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Physical properties of the African walnut (*Tetracarpidium conophorum*) from Nigeria

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Abstract: In this research about 1,700 samples of the African walnut (*Tetracarpidium conophorum*) were measured for their axial dimensions, mass, geometric mean, sphericity index, surface area, aspect ratios, angle of repose on steel, wood and glass, porosity, bulk and true density of the nut, kernel and shell at five moisture levels and three size ranges. Various equations linking the nut moisture content with other physical properties for nut and kernel were established using regression models. The studies showed that at initial moisture content of 28.2% w.b, the African wild walnut fall mostly within the mass (*m*) range of $5.5 \le m \le 6.5$ g with shell thicknes of 0. 135 ± 0.04 cm, kernel mass of 4.22 ± 0.26 g, kernel moisture content of 28.9% w.b, porosity of 45%, nut true density of 0.815 g/cm^3, nut bulk density of 0.45 g/cm^3, nut aspect ratio of 76% and nut surface area of 15.41 cm^2. This various properties are affected by increase in moisture contents and change in nut mass.

Subjects: Bioscience; Engineering & Technology; Environment & Agriculture; Food Science & Technology

Keywords: nut size; nut mass; moisture contents; sorting; regression modeling

1. Introduction

Persian Walnut (*Juglans regia L.*) is known to be rich in oil, vitamins, minerals and proteins (Ozcan, 2009; Özcan, İman, & Arslan, 2010) and is mostly produced in orchards in temperate zones like Turkey, China, Iran and USA (Erturk & Dalkilic, 2011; FAO, 2013). Less is known about the African walnut (Ogunsua and Adebona, 1983), gotten from the wild in Nigeria, and it might differ in physical characteristics from Persian walnuts found in these countries. This is because researchers (Altuntas & Erkol, 2010; Asma, 2012; Cerović, Gološin, Todorović, Bijelić, & Ognjanov, 2010; Keles, Akca, & Ercisli, 2014; Ozkan & Koyuncu, 2005) have shown that several genotypes and cultivars of the walnut family abound from different regions with their physical properties modified by the environment and climatic condition (Cosmulescu, 2013; Ebrahimi, Zarei, Fatahi, & Varnamkhasti, 2009). Very few open literature exist in physical properties of the African walnut and focused on the Persian walnut from USA, Iran and Turkey (Altuntas & Erkol, 2009, 2010; Ebrahimi et al., 2009, Heydari, Jafari, Mobli,

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PUBLIC INTEREST STATEMENT

With the recent dwindling revenue from crude oil, Nigeria is turning to all this undocumented crops in the wild like walnut, domesticating and commercializing them to boast its export revenue. However understanding the physical properties will aid in machine design for planting and processing to enhance its mass production but literature on physical properties of wild walnut cultivar from tropical Africa in particular is very rare. This physical properties is majorly affected by moisture content.

Rafee, & Portahmasi, 2011; Khir, Pan, Atungulu, Thompson, & Shao, 2011; Ozkan & Koyuncu, 2005), while the study of wild walnut from Nigeria or Africa is scarce. Research has shown that the adaptability of agro processing machines is crop and most cases cultivar specific and mostly affected by physical properties of the particular crop. This has led to the studies of physical properties of several crops and crops of the same species but different genotype and cultivars (Dash, Pradhan, Das, & Naik, 2008; Jahromi et al., 2008; Khir, Atungulu, Pan, Thompson, & Zheng, 2014; Khir et al., 2011; Kılıçkan & Güner, 2008; Sessiz, Esgici, & Kızıl, 2007; Seyed & Taghizadeh, 2007). Lack of this knowledge might lead to the underperformance of these machines and equipment for the intended purpose. Therefore the objective of the present research is to characterize some physical properties of the African walnut from Nigeria at different moisture content in order to establish physical properties data for designing and production of planting processing and material handling equipment.

2. Materials and methods

2.1. Sample preparations

This study was carried out at the post harvest and processing engineering laboratory of Michael Okpara University of Agriculture Umudike Nigeria. In total 1,700 samples of walnut were obtained from the open market in South Eastern Nigeria because there is no known walnut orchard in the area. The walnuts were sorted and graded according to three mass ranges of $m < 5.5$, $5.5 \le m \le 6.5$ and $m > 6.5$ g. The grading of the walnut is because it has been established that there is enormous variations in moisture contents of individual walnut of the same cultivar (Ebrahimi et al., 2009; Khadivi-Khub & Ebrahimi, 2015; Khir et al., 2011). For each experiment 150 samples of walnut were randomly selected and used.

2.2. Determination of physical properties

The summary of the measured and calculated physical properties and the various equations used in determining them is shown in Table 1. The moisture contents of nut, kernel and shell were determined by using a laboratory oven (UMB 500 Sehutzart, DIN EN 60529-IP 20, Memmert, Germany) at an isothermal temperature of 100°C for 24 h (Khir et al., 2014). The mass of the nut, kernel and the shell was measured using electronic weighing balance (Scout Pro SPU 405, China) with a sensitivity of 0.01 g. Variation of the moisture contents and the masses were achieved by soaking the entire nut in water between 6 and 30 h (Altuntas & Erkol, 2010). The soaked samples were removed from the water and stored with black polyethylene bag in the refrigerator for 2 days. Each sample was removed from the fridge 24 h before each experimental evaluation to achieve moisture equilibrium within the sample and thawing. Also the axial dimensions were determined with a venire caliper (mitutoyo, JIS.B.7502). True density measurement was carried out by water immersion method as described by Jahromi et al. (2008) and water displacement method as described by Spreer and Müller (2011). The bulk density was determined with the methods described by Jahromi et al. (2008) and Ndukwu (2009). This was done by loosely filling a container of known volume and mass with the nut, kernel or shell from a constant height. Also the angle of repose on wood, glass and steel were determined by the method of inclined plane as described by Jahromi et al. (2008). All other derived physical properties were determined quantitatively as presented in Table 1. Microsoft Excel 2007 was used to run the statistical analysis. Analysis of variance (ANOVA) was used to test the level of significance of data at different moisture contents at 95% confidence limit.

2.3. Regression curve fitting equations

It is very important to have the knowledge of the moisture contents and mass of the walnut in relationship with the kernel to avoid over drying of the kernel. Regression modeling was done by curve fitting some physical properties with the moisture contents of the nut (n/mc) into two, two parameter logarithm function (positive and negative coefficient), a linear function and an *allometric* power function using *Levenberg Marquardt* iteration algorithm (Table 2). This is because from literature (Altuntas, & Erkol, 2010; Jahromi et al., 2008; Khir et al., 2011), most moisture content relationships with other physical properties follow any of this functions. "*y*" represents the physical properties while "*x*" is the nut moisture content. Where *a*, *b* and *n* are constants in the predicting equations. The four equations are expressed as in Table 2. In each case the four equations were generally tested

Table 1. Determined physical properties of nut, shell and kernel of the wild walnut

S/no	Physical properties	Symbol	Unit	Formula/method	Source
1	Nut moisture content	n/mc	(%wb)	$M_{ni} - M_{dn}/M_{ni}$	Khir et al. (2011, 2014)
2	Kernel moisture content	k/mc	(%wb)	$M_{ki} - M_{dk}/M_{ki}$	Khir et al. (2011, 2014)
3	Nut mass	W_n	(g)	Direct measurement	Spreer and Müller (2011), Ebrahimi et al. (2009)
4	Kernel mass	W_k	(g)	Direct measurement	Spreer and Müller (2011), Ebrahimi et al. (2009)
5	Nut major diameters	d_1	(cm)	Direct measurement	Altuntas and Erkol (2010)
6	Nut minor diameters	d_2	(cm)	Direct measurement	Altuntas and Erkol (2010)
7	Nut intermediate diameters	d_3	(cm)	Direct measurement	Altuntas and Erkol (2010)
8	Nut geometric mean diameters	nd_g	(cm)	$(d_1 d_2 d_3)^{1/3}$	Mohsenin (1986), Dash et al. (2008)
9	Kernel geometric mean diameters	kd_g	(cm)	$(d_1 d_2 d_3)^{1/3}$	Jahromi et al. (2008)
10	Nut sphericity index	$nø$	–	nd_g/d_1	Dash et al. (2008), Jahromi et al. (2008)
11	Kernel sphericity index	$nø$	–	kd_g/d_1	Dash et al. (2008), Jahromi et al. (2008), Sessiz et al. (2007)
12	Angle of repose of nut on wood	θ_w	(°)	Direct measurment	Jahromi et al. (2008)
13	Angle of repose of nut on glass	θ_g	(°)	Direct measurment	Jahromi et al. (2008)
14	Angle of repose of nut on steel	θ_s	(°)	Direct measurment	Jahromi et al. (2008)
15	Shell thickness	S_T	(cm)	Direct measurment	Altuntas and Erkol (2010)
16	Shell mass	S_m	(g)	Direct measurment	Altuntas and Erkol (2010)
17	Nut surface area	S_n	(cm^2)	πnd_g^2	Dash et al. (2008)
18	Kernel surface area	S_k	(cm^2)	πkd_g^2	Dash et al. (2008)
19	Nut aspect ratio	R_{an}	–	d_2/d_1	Dash et al. (2008)
20	Kernel aspect ratio	R_{ak}	–	d/d_1	Dash et al. (2008)
21	Nut true density	σ_T	(g/cm^3)	$(m_{air}/m_{air} - m_w)\sigma_w$ and m/v	Jahromi et al. (2008)
22	Nut bulk density	σ_B	(g/cm^3)	M/V	Jahromi et al. (2008)
23	Nut porosity	$n\varepsilon$	–	$(1 - \sigma_B/\sigma_T)$	Ndukwu (2009)
24	Shell porosity	$s\varepsilon$	–	$(1 - \sigma_B/\sigma_T)$	Dash et al. (2008)

Table 2. Regression equations

S/no	Function	Equation type	Iteration algorithm
Predictor 1	$y = b\,ln(x - a)$	Logarithm function (negative coefficient)	*Levenberg Marquardt*
Predictor 2	$y = ln(a + bx)$	Logarithm function (positive coefficient)	*Levenberg Marquardt*
Predictor 3	$y = bx + a$	Linear function	*Levenberg Marquardt*
Predictor 4	$y = a + bx^n$	*Allometric* power function	*Levenberg Marquardt*

and the predictor with higher coefficient of determination (R^2) was chosen to predict the relationship between the moisture contents and the physical properties. The modeling tool is ORIGIN PRO 9.1 data analysis and graphing software.

3. Results and discussion

Figure 1, presents the frequency distribution of the walnut. The frequency distribution depicts a Guassian model, with nut in the mass range of $5.5 \le m \le 6.5$ g depicting the modal class. About 3.14% of the whole nut was found to be either cracked or with a decayed kernel. This group of nuts were classified as bad nuts and shown in Figure 1. The initial moisture content difference for the three groups varied from 1.5–3.8% (w.b). Table 3 shows that the increment of the moisture content of the whole nut by 16.4% (w.b) resulted in the increment of the moisture content of the kernel by 14.4% (w.b) for mass range $m > 6.5$ g while Table 4 shows increment of 23.1% (w.b) resulted in 14.9% (w.b) increase in kernel moisture content for mass range of $5.5 \le m \le 6.5$ g. Table 5 also showed that 19.4% (w.b) nut moisture increase for the mass size of $m < 5.5$ g led to 10.6% (w.b) moisture increase for the kernel. There is considerable difference between the moisture content of the whole nut and the kernel. This is significant in the drying process of walnut to avoide over drying and loss of essesntial oils from the kernel. Furthermore, increase in moisture level affected the overall size of the nut and kernel as expected (Tables 3–5). This is in agreement with various researchers (Gharibzahedi, Etemad, Mirarab-Razi, & Foshat, 2010; Sessiz et al., 2007) which reported that water uptake into the intracellular pores within the nut or kernel of crops resulted in the swelling or enlargement of the nut and kernel (Tables 3–5).

3.1. Nut and kernel dimensions and shapes

3.1.1. Axial dimensions

The axial dimensions and masses in Tables 3–5 showed that the African walnut from Nigeria is smaller than the Kaman, Buyuk Oba, DE and 32.YS Persian walnut genotype from Turkey (Altuntas & Erkol, 2010; Dogan et al., 2005; Özcan et al., 2010; Ozkan & Koyuncu, 2005). Tables 3–5 shows that at initial moisture content of 24.4–28.2% (w.b) the major diameter ranged from 2.48 to 2.73 cm while the minor diameter ranged from 1.85–2.17 cm. Table 3 shows that when the nut moisture content rose from 24.4–38.8% (w.b) for the size of $m > 6.5$ g, the geometric mean diameter (nd_g) of the nut increased by 5.98% while that of the kernel (kd_g) increased by 8.95%. Also for the size of $5.5 \le m \le 6.5$ g, increase of moisture from 28.2–43.3% (w.b) resulted in a geometric mean diameter increase of 4.98% for the nut and 2.15% for the kernel as shown in Table 3. The same trend was observed for the size of $m < 5.5$ g where its nd_g and kd_g increased by 2.84 and 5.39% respectively as shown in Table 4. The regression equation depicting the relationship between the nut geometric mean ($nd_{e)}$ and moisture content (n.mc) is shown in Equations (1)–(3).

Figure 1. The frequency distribution curve of the walnut samples.

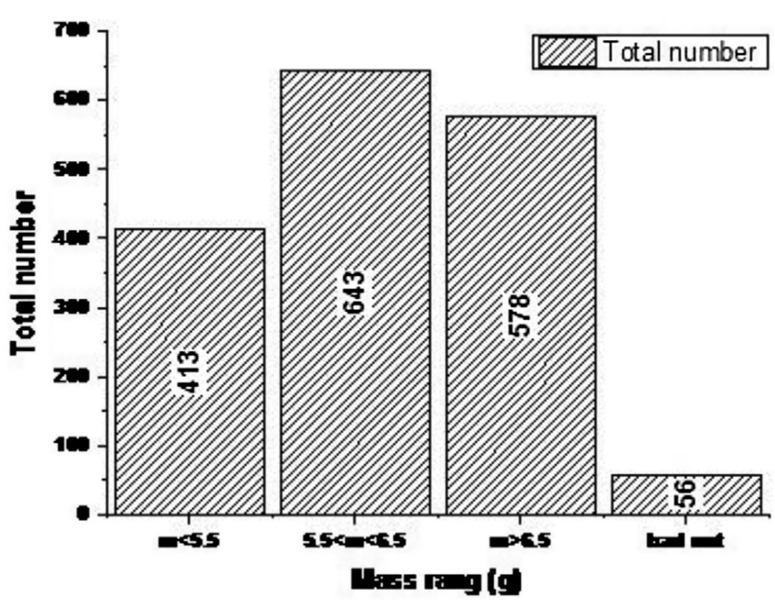

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Table 3. Physical properties of walnut of size range m > 6.5 g

No. of nuts	k M/c (%wb)	n M/c (%wb)	W_n (g)	W_k (g)	d_1(cm)	d_2(cm)	d_3(cm)	nd_g(cm)	kd_g(cm)	$nø$	$kø$	θ_w(°)	θ_g(°)	θ_s(°)	S_T (cm)	S_m (g)	S_n (cm²)	S_k (cm²)	R_{an}	R_{ak}	σ_T (g/cm³)	σ_B (g/cm³)	$n\varepsilon$	$s\varepsilon$
150	24.4	24.2	7.41	4.77	2.73	2.17	2.17	2.34	1.90	0.86	0.81	38.47	37.93	37.47	0.144	2.58	17.20	11.38	0.80	0.66	1.06	0.49	0.54	0.75
			(0.77)	(0.72)	(0.21)	(0.11)	(0.11)	(0.11)	(0.18)	(0.04)	(0.07)	(0.92)	(0.88)	(1.06)	(0.04)	(0.37)	(1.66)	(2.06)	(0.06)	(0.09)	–	–	–	
150	30.6	38	7.45	4.84	2.75	2.20	2.27	2.39	1.96	0.87	0.84(0.	41	40	40	0.121	2.00	17.95	12.08	0.80	0.72	0.970	0.49	0.50	0.65
			(0.37)	(0.53)	(0.11)	(0.13)	(0.09)	(0.07)	(0.08)	(0.03)	04)	(1.10)	(1.12)	(1.18)	(0.05)	(0.70)	(1.00)	(0.96)	(0.06)	(0.07)	–	–	–	–
150	34.5	38.8	7.47	4.98	2.76	2.21	2.29	2.41	1.97	0.87	0.84	39.07	37.6	38.4	0.134	2.16	18.25	12.12	0.80	0.74	0.907	0.49	0.46	0.49
			(0.36)	(0.32)	(0.20)	(0.16)	(0.09)	(0.11)	(0.12)	(0.04)	(0.05)	(2.55)	(2.13)	(2.41)	(0.04)	(0.20)	(1.70)	(1.51)	(0.06)	(0.09)	–	–		
150	37.3	39.8	7.49	4.99	2.81	2.23	2.29	2.43	1.99	0.87	0.86(0.	40.26	38.26	39.26	0.135	2.19	18.55	12.21	0.79	0.75	0.905	0.50	0.45	0.49
			(0.29)	(0.36)	(0.14)	(0.14)	(0.10)	(0.24)	(0.06)	(0.04)	02)	(1.98)	(1.98)	(1.98)	(0.21)	(0.34)	(2.81)	(0.74)	(0.07)	(0.04)	–	–		
150	38.4	40.2	7.97	4.97	2.85	2.24	2.30	2.46	1.99	0.88	0.86	43.46	41.06	42.4	0.140	2.5	19.01	11.47	0.79	0.77	0.905	0.53	0.41	0.48
			(0.13)	(0.28)	(0.29)	(1.00)	(0.08)	(0.10)	(0.06)	(0.096)	(0.04)	(1.81)	(1.79)	(1.96)	(0.04)	(0.21)	(1.38)	(0.66)	(0.14)	(0.16)	–	–	–	–
150	38.8	40.6	8.11	5.01	2.88	2.29	2.31	2.48	2.07	0.86	0.86	58.53	57.26	56.20	0.140	2.09	19.32	12.21	0.80	0.77	0.895	0.57	0.36	0.48
			(0.33)	(0.37)	(0.14)	(0.13)	(0.10)	(0.083)	(0.06)	(0.04)	(0.05)	(2.39)	(2.84)	(3.45)	(0.02)	(0.38)	(1.19)	(0.72)	(0.07)	(0.05)	–	–	–	–

Note: Figures in the brackets are the standard deviations.

Table 4. Physical properties of walnut of size range 5.5 ≤ m ≤ 6.5 g

No. of nuts	nM/c (%wb)	kM/c (%wb)	W_n (g)	W_k (g)	d_1 (cm)	d_2 (cm)	d_3 (cm)	nd_g (cm)	kd_g (cm)	nø	kø	θ_w (°)	θ_g (°)	θ_s (°)	S_T (cm)	S_m (g)	S_n (cm²)	S_k (cm²)	R_{an}	R_{ak}	σ_T (g/cm³)	σ_B (g/cm³)	$n\varepsilon$	$s\varepsilon$
150	28.2	23.9	6.00	4.22	2.57	1.93	2.19	2.21	1.86	0.81	0.88	41.07	40.2	39.53	0.135	1.83	15.41	10.88	0.76	0.75	0.819	0.45	0.45	0.75
			(0.26)	(0.26)	(0.16)	(0.15)	(0.09)	(1.00)	(0.11)	(0.19)	(0.11)	(0.80)	(0.68)	(0.64)	(0.04)	(0.31)	(1.36)	(1.33)	(0.07)	(0.17)	–	–	–	–
150	37.7	33.3	6.08	4.25	2.58	1.94	2.21	2.23	1.86	0.86	0.89	42.33	40.53	41.6	0.123	1.85	14.36	10.93	0.75	0.75	0.809	0.46	0.43	0.63
			(0.24)	(0.26)	(0.12)	(0.29)	(0.07)	(0.07)	(0.10)	(0.03)	(0.08)	(0.90)	(0.52)	(0.74)	(0.04)	(0.20)	(0.95)	(1.21)	(0.13)	(0.07)	–	–	–	–
150	41	34.4	6.18	4.25	2.58	1.96	2.27	2.26	1.90	0.88	0.89	41.33	39.27	40.33	0.132	1.76	15.48	11.42	0.76	0.75	0.797	0.46	0.42	0.60
			(0.09)	(0.32)	(0.13)	(0.08)	(0.06)	(0.06)	(0.09)	(0.03)	(0.06)	(1.39)	(1.49)	(1.40)	(0.05)	(0.18)	(0.79)	(1.01)	(0.05)	(0.06)			–	–
150	41.9	34.8	6.18	4.43	2.61	1.94	2.31	2.27	1.91	0.87	0.90	43.73	41.8	42.53	0.136	1.62	14.36	11.54	0.74	0.79	0.794	0.46	0.42	0.60
			(0.37)	(0.36)	(0.09)	(0.06)	(0.09)	(0.06)	(0.09)	(0.03)	(0.07)	(1.53)	(1.61)	(1.41)	(0.02)	(0.25)	(0.82)	(1.07)	(0.4)	(0.08)	–	–	–	–
150	42.5	35.1	6.27	4.43	2.65	1.99	2.30	2.30	1.90	0.87	0.91	46.53	44.13	45.67	0.133	1.62	14.42	11.54	0.75	0.78	0.778	0.53	0.32	0.60
			(0.51)	(0.33)	(0.13)	(0.13)	(0.12)	(0.09)	(0.12)	(0.06)	(0.07)	(1.59)	(1.25)	(1.63)	(0.04)	(0.22)	(1.28)	(3.43)	(0.07)	(0.15)	–	–	–	–
150	43.1	37	6.40	4.45	2.65	1.98	2.39	2.32	1.90	0.88	0.95	50.86	51.29	52.07	0.135	1.69	15.33	11.53	0.75	0.78	0.736	0.52	0.29	0.60
			(0.33)	(0.24)	(0.24)	(0.12)	(0.08)	(0.08)	(0.28)	(0.04)	(0.13)	(1.23)	(1.20)	(1.69)	(0.04)	(0.36)	(1.05)	(0.27)	(0.07)	(0.05)	–	–	–	–

Note: Figures in the brackets are the standard deviations.

Table 5. Physical properties of walnut of size range *m* < 5.5 g

No. of nuts	*kM/c* (%wb)	*nM/c* (%wb)	W_n (g)	W_k (g)	d_1 (cm)	d_2 (cm)	d_3 (cm)	nd_g (cm)	kd_g (cm)	*nø*	*kø*	θ_w (°)	θ_g (°)	θ_s (°)	S_T (cm)	S_m (g)	S_n (cm²)	S_k (cm²)	R_{an}	R_{ak}	σ_T (g/cm³)	σ_B (g/cm³)	$n\varepsilon$	$s\varepsilon$
150	25.8	23.1	4.76	3.32	2.48	1.85	2.07	2.11	1.67	0.85	0.82	35.27	33.67	34.53	0.132	1.42	13.86	8.99	0.75	0.70	1.05	0.47	0.55	0.73
			(0.52)	(0.47)	(0.17)	(0.16)	(0.15)	(0.12)	(0.19)	(0.04)	(0.03)	(0.79)	(0.62)	(0.74)	(0.04)	(0.93)	(1.46)	(1.43)	(0.08)	(0.05)	–	–	–	
150	31.6	36.5	4.82	3.34	2.48	1.84	2.08	2.12	1.69	0.86	0.82	35.2	33.53	34.47	0.145	1.55	14.05	8.99	0.74	0.73	1.02	0.47	0.54	0.75
			(0.51)	(0.54)	(0.16)	(0.17)	(0.15)	(0.14)	(0.14)	(0.03)	(0.03)	(0.94)	(0.74)	(0.83)	(0.04)	(0.20)	(1.95)	(1.44)	(0.05)	(0.14)				
150	32.4	38.2	4.85	3.34	2.48	1.84	2.08	2.12	1.69	0.86	0.83	36.13	33.8	35	0.113	1.53	13.88	9.10	0.74	0.75	0.909	0.50	0.45	0.71
			(0.81)	(0.93)	(0.13)	(0.16)	(0.12)	(0.11)	(0.29)	(0.04)	(0.05)	(1.12)	(1.26)	(1.13)	(0.02)	(0.22)	(1.43)	(2.37)	(0.07)	(0.09)				
150	33.3	39.4	4.98	3.39	2.49	1.84	2.13	2.14	1.71	0.86	0.86	50.87	48.07	49.4	0.134	1.65	13.60	9.28	0.74	0.77	0.904	0.54	0.40	0.69
			(0.62)	(0.57)	(0.20)	(0.10)	(0.18)	(0.11)	(0.16)	(0.03)	(0.05)	(1.68)	(1.49)	(1.64)	(0.04)	(0.30)	(1.46)	(1.58)	(0.05)	(0.08)				
150	34.6	41.4	4.98	3.39	2.49	1.84	2.15	2.14	1.72	0.86	0.85	45.27	42.87	44	0.109	1.42	12.17	9.29	0.74	0.77	0.908	0.54	0.41	0.69
			(0.41)	(0.24)	(0.12)	(0.10)	(0.08)	(0.08)	(0.07)	(0.03)	(0.04)	(3.39)	(3.04)	(3.25)	(0.04)	(0.20)	(1.02)	(0.09)	(0.04)	(0.06)				
150	36.4	42.5	5.18	3.65	2.52	1.86	2.18	2.17	1.76	0.86	0.85	64.26	60.53	62.6	0.121	1.57	12.94	9.77	0.74	0.77	0.908	0.56	0.38	0.63
			(0.61)	(0.49)	(0.33)	(0.09)	(0.12)	(0.11)	(0.09)	(0.07)	(0.05)	(0.70)	(0.99)	(0.51)	(0.02)	(0.34)	(1.4)	(3.80)	(0.16)	(0.07)				

Note: Figures in the brackets are the standard deviations.

$$nd_g = 2.321 + 7.249 \times 10^{-8} n.mc^{3.96739} \quad \left(m > 6.5\,\text{g},\, R^2 = 0.92225\right) \tag{1}$$

$$nd_g = 2.321 + 7.249 \times 10^{-8} n.mc^{3.96739} \quad \left(5.5 \le m \le 6.5\,\text{g},\, R^2 = 0.96359\right) \tag{2}$$

$$nd_g = 2.1076 + 4.2458 \times 10^{-14} n.mc^{7.7927} \quad \left(m < 5.5\,\text{g},\, R^2 = 0.84540\right) \tag{3}$$

Furthermore, the nut moisture content and kernel moisture content (*k.mc*) is best predicted by two term negative coefficient logrithimic function (Table 2 as shown in Equations (4)–(6). This results is similar to that obtained for Tulare, Howard, and Chandler walnut genotype from California (Khir et al., 2011).

$$k.mc = 13.693\, ln\left(n.mc - 18.071\right) \quad \left(m > 6.5\,\text{g},\, R^2 = 0.90462\right) \tag{4}$$

$$k.mc = 15.7066\, ln\left(n.mc - 23.533\right) \quad \left(5.5 \le m \le 6.5\,\text{g},\, R^2 = 0.96832\right) \tag{5}$$

$$k.mc = 21.530\, ln\left(n.mc - 15.926\right) \quad \left(m < 5.5\,\text{g},\, R^2 = 0.99703\right) \tag{6}$$

3.1.2. Nut and kernel mass

Tables 3–5 also shows that at initial nut moisture content of 24.4–28.2% (w.b) and kernel moisture content of 23.1–25.8% (w.b), the nut mass ranged from 4.76 to 7.41 g while the kernel mass ranged from 3.32 to 4.77 g. The nut and kernel mass also increased linearly with moisture content. The data obtained above showed that the African walnut has lower nut mass range than the 32.YS, Buyuk Oba and Persian genotype group from Turkey (Özcan et al., 2010; Ozkan & Koyuncu, 2005). However when the kernel mass is compared, it is similar to the 32.YS.051, 32.YS. 098, 32.YS .075, 32.YS .031 and Kaman-2 genotype. The difference can be found in the shell mass because of the temperate nature of turkey, the 32.YS genotype has thicker shell (Ozkan & Koyuncu, 2005) compared to the tropical wild walnut from Nigeria with thinner shell.

The fitting of the curve through the plot of nut mass (*N*) with kernel mass (*K*) at different mass sizes and moisture content in Tables 3–5. The prediction of measured and estimated kernel mass is given in Equations (7)–(9) for $m > 6.5$ g, $5.5 \le m \le 6.5$ g and $m < 5.5$ g respectively.

$$N = 4.49623 + 1.245 \times 10^{-5} K^{4.013} \quad \left(R^2 = 0.8949\right) \tag{7}$$

$$N = Ln\left(49.59K - 229.86\right) \quad \left(R^2 = 0.9687\right) \tag{8}$$

$$N = 3.311 + 6.902 \times 10^{-23} K^{37.63} \quad \left(R^2 = 0.8949\right) \tag{9}$$

3.1.3. Shell thickness and shell mass

It was observed that there was very large variations in shell thickness and mass among individual walnuts of the same mass size and mosture content. High coeffifficient of variation (CV) for shell thickness has also been observed by Khadivi-Khub and Ebrahimi (2015) on Iranian walnuts. One of the reasons might be the diversity of the nuts from different trees (Khadivi-Khub & Ebrahimi, 2015). Therefore the measurement of the shell thickness and shell mass presented a wide range of values. However the shell thicknes and shell mass ranged from 0. 121–0.144 cm and 2.58–2.79 g respectively for $m > 6.5$ g while for $5.5 \le m \le 6.5$ g, they ranged from 0.123 to 0.135 cm and 1.83–1.99 g respectively. Also for $m < 5.5$ g, the shell thickness and shell mass ranged from 0.109 to 0.145 cm and 1.42–1.83 g respectively. The values of the shell thickness determined were lower than the 32.YS Persian walnut genotype from Turkey (Ozkan & Koyuncu, 2005). However, it is in the same range with the G-570 genotype from Iran (Ebrahimi et al., 2009). The shell on the Nigerian wild walnut is smooth and very thin and can be classified as fine walnut. The thinner nature of the shell makes it easy to crack. Infact locally these wild walnut is cracked with human teeth to remove the kernel for consumption. The result obtained is useful in designing the cracking machine.

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3.1.4. Sphericity, aspect ratio and surface area

The sphericity index and aspect ratio defines the shape of the nut and kernel. For all sizes, the sphericity index was above 0.81 (81%) and increased with moisture contents for the nut and kernel as shown in Tables 3–5. Furthermore, Tables 3–5 show that the aspect ratios ranged from 0.74–0.80 to 0.66–0.79 for the nut and kernel respectively. Garnayak, Pradhan, Naik, and Bhatnagar (2008) described seed with sphericity above 70% as spherical, therefore the wild walnut and kernel has spherical shape and can roll down the hopper during processing. Comparetively, nut with mass greater than 6.5 g is less spherical while the mass range of $5.5 \le m \le 6.5$ g is more spherical (Tables 3–5). There surface area can be calculated as that of equivalent sphere with there values ranging from 12.17–19.32 cm^2 for nut and 8.99–12.21 cm^2 for kernel. The difference in spherity index show a very low variations among moisture contents for all sizes with a coefficient of variation (CV) of $1.39 \times 10^{-5} - 5.81 \times 10^{-4}$ for the nut and $2.47–5.22 \times 10^{-4}$ for kernel. Lowest CV was observed for mass size below 5.5 g while highest value was for mass size of $5.5 \le m \le 6.5$ g.

3.2. Frictional property

The angle of repose (for all surfaces) increased with moisture content (Tables 3–5). This is the tendency of nut beign more cohesive at higher moisture content (Malik & Saini, 2016). However wood surface consistently presented a higher angle of repose than steel and glass in that order. The maximum angle of repose of 64.26° occurred at the highest moisture content of 36.4% moisture cotent for $m < 5.5$ g.

3.3. Gravimetric properties

3.3.1. Porosity and densities

The bulk densities increased with moisture content while the true density and porosities decreased as shown in Tables 3–5. The porosity of the nut and shell, were not statististicall different at all sizes for the initial moisture contents but its statistically significant at the same size at different moisture level. When the initial moisture content is considered, nuts with mass greater than 6.5 g has the highest initial true density of 1.05 g/cm^3 while the modal size range of $5.5 \le m \le 6.5$ g has the lowest initial true density of 0.819 g/cm^3. The bulk density at the initial moisture contents for all sizes ranged from 0.45 to 0.49 g/cm^3 and increased with moisture content. The bulk and true density is lower than G-500 walnut genotype group from Iran (Ebrahimi et al., 2009) but higher than Yalova walnut from Turkey (Altuntas & Erkol, 2010). The porosity of the walnut is lower than the Yalova from Turkey (Altuntas & Erkol, 2010). Equations (10)–(15) depicts the variation of nut true density (δ_T) and porosity ($n\varepsilon$) at different moisture content (X) and sizes.

$$\delta_T = 1.32 - 0.11X \quad \left(m > 6.5\,\mathrm{g},\ R^2 = 0.9247\right) \tag{10}$$

$$n\varepsilon = ln\left(2.152 - 0.017X\right) \quad \left(m > 6.5\,\mathrm{g},\ R^2 = 0.8469\right) \tag{11}$$

$$\delta_T = 0.83 - 7.07^{-21}X^{11.61} \quad \left(5.5 \le m \le 6.5\,\mathrm{g},\ R^2 = 0.7693\right) \tag{12}$$

$$n\varepsilon = 0.48 - 1.24^{-12}X^{-6.8} \quad \left(5.5 \le m \le 6.5\,\mathrm{g},\ R^2 = 0.6303\right) \tag{13}$$

$$\delta_T = 5.06X^{-0.48} \quad \left(m < 5.5\,\mathrm{g},\ R^2 = 0.7101\right) \tag{14}$$

$$n\varepsilon = -0.017X + 1.017 \quad \left(m < 5.5\,\mathrm{g}, R^2 = 0.8585\right) \tag{15}$$

4. Conclusion

Several physical properties of African walnut was investigated and reported at five moisture levels and three size range. Among the physical properties investigated, only the true density and porosity decreased with moisture content while the rest increased. The physical properties show that the African walnut Nigeria cultiva is smaller in nut dimensions and mass compared to Persian walnuts from Turkey, Serbia, Romanian, USA and Iran but their range of true density and sphericity did not vary much. Also despite the smaller size of the whole nut, the kernel mass fall within the same range in some cases. Therefore the larger size of the walnut from these temperate zones might be as a result of thicker shell and not necessarily the kernel size. The shell on the African walnut is smooth and very thin, similar to G-570 genotype from Iran and can be classified as fine walnut. This is important for industrial application for shelling and drying purposes. In addition, due to the smaller sizes they have higher bulk density which is important for packaging and transportation purposes.

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