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Physical and mechanical properties of palm fruit, kernel and nut

Davies, R.M.[*]

Department of Agricultural and Environmental Engineering, Niger Delta University, Wilberforce Island, Amassoma, Bayelsa State, Nigeria

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Experiments were carried out to determine the physical and mechanical properties of palm fruit, kernel and nut as essential parameters in the designing of equipment for processing, transportation, sorting and separating palm fruit, nut and kernel. The parameters investigated were linear dimensions, mean diameters, sphericity, surface area, volume, true and bulk densities, porosity, angle of repose and static coefficient of friction of palm fruit, kernel and nut were determined at 8.3, 10.7 and 9.5% (d.b.) moisture content respectively. The results revealed that the mean length, width and thickness of palm fruit, nut and kernel were significantly different at 5% probability level. The arithmetic and geometric mean diameters, sphericity, surface area and 1 000 grain mass, true and bulk densities were also significantly different ($P<0.05$). The static coefficient of friction on plywood, galvanished steel sheet and glass structural surfaces were observed to be the highest and lowest respectively for palm fruit, kernel and nut.

Key words: Palm fruit, physical properties, parameters, moisture content.

Introduction

The oil palm, *Elaeis guineensis* Jacq., is grown commercially in Africa, South America, Southeast Asia, and the South Pacific, and on a small scale in other tropical areas. In Africa it remained a domestic plant, supplying a need for oil and vitamin A in the diet. The oil palm is rich in vegetable oil. On per unit area basis the oil palm is considerably higher yielding than any other vegetable oil crops. Record yields for other crops such as soybean are about 2 tons of oil per hectare, 3 tons for rapeseed and olive, and 4 for coconut and sunflower. In contrast, thousands of hectares of oil palm plantations in Southeast Asia regularly yield 5 tons of oil per hectare per year, and record yields are appreciably higher (Yusof, 2005).

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[*] Corresponding author: Davies, R.M.; e-mail: rotimidavies@yahoo.com

To develop appropriate equipment for harvesting, handling, conveying cleaning, delivering, separation, packing, storing, drying, mechanical oil extraction and processing of agricultural products the detailed knowledge of physical properties of crops are essential (Davies and EI-Okene, 2009 and Aviara *et al*.,1999). Oil yield and quality have been reported to depend on design parameters (Mohsenin, 1980). Palm oil as a vegetable oil is utilized for various applications-both edible and non-edible. It has technical and economic advantages over other oils and fats, such as beniseed, groundnut, soybean and sunflower due to its various uses. Its price competitiveness and readily available supply is able to serve the needs of oils and fats consumers globally.

The physical properties have been studied for various agricultural products by other researchers such as arigo seed (Davies, 2010), cowpea (Davies and Zibokere (2011), soybean (Manuwa and Afuye, 2004), bambara groundnut (Adejumo, *et al*., 2005), caperfruit (Capparisspp), (Sessiz *et al*., 2005) cocoa bean (Bart-Plange and Baryeh, 2002), pigeon pea (Shepherd and Bhardwaj, 1986), locust bean seed (Ogunjimi *et al*., 2002), wheat (Tabatabaeefar, 2003) nutmeg (Burubai, 2007) and pistachio nut and its kernel (Razari *et al*., 2007).

This work was carried out to study the some physical and mechanical properties of palm fruit, nut and kernel of dura variety of oil Palm tree.

Materials and methods

The palm fruits, kernel and nut were procured for the study from Yenegoa market in Bayelsa State, Niger Delta, Nigeria on 12th June, 2012. The samples were selected and cleaned manually. It was ensured that the fruit were cleaned ~~free~~ of dirt, broken ones and other foreign materials. Moisture content was immediately measured on arrival. The physical properties of palm fruit, kernel and nut were determined at 8.3, 10.7 and 9.5% (d.b.) moisture content respectively.

For this experiment, 100 palm fruit, kernel and nut were randomly selected; the length, width and thickness were measured using a micrometer screw gauge with a reading of 0.01mm. The arithmetic mean diameter and geometric mean diameter of the palm fruit, kernel and nut were calculated by using the following relationships (Galedar *et al*., 2008; Mohsenin, 1980).

$$D_a = (X + Y + Z)/3 \qquad (1)$$

$$D_g = (X\ Y\ Z)^{1/3} \qquad (2)$$

The sphericity was calculated by using the following relationship (Koocheki *et al.*, 2007 and Milani, 2007)

$$\Phi = \frac{(X\,YZ)(X\,Y\,Z)^{1/3}}{X} \tag{3}$$

The surface area S was found by the following relationship given by Mc Cabe *et al*. (1986).

$$S = \pi \; D_g^2 \tag{4}$$

The aspect ratio, R_a was calculated by applying the following relationships given by (Maduako and Faborode, 1990):

$$R_a = (Y/X)\,100 \tag{5}$$

The unit volume of 100 individual palm fruit, kernel and nut were calculated following the formula given by Burubai *et al.* (2007).

$$V = \pi \; X\,Y\,Z\,/6 \tag{6}$$

The 1000 unit mass of palm fruit, kernel and nut were determined using precision electronic balance to an accuracy of 0.01g. To evaluate the 1000 unit mass, 50 randomly selected samples were weighed and multiplied by 20. The reported value was a mean of 20 replications.

The bulk palm fruit, kernel and nut were put into a container with known mass and volume (500ml) from a height of 150mm at a constant rate (Garnayak *et al.*, 2008). Bulk density was calculated from the mass of bulk fruit and kernel divided by the volume containing mass.

$$\rho_b = M_b/\,V_b \tag{7}$$

The true density was determined using the unit values of unit volume and unit mass of individual palm fruit, kernel and nut were calculated using the following relationship by Li *et al*. (1998).

$$\rho_t = M/V \tag{8}$$

The porosity of the bulk palm fruit, kernel and nut were computed from the values of the true density and bulk density of the by using the relationship given by Mohsenin (1980).

$$\varepsilon = (1 - \rho_b) / \rho_t \ \text{x} \ 100 \qquad (9)$$

The static coefficient of friction was determined with respect to four test surfaces namely: plywood, galvanized steel sheet and glass. The static coefficient of friction was calculated based on this equation (Mohsenin, 1980).

$$\mu_s = \tan \theta \qquad (10)$$

The static angle of repose with the horizontal at which the material will stand when piled. This was determined using topless and bottomless cylinder of 0.15m diameter and 0.25m height. The cylinder was placed at the centre of a raise circular plate having a diameter of 0.35m and was filled with palm fruit, kernel and nut. The cylinder was raised slowly until it formed a cone on a circular plane. The height of the cone was measured and the filling angle of repose was calculated by the following relationship (Karababa, 2006 and Kaleemullah and Gunasekar, 2002).

$$\Theta_s = \tan^{-1} \left(\frac{2d}{h} \right) \qquad (11)$$

The axial fracture force (N) of the palm fruit, kernel and nut were measured using Universal Testing Machine. The sample was position directly under the plunger to be pressed. The machine operated until failure occurred on the samples. Then, record the maximum force that corresponds to failure. The accuracy of the machine was ±0.5% with a maximum force of 2 kN. This machine consists of a sensor to measure the breaking force of the sample. The maximum load to cause failure was read on the computer attached to the equipment.

Nomenclature		μ_s	Static coefficient of friction for palm fruit
X	Length of the fruit, mm	M	Mass of individual fruit or kernel (kg),
Y	Width of the fruit, mm	M_b	Mass of fruit or kernel (kg)
Z	Thickness of the fruit, mm	V_b	Volume of container (m^3)
h	Height of the cone, (mm)	V	Unit volume (mm^3).
d	Diameter of the cone, (mm)	Φ	Sphericity (%)
Ra	Aspect ratio	D_g	Geometric means diameter (mm)
ε	Porosity (%)	S	Surface area (mm^2)
ρ_b	Bulk density, (kgm^{-3})	D_a	Arithmetic mean diameter (mm)
ρ_t	True density, (kgm^{-3})	F_x	Vertical fracture force (N)
s_f	Static angle of repose	F_y	Horizontal fracture force (N)
μ_s	Static coefficient of friction		

Results and discussions

The physical and mechanical properties of palm fruit, kernel and nut are shown in Table 1, 2 and 3. The properties were determined at specific moisture content for the three parts of palm fruit: fruit, kernel and nut at 8.3, 10.7 and 9.5% dry basis respectively. The highest axial dimension was observed from *palm fruit,* 42.32, 28.04, and 34.99mm corresponded to length width and thickness respectively. These values were significant different at 5% level. Palm nut had the lowest values of length, width and thickness. The corresponding mean size of the fresh dura palm kernel were length, width and thickness were found to be 30.25mm, 19.94mm and 15.66mm, respectively (Owolarafe *et al*., 2007). The corresponding values of axial dimensions for palm kernel (*Dura variety*), average length, width and thickness ranged from 26.50 - 44.00mm, 16.50 - 28.00mm and 21.50 -34.50mm respectively (Mijinyawa and Omoikhoje, 2005). The mean corresponding axial dimension of simarouba fruit as reported by Dash *et al*. (2008) were 21.26mm, 13.81mm and 11.03mm respectively. While Owolarafe *et al.* (2007) reported also axial dimensions for palm fruit (Dura variety) were length, 30.25mm, width, 19.94mm and thickness, 15.66mm. The parameters are essential for the design of appropriate equipment for processing such as cleaning, sorting, packaging and storage processes. The values of the measured parameters and the corresponding values indicated that the machines required for utilization and processing these products would be different. The mean geometric and arithmetic mean diameter, sphericity and surface area, 1000unit mass, and volume were determined. Palm fruit had the highest geometric and arithmetic mean diameters values ranged from 21.36 to 29.23mm and 20.80mm to 27.80 respectively. The corresponding values for watermelon as reported Koocheki *et al.* (2007) were 6.89 and 8.24mm for Kolaleh, 8.37 and 10.79mm for Ghemez and 7.61 and 9.28mm for Sarakhsi at moisture content of 5.02, 4.75 and 4.55% wet basis. Palm nut was recorded lowest surface area 626.43mm^2 and the highest surface area recorded was palm fruit 2428.26mm^2. As investigation is made by Davies and Zibokere *et al.* (2011) that for mean value of gbafilo fruit and kernel ranged from 1584.80 to 2455.90mm^2 and 737.37 to 1378.90mm^2. The values were lower than the measured parameter. Palm nut had the highest sphericity mean value while the mean sphericity of palm kernel and palm nut were significantly different ($P<0.05$). Galedar *et al*. (2008) reported sphericity for pistachio nut at moisture content of 5.83% and kernel at moisture content of 6.03% were 69.34% and 72.59% respectively. According to Garnayak *et al.* (2008) considered any grain, fruit and seed as spherical when the sphericity value is above 80 and 70% respectively. Therefore, palm nut it can be describe as been spherical based on the sphericty values obtained were above 70-80%.

The palm fruit had the highest 1000unit mass value ranged from 6780.14 to 1239.63g for palm fruit while the least value ranged from 1370.75 to 3583.81g was recorded for palm nut. The corresponding values reported for japtropha seed and kernel, arigo seed, simarouba fruit and kernel, maize, red gram, wheat, green gram, chickpea, faba bean, pigeon pea were 1322.41, 688, 1124.7(±111.3), 1120(±52.54), 330.26(±29.35), 268.30(±0.002), 102(±0.06), 346g, 30.15g, 120g and 75g respectively (Dash *et al*., 2008; Dulta *et al*., 1998; Shephered and Bhardwaj, 1986 and Tabatabaeefar, 2003). It was observed that the highest porosity corresponded to Palm fruit, 31.43% while the least porosity value was shown as palm kernel, 24.03%. The corresponding values of simarouba fruit and kernel were 33.2 (±2.03) and 28.6% (±2.9). Burubai *et al*. (2007) reported porosity of 41% (±4.2) for nutmeg. The values obtained for porosity is solely dependent on the true and bulk density. This can be furthered explained from obtained result that air circulation through the products will be more pronounced in palm fruit compared to palm kernel and palm nut. Table 2 showed the result of true and bulk densities, angle of repose and coefficient of friction for the three parts of palm kernel fruit. Palm fruit had the highest bulk density 0.71g/m^3 and followed by palm nut. Palm kernel had the lowest bulk density 0.64g/m^3. The mean true density values ranged from 1.01±0.04c to 1.22±0.05a gm^{-3} for the three parts palm fruit. The corresponding values as reported by Owolarafe *et al.,* 2007 for true density, bulk density and porosity of fresh dura were 1112.50kg/m3, 995.70kg/m3, 40.67% respectively.

The corresponding values for true and bulk densities for nutmeg and simarouba fruit and kernel were 0.837 488.76, 622.27 and 727.27 kgm^{-3}. The true and bulk densities values of dura palm fruit were 1112.50kgm^{-3} and 659.4kgm^{-3} (Owolarafe *et al.,* 2007). Mijinyawa and Omoikhoje (2005) studied the true density of dura palm kernel and nut. The values ranged from 0.8gcm^{-3} to 2.0gm^{-3} for palm nut while kernel density ranged from 0.93gm^{-3} to 1.33gm^{-3}. The present result is within the mentioned range. The coefficient of static friction on the tested surfaces namely: glass, plywood, galvanized steel and concrete significantly difference at 5% probability level. On the glass surface, the static coefficient of friction values of palm kernel recorded the highest while Palm nut was the lowest. On galvanized metal sheet surface and plywood, the static coefficient of friction palm kernel had the highest values while least was palm fruit. This observation could be attributed to smoothness of surface of palm fruit and as well as contact surfaces. Tabatabaeefar (2007) observed similar trend in the static coefficient of friction of wheat. He recorded lowest static coefficient of friction on glass surface, followed by galvanized iron and lastly plywood. According to Owolarafe *et al*. (2007) reported the coefficient of static friction for glavanised steel, aluminum sheet, plywood and mild steel. They observed that aluminum had the lowest coefficient of friction while plywood was the highest for dura palm fruit. The experimental result of angle of repose for palm fruit ranged from 23.35±0.02˚ to 28.51±0.23˚ for all the three surfaces studied. The highest mean value of angle repose was found to be plywood sheet while the least recorded surface was glass for palm fruit, kernel and nut.

The correlation statistics, for example X/Y, X/Z and X/M with respect to dimensional properties of three parts of palm fruit showed that values were significantly different at 5% probability level as shown Table 3. According to the observed results, the lowest and the highest X/Y value were found with palm kernel and palm nut with mean values of 2.01 and 1.29. The highest and lowest X/Z values were found to be palm nut and palm kernel with average values of 1.97 and 1.74. The highest and lowest of X/M was observed with palm kernel 7.11 and 4.14 palm fruit.

The mean fracture force required breaking the palm fruit, kernel and nut on horizontal position were 0.39, 2.83 and 0.80kN, respectively. The mean fracture force required to break the palm fruit, kernel and nut vertical position were 0.39, 11.00 and 0.92KN. The average c force required to break the dura and tenera palm kernel according to Owolarafe *et al*. (2007) were 2301N and 1149N, respectively.

Table 1. Physical properties of Palm fruit, kernel and nut at moisture (8.3, 10.7 and 9.5%) dry basis

Physical properties	**Fruit**			**Nut**			**Kernel**		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Length (mm)	42.32	28.04	34.99	33.29	25.19	28.77	21.47	15.48	18.63
Width (mm)	25.37	20.01	22.05	24.02	14.33	19.41	17.90	11.80	15.20
Thickness	20.01	16.03	17.87	20.04	13.05	14.60	20.80	15.40	18.06
Arithmetic mean diameter Da (mm)	29.23	21.36	24.97	25.78	17.52	20.92	20.05	14.23	17.47
Geometric mean diameter (Dg) (mm)	27.80	20.80	23.98	25.21	16.76	20.13	20.95	14.12	17.23
Sphericity (%)	65.7	74.2	68.5	75.7	66.5	70.0	97.6	91.2	92.5
Surface area (mm^2)	2428.26	1359.35	1806.78	1996.88	773.37	882.58	1379.03	626.43	932.77
Aspect ratio (%)	59.94	71.36	63.02	72.15	56.89	50.75	83.37	76.23	81.59
Unit Mass (g)	12.791	5.780	8.451	9.832	2.611	5.124	4.583	1.725	3.019
Volume (cm^3)	11.250	4709.92	7220.32	8.392	2.466	4.270	4.185	1.474	2.677

Table 2. Gravimetric and frictional properties palm fruit, nut and kernel at moisture 8.3% dry basis at 8.3% dry basis

Properties	Palm fruit Mean (±S.E.M)	Palm kernel Mean (±S.E.M)	Palm nut Mean (±S.E.M)
True density gcm^{-3}	1.01±0.04c	1.19±0.01b	1.22±0.05a
Bulk density (gcm^{-3})	0.64±0.01a	0.69±0.07b	0.71±0.02c
Porosity (%)	31.43±0.61a	27.73±0.15b	24.03±0.08c
Static angle of repose			
Glass (˚)	23.35±0.12a	27.94±0.18b	25.49± 0.12c
Galvanised steel sheet	26.94 ±0.08a	27.43±0.23a	27.21±0.09a
Plywood sheet	28.51±0.23a	28.87± 0.31a	26.58± 0.05b
Static coefficient of friction			
Glass	0.45±0.02c	0.56±0.04a	0.48±0.01b
Galvanised steel sheet	0.59±0.01c	0.63±0.02a	0.61±0.05b
Plywood	0.61±0.04c	0.68±0.06a	0.64±0.07b
F_x Vertical fracture force (N)	0.39±0.03c	2.83±0.01a	0.80±0.01b
F_y Horizontal fracture force (kN)	0.27±0.01c	11.99±0.98a	0.92±0.02b

S.E.M- Standard error of means. Means with same letter are not significantly different ($P>0.05$)

Table 3. Dimensional parameters ratio of the studied palm fruit parts

Product part	No of observation	Parameters	Ratio
Fruit	20	X/Y	1.59
	20	X/Z	1.96
	20	L/M	4.14
Kernel	20	X/Y	2.01
	20	X/Z	1.97
	20	L/M	4.16
Nut	20	X/Y	1.29
	20	X/Z	1.74
	20	L/M	7.11

Conclusion

Based on study carried on the some physical and mechanical properties of three parts palm fruit namely palm fruit, kernel and nut at moisture content of 8.3, 10.7 and 9.5% dry basis respectively the following conclusion were drawn. The mean major, intermediate, minor, arithmetic and geometric mean diameter, sphericity, surface area, 1000-seed unit mass, for the three parts of palm fruit were significantly different (P<0.05), The mean porosity, true and bulk densities, hardness and angle of repose were investigated for the three varieties were significantly different at 5% probability level, The coefficient of static friction of cowpea was determined for three different surfaces, glass, galvanished steel sheet and plywood. plywood surface was observed to have higher coefficient of static friction for the three varieties, The mean fracture force required to break the palm fruit, kernel and nut on vertical and horizontal orientation position were significantly different (P<0.05).

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