angle of *Canarium schweifurthii* (a) large and (b) long short varieties on various material surfaces



(c)

Figure 2b: Frictional angle of *Canarium schweifurthii* (c) short varieties on various material surfaces

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