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Effect of moisture content on some physical properties of *Canarium schweinfurthii* Engl. fruits

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Abstract

Ehiem J.C., Ndirika V.I.O., Onwuka U.N. (2016): **Effect of moisture content on some physical properties of *Canarium schweinfurthii* Engl. fruits**. Res. Agr. Eng., 62: 162–169.

The effect of moisture content on some physical properties of three varieties of *Canarium schweinfurthii* Engl. fruits (small, large and long) was studied at 40.91%, 34.92%, 23.44%, 18.5% and 11.03% moisture content on wet basis in order to solve problems associated with designing and development of processing and handling equipment for these fruits. The physical parameters investigated were major, intermediate, minor diameters, geometric mean diameter, unit mass, volume, sphericity, density, bulk density, roundness, aspect ratio, porosity, surface and specific surface area. The results obtained showed that the physical parameters decreased linearly with a decrease in moisture content. Major diameter and true density of all the fruit varieties were not affected significantly ($P < 0.05$) by moisture content. *Canarium schweinfurthii* Engl. fruits are not round but spherical and oblong, hence, they can rather roll than slide. Among the studied varieties, small *Canarium schweinfurthii* Engl. is less bulky, has the highest specific surface area and is more porous.

Keywords: sphericity; area; density; porosity; variety

Canarium schweinfurthii Engl. tree is one of the economic tree crops that belong to the family of *Burseraceae* and popularly is called "ube mgba" in Igbo and "elemi" in Hausa land. The English name is African bush candle. It is grown widely in the equatorial forest regions of East, West and Central Africa (Orwa et al. 2009). In Nigeria, it is mostly grown in the southeast part of the country. The tree produces edible fruits that contain 20.43% crude protein, 23% crude fat, 0.75% crude fibre, 20.10% carbohydrate, 11.8% cellulose and 3.25% ash (Onimawo, Adukwu 2003). The fruits are eaten fresh or boiled. Edou et al. (2012) reported that the fruit pulp and kernel contain about 30% to 50% oil, which are used industrially for the manufacturing of shampoo and waxes and, pharmaceutically to produce drugs for treatment of wounds and microbial infections. Olawale (2012) also reported that the extraction of oils from elemi pulp and kernel is not being carried out at commercial level at present, despite the availability of the fruit in large quantity in Nigeria and elsewhere in Sub-Saharan Africa. This situation would improve if data needed for the design and operation of the oils' extraction plants were available. In handling and processing agricultural products, some fundamental information about their characteristics is essentially needed. This information can be obtained through the knowledge of engineering properties of the products, which constitutes essential engineering data in designing modern technology for their production, handling, processing, storage, preservation, quality

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evaluation, distribution and marketing and utilization. Engineering properties of agricultural product is profitably used for planting, harvesting, drying and storage. It improves working efficiency of processing equipment, reduces losses and waste of constructional materials. It also saves time and money, offer ways in which products can be utilized effectively and helps to maintain quality even in adverse storage and handling conditions. Literature reveals that several studies have been carried out on engineering properties of different agricultural products; millet (*Pennisetum glaucum* L.) (Ndirika, Oyeleke 2006), *Lablab purpureus* L. (Simonyan et al. 2009), *Jatropha curcas* L. fruit, nut and kernel (Sirisomboon et al. (2007), *Jathropha curcas* L. seed (Kabutey et al. 2011). Despite all these studies and numerous economic values of *Canarium schweinfurthii* fruits, no work has been published on the post-harvest physical properties of *Canarium schweinfurthii* Engl. fruits. The aim of this study therefore was to investigate the effect of moisture content on some physical properties of *Canarium schweinfurthii* Engl. fruits, like principal dimensions, unit mass, volume, sphericity, density, bulk density, roundness, aspect ratio, porosity, surface and specific surface area which will be useful in designing and developing processing and handling equipment for this fruits.

MATERIAL AND METHODS

Three varieties of *Canarium schweinfurthii* Engl. fruits (small, large and long size ($CSHT_S$, $CSHT_L$ and $CSHT_{LG,}$ respectively)) used for this investigation were sourced from Ebonyi (6°15'N 8°05'E) state of Nigeria. They were cleaned and initial moisture content of the fruits was attained by keeping the fruits in refrigerator at 0°C for 24 hours. Other moisture levels were attained by exposing the fruits to environmental temperature and measurement taken at two-days interval. Moisture content was determined as:

$$MC_{\text{wb}} = \frac{w_1 - w_2}{w_1} \times 100 \quad (1)$$

where:
MC_{wb} – moisture content wet basis; w_1, w_2 – initial weight and final weight, respectively

For each of the moisture contents obtained, the principal dimensions (major (a), intermediate (b) and minor diameters (c)) of 50 samples were measured using the digital vernier caliper (JIS7502; Mitutoyo, Aurora, USA) of 0.01mm accuracy while the weight of individual fruit was measured using the electronic weighing balance (FEJ-300; Fuzhou Furi Electronic, Ltd., Fuzhou, China) with sensitivity of 0.01g. Geometric mean diameter (GMD), sphericity, arithmetic mean diameter (AMD) and aspect ratio were calculated as shown in Eqs (2–5), Ndirika and Oyeleke (2006); Ehiem and Simonyan (2012):

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

$$Sphericity = GMD/a \quad (3)$$

$$AMD = (a + b + c)/3 \quad (4)$$

$$Aspect\ ratio = b/a \quad (5)$$

Roundness was obtained by tracing each fruit in its rest position on a transparent paper using a sharp pencil. The radius of the sharpest corner and the circumscribed circle were measured and roundness estimated as:

$$R = A_p/A_c \quad (6)$$

where:
R – roundness; A_p – area of the sharpest corner (mm^2); A_c – area of the circumscribed circle (mm^2)

Water displacement method was used to estimate the volume of the fruits. The density (r) of each fruit was calculated using the Eq. (7):

$$r = mass/volume\ (\text{g/cm}^3) \quad (7)$$

Bulk density was taken as the ratio of mass of samples to the volume of container it occupies. It was determined by filling to the brim a 2,580 cm^3 container with the sample and level off the excess samples with a flat object. The whole sample was weighed and bulk density (ρ_b) and porosity calculated with Eq. (8) and Eq. (9), Eke et al. (2007):

$$\rho_b = M_p/V_c \quad (8)$$

where:
M_p – mass of sample (g); V_c – volume of the container (cm^3)

$$Porosity = 1 - \frac{\rho_b}{\rho} \times 100 \quad (9)$$

Surface area (mm^2) and specific surface area (mm^2/cm^3)of the fruits were estimated with formu-

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las shown in Eq. (10) and Eq. (11), Sirisomboon et al. (2007):

$$A_s = \pi D^2 \quad (10)$$

$$A_{ss} = \frac{A_s \rho_b}{mass} \quad (11)$$

where:

A_s – surface area (mm^2); A_{ss} – specific surface area (mm^2/cm^3); D^2 – geometric mean diameter

The data obtained from the experiment were analysed using Excel and Genstat (Genst discovery Ed. 3; United Kingdom.) statistical packages.

RESULTS AND DISCUSSION

Principal dimension and size distributions

Major, intermediate and minor diameters of *Canarium schweinfurthii* Engl. fruits for all the varieties evaluated decreased as moisture content decreased from 40.91% to 11.03% w.b. (Table 1). Similar trend was reported by Ndirika and Oyeleke (2006), Simonyan et al. (2009), Razavi et al. (2009), Fathollhzadeh et al. (2008) for millet (*Pennisetum glaucum* L.), *Lablab purpureus*, canola seeds and barberry fruits respectively. Major, intermedi-

Table 1. Measured parameters and coefficient of variation of *Canarium schweinfurthii* Engl. fruits at different moisture content

Samples	Moisture content (% w.b.)	Major diameter (*a*, mm)	Intermediate diameter (*b*, mm)	Minor diameter (*c*, mm)	Mass (g)	Volume (cm^3)	Density (g/cm^3)
$CSHT_S$	40.91	26.06 ± 1.09 (4.18)	16.69 ± 0.59 (3.52)	16.17 ± 0.27 (1.98)	4.87 ± 0.26 (5.71)	3.69 ± 0.52 (2.94)	1.36 ± 0.37 (2.71)
	34.92	25.08 ± 1.37 (5.47)	15.89 ± 0.56 (3.56)	15.36 ± 1.54 (1.05)	3.99 ± 0.38 (4.42)	3.22 ± 0.46 (1.49)	1.23 ± 0.32 (2.58)
	23.44	24.20 ± 2.08 (8.62)	15.05 ± 0.78 (5.24)	14.57 ± 1.54 (1.05)	3.46 ± 0.39 (2.5)	2.8 ± 0.51 (1.81)	1.23 ± 0.35 (2.82)
	18.5	23.87 ± 2.24 (9.39)	14.45 ± 0.84 (5.8)	13.94 ± 1.59 (1.14)	3.18 ± 0.38 (1.2)	2.54 ± 0.49 (1.95)	1.26 ± 0.42 (3.36)
	11.03	23.05 ± 2.73 (1.18)	13.99 ± 0.96 (1.20)	13.48 ± 1.62 (1.2)	2.74 ± 0.48 (1.75)	2.31 ± 0.52 (2.26)	1.19 ± 0.42 (3.54)
$CSHT_L$	40.91	35.14 ± 0.95 (2.59)	22.44 ± 0.62 (1.72)	22.03 ± 0.61 (1.71)	11.37 ± 0.82 (2.84)	9.11 ± 0.65 (5.01)	1.25 ± 0.04 (0.14)
	34.92	34.65 ± 0.89 (2.58)	21.74 ± 0.62 (2.84)	21.35 ± 0.59 (2.75)	10.33 ± 0.78 (3.48)	8.43 ± 0.62 (2.38)	1.23 ± 0.04 (3.62)
	23.44	34.42 ± 0.89 (2.59)	21.05 ± 0.51 (2.44)	20.76 ± 0.55 (2.67)	9.18 ± 0.77 (3.85)	7.89 ± 0.55 (7.01)	1.16 ± 0.05 (4.43)
	18.5	34.09 ± 0.82 (2.33)	20.25 ± 0.57 (2.76)	20.41 ± 0.57 (2.81)	8.51 ± 0.67 (4.71)	7.58 ± 0.55 (6.85)	1.12 ± 0.059 (5.24)
	11.03	34.09 ± 0.80 (2.35)	20.25 ± 0.53 (2.63)	19.92 ± 0.52 (2.61)	8.04 ± 0.62 (3.74)	7.21 ± 0.49 (6.74)	1.12 ± 0.053 (4.73)
$CSHT_{LG}$	40.91	42.86 ± 0.91 (2.13)	20.05 ± 0.66 (3.27)	19.56 ± 0.65 (3.33)	9.68 ± 0.66 (4.81)	7.89 ± 0.59 (7.45)	1.226 ± 0.03 (2.39)
	34.92	42.59 ± 0.88 (2.09)	18.54 ± 0.63 (3.41)	18.06 ± 0.64 (3.56)	8.95 ± 0.49 (2.43)	7.13 ± 0.54 (7.55)	1.16 ± 0.17 (14.26)
	23.44	42.36 ± 0.93 (2.09)	18.44 ± 0.51 (2.77)	17.89 ± 0.53 (2.97)	7.09 ± 1.23 (1.73)	7.15 ± 1.07 (2.91)	1.144 ± 1.15 (1)
	18.5	42.02 ± 0.97 (2.30)	17.39 ± 2.38 (1.36)	17.18 ± 0.98 (3.74)	6.68 ± 1.25 (1.87)	6.59 ± 1.04 (2.82)	1.10 ± 1.80 (2.78)
	11.03	41.71 ± 1.36 (3.27)	16.90 ± 2.43 (1.44)	16.58 ± 1.13 (3.82)	6.22 ± 1.34 (2.16)	6.14 ± 1.07 (2.50)	1.06 ± 3.28 (2.27)

$CSHT_S$ – *Canarium schweinfurthii* Engl. small; $CSHT_L$ – *Canarium schweinfurthii* Engl. long; $CSHT_{LG}$ – *Canarium schweinfurthii* Engl. large; values in brackets are the coefficient of variation

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Table 2. ANOVA summary of physical parameters of *Canarium schweinfurthii* fruit studied at moisture content range of 40.91–11.03%

Source of variation	*Df*	*a* (mm)	*b* (mm)	*c* (mm)	Mass (g)	Sphericity	Vol.	Density	S. area	Roundness	*P* 0.05	*P* 0.01
Samples	2	790.50**	976.50**	1,084.9**	31.52**	648.74**	1,678.39**	1.35ns	920.72**	20.62*	4.46	8.65
Moisture content	4	2.62ns	7.14*	68.02**	314.29**	13.15*	57.53	0.29ns	38.69**	5.23*	3.84	7.01
Interaction	8	5.56*	43.40**	12.22*	68.79**	36.12**	137.26	8.10*	65.53**	8.10*	2.266	3.17
Error	8											

*significant; **highly significant; ns – not significant; *Df* – degree of freedom; *a* – major diameter; *b* – intermediate diameter; *c* – minor diameter; *S.* area – surface area; 50 samples; 5% level of signifikance

ate and minor diameters of $CSHT_S$, $CSHT_L$, and $CSHT_{LG}$ fruits decreased by 11.5%, 3.22%, and 2.68%; 16.18%, 9.76% and 15.771%; 16.63%, 9.58% and 15.24%, respectively, as moisture reduced from 40.91 to 11.03% w.b. All the principal dimensions had low coefficient of variation, which indicates evenly distributed values about their means. Grains of chickpea (Konak et al. 2002) and Samaru sorghum 17 (Simonyan et al. 2007) also behaved the same way at 16.52% d.b., 6.5% d.b., 16.5–8.89% d.b, and 13.5% w.b., respectively. The ANOVA shown in Table 2 also revealed that moisture content had no significant (5%) effect on the major diameter of all the varieties studied. Regression equations of the principal dimensions in Table 3 showed high values of coefficient of determination (R^2) indicating good relationship between the parameters evaluated.

Mass and volume

The mean values of mass and volume are summarized in Table 1. Mass and volume decreased by 43.74% and 29.29%; 36.34% and 17.87%; 27.56% and 14.51% for $CSHT_S$, $CSHT_L$ and $CSHT_{LG}$ respectively as moisture content decreased from 40.91 to 11.03% w.b. Fathollahzadeh et al. (2008), Akinoso and Raji (2010) observed 70.77% and 57.82%; 9.71% and 8.89% decrease in mass and volume of barberry fruits and tenera, respectively as moisture content decreased from 89.19–12.64% and 11–5% w.b. Low coefficient of variation of mass and volume showed a uniform dispersion of their values about their means. Both physical properties are highly influenced by moisture content and variety at 5% and 1% levels of significance as shown in

Table 3. Equations representing relationship between physical parameters and moisture content

Parameters	$CSHT_S$ regression equation	$CSHT_S$ R^2	$CSHT_L$ regression equation	$CSHT_L$ R^2	$CSHT_{LG}$ regression equation	$CSHT_{LG}$ R^2
c	$0.062h^2 - 1.095h + 27.05$	0.987	$0.055h^2 - 0.592h + 35.66$	0.993	$0.130h^2 - 0.865h + 43.07$	0.906
b	$0.065h^2 - 1.074h + 17.72$	0.998	$0.044h^2 - 0.781h + 22.75$	0.996	$-1.89\ln(h) + 20.01$	0.989
c	$0.062h^2 - 1.053h + 17.17$	0.999	$-0.517h + 22.44$	0.986	$-1.73\ln(h) + 19.50$	0.975
Mass	$0.091h^2 - 1.068h + 5.823$	0.997	$0.115h^2 - 1.541h + 12.84$	0.997	$0.142h^2 - 1.771h + 11.47$	0.960
Sphericity	$0.000h^2 - 0.011h + 0.745$	0.907	$0.745e -0.01h$	0.987	$0.001h^2 - 0.021h + 0.620$	0.973
Roundness	$0.009h^2 - 0.106h + 0.536$	0.977	$-0.01\ln(h) + 0.505$	0.984	$0.007h^2 - 0.090h + 0.582$	0.954
Volume	$0.045h + 1.75$	0.907	$0.019h + 6.924$	0.986	$0.069h + 5.468$	0.879
Density	$0.009h^2 - 0.095h + 1.437$	0.958	$0.022h + 0.795$	0.993	$0.001h^2 - 0.057h + 1.991$	0.986
Surfaces area	$0.001h^2 + 0.044h + 7.785$	0.991	$0.001h^2 + 0.039h + 17.51$	0.987	$0.002h^2 - 0.019h + 16.22$	0.844
Bulk density	$-0.016h^2 + 2.494h - 1.054$	0.997	$-0.005h^2 + 0.638h + 47.02$	0.983	$0.006h^2 + 0.409h + 41.72$	0.987
Porosity	$0.023h^2 - 2.406h + 104.0$	0.985	$0.007h^2 - 0.485h + 56.33$	0.925	$0.018h^2 - 1.298h + 65.61$	0.942

$CSHT_S$ – *Canarium schweinfurthii* Engl. small; $CSHT_L$ – *Canarium schweinfurthii* Engl. long; $CSHT_{LG}$ – *Canarium schweinfurthii* Engl. large; *h* – moisture content; *e* – mean exponential expression; *a* – major diameter; *b* – intermediate diameter; *c* – minor diameter

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Table 4. Mass and volume were linearly regressed with moisture content with high values of R^2. The regression equations are shown in Table 3.

Sphericity, roundness and aspect ratio

The influence of moisture content on aspect ratio, sphericity and roundness of different varieties of *Canarium schweinfurthii* Engl. fruits are also presented in Table 4 and Figs 1 and 2. The values of the above physical parameters decreased with reduction in moisture content. Aspect ratio, sphericity and roundness of $CSHT_S$, $CSHT_L$ and $CSHT_{LG}$ were reduced by 5.27%, 3.80% and 45.10%; 4.65%, 6.98% and 4.62%; and, 9.54%, 13.30% and 35.80%, respectively as moisture content decreased from 40.91% to 11.03% w.b. Fathollahzadeh et al. (2008), Razavi et al. (2009) and Berydeh and Mangope (2002) also reported 40.43%, 2.29%, 18.5% and 0.475% reduction in sphericity of barberry fruits, canola seeds (SLM spp.) and pigeon pea as moisture content reduced from 89.23 to 11.64% w.b., 21 to 6% and at 25%, respectively. At 40.91% w.b., the

Table 4. Calculated parameters and coefficient of variation of *Canarium schweinfurthii* Engl. fruits at different moisture content

Samples	Moisture content (% w.b.)	GMD	AMD	SQMD	EQD	Surface area (mm^2)	Specific surface area (cm^2/cm^3)	Aspect ratio
$CSHT_S$	40.91	19.13 ± 1.09 (5.09)	19.64 ± 0.92 (4.67)	19.37 ± 0.98 (5.05)	19.38 ± 0.99 (5.10)	11.54 ± 1.18 (1.09)	1.74 ± 0.18 (1.09)	64.09 ± 2.14 (3.34)
	34.92	18.26 ± 1.06 (3.81)	18.78 ± 0.63 (3.33)	18.49 ± 0.96 (3.18)	18.51 ± 0.83 (4.16)	1,051 ± 1.10 (1.04)	1.77 ± 0.18 (1.04)	63.52 ± 2.97 (4.68)
	23.44	17.41 ± 1.25 (4.17)	17.94 ± 0.80 (4.47)	17.65 ± 1.18 (4.39)	17.67 ± 1.00 (4.68)	9.57 ± 1.25 (1.31)	1.31 ± 0.17 (1.31)	62.49 ±4.27 (4.83)
	18.5	16.84 ± 1.34 (4.92)	17.42 ± 0.87 (4.98)	17.10 ± 1.26 (4.36)	17.12 ± 1.08 (4.28)	8.96 ± 1.28 (1.42)	1.18 ± 0.17 (1.42)	60.86 ± 4.32 (0.09)
	11.03	16.27 ± 1.47 (3.04)	16.84 ± 1.41 (3.62)	16.53 ± 1.43 (3.65)	16.55 ±1.26 (3.62)	8.38 ± 1.38 (1.64)	0.74 ± 0.122 (1.64)	60.71 ± 4.88 (4.73)
$CSHT_L$	40.91	25.90 ± 0.644 (1.61)	26.54 ± 0.66 (1.62)	26.19 ± 0.65 (1.61)	26.21 ± 0.65 (1.61)	21.09 ± 1.04 (0.05)	1.117 ± 0.059 (0.05)	63.87 ± 1.51 (0.036)
	34.92	25.23 ± 0.63 (2.48)	25.91 ± 0.63 (2.44)	24.54 ± 0.63 (2.47)	25.56 ± 0.63 (2.46)	20.03 ± 9.9 (4.94)	1.21 ± 0.06 (4.94)	62.76 ± 1.37 (2.21)
	23.44	24.69 ± 0.57 (2.33)	25.41 ± 0.59 (2.31)	25.01 ± 0.58 (2.31)	25.04 ± 2.32 (2.32)	19.16 ± 0.89 (4.67)	1.24 ± 0.057 (4.67)	61.17 ± 1.29 (2.12)
	18.5	24.36 ± 0.55 (2.25)	25.11 ± 0.55 (2.18)	24.69 ± 0.55 (2.21)	24.72 ± 0.55 (2.21)	18.65 ± 0.84 (4.54)	1.22 ± 0.056 (4.54)	60.62 ± 1.60 (2.63)
	11.03	23.95 ± 0.54 (2.24)	24.75 ± 0.54 (2.17)	24.31 ± 0.54 (2.20)	24.33 ± 0.54 (2.19)	18.03 ± 0.808 (4.48)	1.20 ± 0.05 (4.48)	59.41 ± 1.36 (2.29)
$CSHT_{LG}$	40.91	25.61 ± 0.61 (2.37)	27.49 ± 0.57 (2.08)	26.39 ± 0.59 (2.24)	26.49 ± 0.58 (2.21)	20.62 ± 0.99 (4.32)	1.46 ± 0.0707 (4.32)	46.78 ± 1.67 (3.57)
	34.92	23.86 ± 57 (2.41)	25.73 ± 0.53 (2.07)	24.63 ± 0.56 (2.25)	24.74 ± 0.55 (2.23)	17.88 ± 0.89 (5)	1.419 ± 0.079 (5)	45.23 ± 1.43 (3.16)
	23.44	23.78 ± 1.87 (7.89)	26.08 ± 0.95 (3.66)	24.75 ± 1.25 (5.01)	24.87 ± 1.35 (5.40)	17.88 ± 2.18 (1.22)	1.36 ± 0.17 (1.22)	43.47 ± 1.43 (3.29)
	18.5	23.12 ± 2.07 (8.95)	25.55 ± 1.007 (3.94)	24.14 ± 1.33 (5.51)	24.27 ± 1.46 (5.99)	16.92 ± 2.24 1.27	1.29 ± 0.17 1.27	41.36 ± 5.72 (3.38)
	11.03	22.53 ± 2.29 (1.14)	25.07 ± 1.10 (4.4)	23.61 ± 1.42 (6)	23.74 ± 1.58 (6.6)	16.11 ± 2.36 (1.69)	1.23 ± 0.18 (1.69)	40.56 ± 5.94 (3.02)

$CSHT_S$ – *Canarium schweinfurthii* Engl. small; $CSHT_L$ – *Canarium schweinfurthii* Engl. long; $CSHT_{LG}$ – *Canarium schweinfurthii* Engl. large; GMD – geometric mean diameter; AMD – arithmetic mean diameter; SMD – square mean diameter; EQD –equivalent mean diameter

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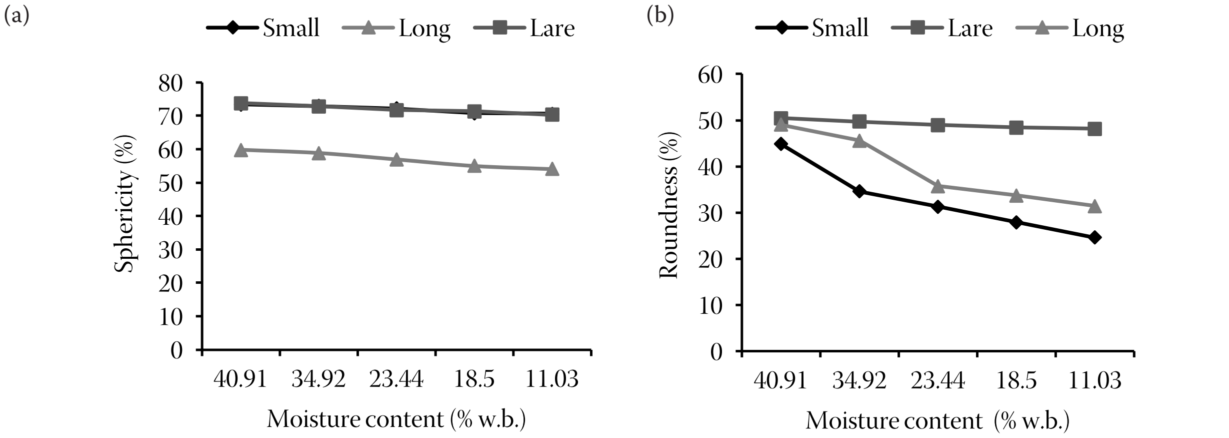

Fig. 1. Influence of moisture content on (a) sphericity and (b) roundness of *Canarium schweinfurthii* Engl. varieties

values of aspect ratio and sphericity of all the varieties were high except the aspect ratio of $CSHT_{LG,}$ showing that at higher moisture content, the fruits are spherical and oblong; hence, they can rather roll than slide. Moisture content affected ($P < 0.05$) the sphericity and roundness of $CSHT_{LG}$. It could be because the structure of $CSHT_{LG}$ fruit has more pore spaces than other varieties, which resulted in high shrinkage effect during moisture loss. Roundness had low values for all the varieties studied, showing that *Canarium schweinfurthii* Engl. fruits are not round, therefore, the shape of screen opening for separation purposes must not be round. Regression equations are shown in Table 3.

True density, bulk density and porosity

The results of true density, bulk density and porosity as influenced by varied moisture content are shown in Table 1 and Figs 3 and 4 respectively. From the table, it was observed that true density of all the varieties are higher than that of water indicating that the fruits cannot float in water. Hence, separation from other dense materials cannot take place in water. True density of $CSHT_S$ decreased with decreased moisture content and had a polynomial relationship with moisture content. Simonyan et al. (2009) reported the same behaviour for *Lablab purpureus*, indicating that agricultural materials are not homogenously formed. Bulk density and porosity also decreased as moisture content decreased. $CSHT_S$ had the least (24.31%) and highest (79.65%) bulk density and porosity, respectively. This means that $CSHT_S$ require lesser space per unit mass and will encourage easier aeration and water vapour diffusion during drying than other varieties. Similar results were observed for apricot kernel, cape fruits, two varieties of corn (Sc 704 and 370) and cowpea (IAR 339-1) by Fathollahzadeh et al.

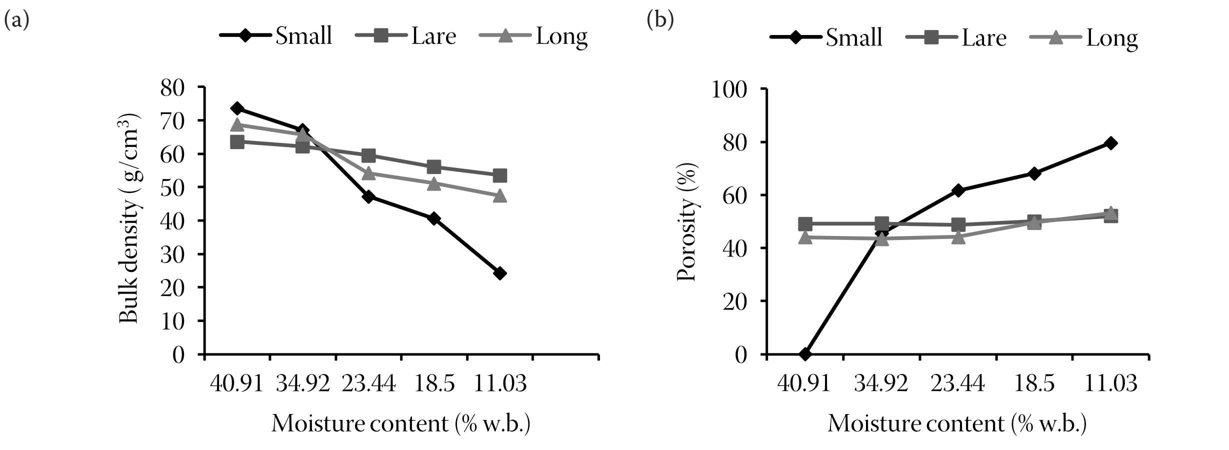

Fig. 2. Influence of moisture content on (a) bulk density and (b) porosity of *Canarium schweinfurthii* Engl. varieties

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(2008), Sessiz et al. (2007), Seifi and Alimardani (2010) and Davies and Zibokere (2011), respectively. True density and bulk density of individual varieties studied had a positive linear correlation against moisture content showing a cordial relationship between the parameters. A similar positive correlation was reported on sunflower seed by Bhise et al. (2013). Negative correlations were also observed by Baumler et al. (2006), Coskun et al. (2005) and Dursun and Dursun (2006) for safflower seed, sweet corn seed and caper seeds respectively. The ANOVA in Table 4 revealed that moisture content and variety had no significant effect on true density at 1% and 5% levels of significance.

Surface area and specific surface area

In the range of moisture content (40.91–11.03% w.b.) evaluated, surface area and specific surface area of $CSHT_S$, $CSHT_L$ and $CSHT_{LG}$ decreased from 11.54–8.38 mm^2 and 1.74–0.74 mm^2/cm^3; 21.09–18.03 mm^2 and 1.117–1.20 mm^2/cm^3; 20.62–16.11 mm^2 and 1.46–1.23 mm^2/cm^3 respectively (Table 2). The table also revealed that $CSHT_L$ and $CSHT_S$ had the highest surface area (21.09 ± 1.04) and specific surface area (1.74 ± 0.18) , meaning that heat and mass transfer in $CSHT_L$ and $CSHT_S$ fruits are faster than in $CSHT_{LG}$. Hence, the prediction of their drying rate can easily be carried out. The coefficient of variation of both surface areas is low showing uniform dispersion about their means. Similar result was reported for *Jatropha curcas* fruits, nuts and kernel and, Redspar and Delbarstival apples by Sirisomboon et al. (2007) and Kheiralipour et al. (2008) respectively. Moisture content, variety and their interactions affected surface area of *Canarium schweinfurthii* Engl. fruits significantly at 1% and 5% levels of significance (Table 4).

CONCLUSION

The study of some physical properties of *Canarium schweinfurthii* Engl. fruits as influenced by moisture content revealed the following:

– All the physical parameters evaluated varied linearly from variety to variety with a decrease in moisture content. The varieties of *Canarium schweinfurthii Engl.* fruits differ significantly (1% and 5%) from each other both in shape and size
– Moisture content does not significantly (1% and 5%) affect major diameter and true density of *Canarium schweinfurthii* Engl. fruits. The fruits cannot be separated by float method since they are denser than water. $CSHT_S$ variety is less bulky, has the highest specific surface area and is more porous than other varieties.
– *Canarium schweinfurthii* Engl. fruits of the three varieties are not round but spherical and oblong, hence they can rather roll than slide.

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