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DETERMINATION OF SOME PHYSICAL PROPERTIES OF PALM KERNEL AND SHELL IN RELATION TO FRICTIONAL SEPARATION

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ABSTRACT

Some physical properties of palm kernel and shell related to frictional separation were determined for *tenera* and *dura* varieties of oil palm fruits. The physical properties of palm kernel and shell of the two varieties were determined through standard procedures. The properties were: geometric mean, arithmetic mean, sphericity, aspect ratio, projected area, one thousand grain mass, true density, bulk density, porosity, angle of repose, mass, coefficient of sliding friction on four canvas materials (fibre, jute, leather tarpaulin and polyurethane foam) and moisture content. Physical properties of the dura variety obtained for kernel and shell ranged from 10.08-13.08 mm for geometric mean; 10.70-13.35 mm for arithmetic mean; 79.51-81.92% for sphericity; 0.78-0.81 for aspect ratio; 105.53-167.13 mm for projected area; 635-1020.5 g for one thousand grain mass; 479.86 – 1543.43 kg/m^3 for true density, 285.08 – 698.32 kg/m^3 for bulk density; 4.48 – 81.53% for porosity, 27.4-29.8^o for angle of repose, 0.45-1.19 g for mass, 0.51- 1.24, and 9.5 -10.7% w.b for moisture content. The canvas materials had significant effect ($p < 0.05$) on the coefficient of sliding friction but the variety had no significant effect ($p \geq 0.05$) for both palm kernel and shell, meaning that irrespective of the component (palm kernel or palm shell) used, the result of their significance would be the same always on any canvas materials. The physical properties of the two varieties that were different from each other which would help in machine designing for palm kernel and shell.

Keywords: Oil palm, coefficient of sliding friction, machine design and canvas material.

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INTRODUCTION

The oil palm (*Elaeis guineensis*) is an indigenous perennial plant to the tropical rain forest region of West Africa, mostly in the southern parts of Ghana and Nigeria. It is widely grown due to its importance as a high yielding source of edible and technical oils.

The palm fruit yields two distinct types of oil which are palm oil and palm kernel oil (PKO). The palm oil is extracted from the mesocarp (pulp) of the fruit which is edible and also used primarily in food products. While the palm kernel oil (PKO) is extracted from the kernel of the fruit. Palm kernel oil is very valuable because it contains lauric acid. Lauric acid is a useful fatty acid where it can be used to produce soaps, washing powders and cosmetics. There is a high demand for both palm oil and palm kernel oil due to their domestic and industrial uses (Emeka and Olomu, 2007).

The hard kernel nut must be cracked after the expression of palm oil from the pulp of the oil palm fruit to obtain the edible kernel from where palm kernel oil is produced. The usual methods employed in Nigeria are manual cracking and use of mechanical crackers. However both methods do not separate the shells from the kernels after cracking. Manual separation and the use of clay-bath are the methods usually employed for separation but they are time and energy consuming. There is therefore the need for the development of machines that can separate cracked shell from kernel.

Physical and mechanical properties of a crop are very important in the design of machines and analysis of the behaviour of the crop during agricultural process operations such as cleaning, sorting, drying, handling, planting, harvesting and threshing (Akaimo and Raji, 2006). Aderinlewo *et al.* (2011) also reported that in the design of any agricultural handling and processing machine, properties of the crop such as the grain size, shape, mass, hardness, angle of repose, grain-straw ratio, moisture content, kernel and bulk density must be taken into account.

Several researchers have investigated the physical and mechanical properties of different crops and food materials which include Soybean (Despande *et al.*, 1993), Cumin Seed (Singh and Goswani, 1996), Paddy Rice (Nalladurai, 2003), Sheanut (Aviara *et al.*, 2005), Green Wheat (Al-Mahasneh and Rababah, 2006), Corinder Seed (Coskuner and Ersankarababa, 2007), Cowpea (Aderinlewo *et al*, 2011) and Beniseed (Olayanju *et al.*, 2009).

This work was therefore carried out to determine the Physical properties of two varieties of oil palm commonly grown in Nigeria, namely: *dura* and *tenera* in order to obtain data for the design and construction of an inclined draper separator.

MATERIALS AND METHODS

Dura and *tenera* varieties of palm kernel nuts were obtained from the Teaching and Research Farm of Federal Universities of Agriculture, Abeokuta, Nigeria. The kernel nuts were manually cleaned to remove foreign materials, dust, dirt and broken kernels. The kernel nuts were thereafter cracked with a palm kernel cracking machine available at the College of Engineering of the University. The moisture content of the shells and kernels were determined by oven drying method for both *dura and tenera* varieties as used by Orhevba *et al.* (2013).

Fifty (50) replicate samples of palm kernels each of the two varieties were randomly selected at a determined level of moisture content (4.9 for *dura* kernel, 2.5 for *tenera* kernel, 4.3 for *dura* shell and 5.1 for *tenera* shell). The three Principal dimensions of kernel, major (length), intermediate (width), and minor (thickness) diameters, were measured with a micrometer screw gauge of reading accuracy of 0.01 mm (Plate 1). The geometric mean diameter, arithmetic mean diameter, sphericity, aspect ratio, project area and shape index of each kernel were determined using the following equation proposed by Mohsenin (1986) as reported by Eric *et al*, 2009 and used by researchers, including Olayanju *et al.* (2002), Lucas and Olayanju (2003), and Aderinlewo *et al.* (2011):

$$D_g = (L \times W \times T)^{1/3} \quad (1)$$

$$A_r = \frac{(L + W + T)}{3} \quad (2)$$

Where: D_g is the geometric mean diameter.

A_r is the Arithmetic mean diameter.

L is the longest intercept (length) in mm

W is the longest intercept normal to 'L' (width) in mm

T is the longest intercept normal to 'L' and 'B' (thickness) in mm.

Sphericity, $\psi = \frac{D_g}{L} \times 100$ (3)

Plate 1: Size determination by micrometer screw gauge

The aspect ratio, R_a, was calculated as follows (Aderinlewo *et al.* (2011)).

$$Aspect\ Ratio, R_a = \frac{W}{L} \quad (4)$$

Palm kernel is ellipsoidal in shape (Koya *et al.*, 2004), the projected area, A_p, was calculated from the following relationship used by Aderinlewo *et al.* (2011).

$$Projected\ area, A_p = \frac{\pi LW}{4} \quad (5)$$

Shape characteristics of the kernels was determined using shape index obtained from the equation 6 (Olayanju *et al.*, 2002).

$$Shape\ index = \frac{a}{\sqrt{b \times c}} \quad (6)$$

Where a is the major diameter in mm
b is the intermediate diameter in mm and c is the minor diameter in mm.

One thousand grain mass was determined by randomly selected two hundred and fifty (250) kernels of the two varieties at each desired moisture level were weighted on an electronic beam balance of reading accuracy of 0.001g. The mass of one thousand seeds was calculated using equation (7) as used by Singh et al. (2004).

$$\mathbf{M_t = \frac{M}{n} \times 1000} \quad (7)$$

Where M_t is the mass of 1000 seeds, M is the weight of 250 seeds and n is the number of seeds.

The true or solid density is defined as the ratio of a given mass of a sample to the volume occupied by the same sample. The true densities of kernel and shell were determined by the water displacement method as described by Olayanju *et al.* (2002). A weighed quantity of kernels and shells was poured into a 250 cm^3 fractionally graduated cylinder containing 120 cm^3 of distilled water. The volume of water displaced by the kernels and shells was noted. The true density was calculated as:

$$\text{True density} = \frac{m_s}{v_w} \quad (8)$$

Where m_s = mass of sample, g

v_w = volume of water displaced, cm^3

The experiment was repeated five times to get an averaged calculated true density.

The bulk density was determined by filling a container of known mass and volume to the brim with each variety of kernels and shells. The net mass each of kernel and shell was obtained by subtracting the mass of the container each from the mass of kernel and the mass of shell respectively. To achieve uniformity in bulk density, the container was tapped 10 times in the same manner in all measurement to consolidate as reported by Irtwange and Igbeka (2002). The bulk density was then calculated as

$$\text{Bulk density} = \frac{m_s}{v_o} \qquad (9)$$

Where m_s = mass of sample, g

v_o = volume occupied, cm^3

The experiment was repeated five times to get an averaged calculated bulk density.

The porosity defined as the space in the bulk grains which is not occupied by the grains was calculated from the following relationship (Mohensin, 1986):

$$P_f = 100\left(1-\frac{\rho_b}{\rho_t}\right) \qquad (10)$$

Where P_f = porosity, %

ρ_b = bulk density, g/cm^3

ρ_t = true density, g/cm^3

The method of determination of the coefficient of sliding friction described by Sitkei (1986) as used by Gbadamosi, (2006), was used for the determination. The crop product components were loaded into a bottomless four-sided cardboard box of dimension 50 mm by 30 mm on the tilting board. One of the edges of the box was not fixed in order to allow for the movement of the crop product component on the board surface covered with a canvas material. The board was tilted by the adjustable screw below it in order to measure the tilted angle of the board by the protractor fixed to the equipment (Plate 2). The surface of the board was covered with the following canvas materials:

1. Jute
2. Polyurethane foam
3. Cloth tarpaulin
4. Fibre

The box was loaded with the kernels and shells of *dura* and *tenera* varieties in turns. The tilt angle at initial sliding of the box on the lined tilting board was noted, for five readings and averaged. The averaged tilted angle was used to obtain the coefficient of friction of the materials by using equation 11.

$$\mu = tan\theta \qquad (11)$$

Where μ is the coefficient of friction

θ is the angle of inclination / tilt angle (degree)

Plate 2: Angle of repose apparatus

The angle of repose is the angle with respect to the horizontal at which the material will stand when piled. The angle of repose of kernel and shell for the two varieties was determined using the plastic hollow pipe of height 18.5 cm and diameter 5.0 cm. According to the method described by Gbadamosi (2006), the spread and the height of each of kernel and shell were noted and recorded for five times (Plate 3). The average value of angle of repose was obtained through equation 12. The angle of repose is the arctangent of the ratio of the height of the resulting cone to the half of the width of the base of the cone.

$$\theta = \tan^{-1}\ (h/\tfrac{D}{2}) \qquad (12)$$

$$\theta = \tan^{-1}(\tfrac{2h}{D}) \qquad (13)$$

Where θ is the angle of repose in degrees
h is the height of piled sample (mm)
D is the diameter of sample (mm)

Plate 3: Determination of angle of repose

Statistical analysis was carried out on the effect of the canvas materials used on the coefficient of sliding friction of palm kernel and shell by Minitab Statistical Package.

RESULTS AND DISCUSSION

True Density

The true densities of the varieties with their shells were: 999.92 kg/m^3 for *dura* kernel, 1108 kg/m^3 for *tenera* kernel, 479.86 kg/m^3 for *dura* shell and 1543.43 kg/m^3 for *tenera* shell (Table 1). True density depends on the form of the particles, the composition of the particles and method of storage. Therefore, rounded, compact particles will be closer together during the pouring than edged, splintery particles. This result is similar to the range of values obtained by Gbadamosi (2006), Koya *et al.* (2004) and Mijinyawa and Omoikhoje (2005) of 1.31 g/cm^3, 1.06 g/cm^3; 1.12 g/cm^3, 1.11 g/cm^3; and 1.09 g/cm^3 for *dura* and *tenera* respectively.

Bulk Density

The bulk densities obtained were: 674.72 kg/m^3 for dura kernel, 698.32 kg/m^3 for tenera kernel, 458.34 kg/m^3 for dura shell and 285.08 kg/m^3 for tenera shell (Table 1). This result is in-line with the results obtained by Koya *et al.* (2004) of 710.0 kg/m^3 for dura and 711.10 kg/m^3 for t*enera* where the value obtained for *tenera* was slightly higher than value for *dura*. The result showed that the bulk density of *tenera* kernel was higher than that of *dura* kernel because the available voids between *tenera* kernels were more than that of *dura* kernels. Conversely, the bulk density of *dura* shell was more than that of *tenera* shell. This can be attributed to the thickness and the shape of the shell formed after cracking the nuts. However, this property is useful in calculating the volume of hopper and mass of required feed of a machine.

Porosity

The porosities obtained were: 32.52 for *dura* kernel, 36.97 for *tenera* kernel, 4.48 for *dura* shell and 81.53 for *tenera* shell (Table 1). The porosity of *tenera* kernels was higher than the porosity of *dura* kernels. This confirmed the fact that *tenera* kernels are closer to sphere which invariably had more voids than *dura* kernels. The ratio of the bulk density to true density of the oil palm kernel varieties also affects the outcome of the porosity. The *dura* shells have the lower porosity than tenera shells because of their shell dimension after being cracked.

Angle of Repose

The angles of repose obtained accordingly for *dura* kernel (28.6°), *tenera* kernel (27.4°), *dura* shell (29.8°) and 29.8° for *tenera* shell (Table 1). The angles of repose obtained by Gbadamosi (2006) for *dura* and *tenera* were 32.60° and 31.40° respectively; the angle of repose obtained for *dura* kernel was higher than the *tenera* kernel. This was in accordance with the result obtained where the angle of repose for *dura* was higher than that of *tenera*. The variation in values can be attributed to the morphology of the material used which affects the angle of repose. The angle of repose as a property can be used in the design of hopper in order to know the steepest angle of the side of hopper for easy flow of materials.

Mass

The average masses were 1.19 for *dura* kernel, 0.65 for *tenera* kernel, 0.45 for *dura* shell and 0.65 for *tenera* shell (Table 1). The values helped in knowing the effect of force of gravity on materials when on the surface of an inclined plane. The force of gravity decreases from *dura* kernel to *tenera* kernel to *tenera* shell and lastly to *dura* shell on an inclined plane. Mixture of kernel and shell of *dura* variety would likely have higher separation efficiencies on an inclined draper separator than mixture of kernel and shell of *tenera* variety because of their mass variation. This information is useful in the design of an inclined separator.

Sphericity

Dura kernel and *tenera* kernel had the following values; 79.51% and 81.92% respectively (Table 1). This result is similar to the results obtained by Akubuo and Eje (2002), Mijinyawa and Omoikhoje (2005) and Gbadamosi (2006) of 0.80 (*dura*); 0.78 (*dura*); and 0.80 (*dura*) and 0.70 (*tenera*) respectively. This shows that *tenera* kernel is closer to sphere than *dura* kernel. Therefore, the tendency for *tenera* kernel to roll faster than *dura* kernel is higher because of its higher sphericity. This information is useful in the design of hoppers, separators and conveyors.

One Thousand Grain Mass

One thousand grain mass of *dura* kernel, 1020.5 g was higher than the one thousand grain mass of *tenera* kernel, 635.0 g by all indication (Table 1). This hereby shows that *dura* kernel is heavier in quantity of matter as compared to *tenera* kernel. This confirmed the result obtained for average masses of fifty (50) *dura* kernels and *tenera* kernels each, which were 1.19g and 0.65 g respectively where the value obtained for *dura* kernel was higher.

Table 1: True density, bulk density, porosity, angle of repose and sphericity of *dura* and *tenera* varieties

Item No	True density (kg/m^3)	Bulk density (kg/m^3)	Porosity (%)	Angle of repose (^{o})	mass (g)	Sphericity %	1000 Grain mass (g)	Moisture Content (wet basis) %
Dura	999.92	674.72	32.52	28.6	1.19	79.51	1020.5	4.9
Tenera	1108	698.32	36.97	27.4	0.65	81.92	635.0	2.5
Dura shell	479.86	458.34	4.48	29.8	0.45	-	-	4.3
Tenera shell	1543.43	285.08	81.53	29.8	0.64	-	-	5.1

Coefficient of Sliding Friction

The coefficient of friction of *dura* kernel, *tenera* kernel, *dura* shell and *tenera* shell ranged from 0.51 to 1.24 on the following canvas materials; *fibre*, jute, leather tarpaulin and polyurethane foam (Table 2). The coefficient of sliding friction decreased accordingly from *fibre* to jute to polyurethane foam and to leather tarpaulin. According to Olaoye *et al.*, 2011, belt slopes less than the angle of sliding friction of the crop product components, the motion of the particles is hyperbolic, and the belt system behaves as a conveyor; for belt slopes greater than the angle of sliding friction of crop product components, the motion of the particles is sinusoidal and with sufficient belt length for the particle motion to be reversed, the crop product components can be discriminately discharged at either the foot or the head of the conveyor belt. Canvas materials with least coefficient of sliding friction which will invariably have the least angle of sliding friction will separate components (for example mixture of kernels and shells) at a lower angle (Table 2). Therefore, out of the four canvas materials tested, leather tarpaulin will likely have the highest separation efficiency than any other materials selected. This property is one of the major factors in frictional separation.

Table 2: The coefficient of sliding friction of *dura* and *tenera* varieties on four surfaces

Item No	*Fibre* front		*Fibre* back		Jute		Leather tarpaulin		Polyurethane foam	
	θ	μ	θ	μ	θ	μ	θ	μ	θ	μ
Dura	39.4	0.8214	38.9	0.8069	37.6	0.7701	28.7	0.5475	37.4	0.7646
Tenera	35.2	0.7054	32.6	0.6395	43.0	0.9325	30.3	0.5844	37	0.7536
Dura shell	51.2	1.2437	50.4	1.2088	50.0	1.1918	26.8	0.5051	44.2	0.9725
Tenera shell	50.4	1.2088	50.4	1.2088	47.4	1.087	31.4	0.6104	44.7	0.9

μ = coefficient of friction; θ = angle of inclination

Surface Area

The surface areas of palm kernel of dura and tenera were 540.24 mm^2 and 349.44 mm^2, respectively (Table 3). The surface area of dura kernel was more than that of tenera kernel because of the linear dimensions of dura kernel are higher than that of tenera kernel.

Projected Area

Projected area is two - dimensional area measurement of a three-dimensional object by projecting its shape on to an arbitrary plane. The projected area of dura kernel (167.13) was higher than that of tenera kernel (105.53) because of surface area, geometric diameter, arithmetic diameter, shape index, major diameter, intermediate diameter and minor diameter of dura kernel are higher than that of tenera kernel (Table 3). This confirmed why tenera kernel was closer to sphere than dura kernel.

Aspect Ratio

The aspect ratios of dura kernel and tenera kernel were 0.78 and 0.81 respectively (Table 3). The tenera kernel value was higher than the dura kernel which shows that tenera kernel variety could roll more easily than dura kernel variety because tenera kernel is closer to sphere than dura kernel. This information is useful in the design of hoppers, separations and conveyors.

Table 3: Linear dimension of *dura* and *tenera* varieties

Item No	Surface Area (mm^2)	Geometic Dia. (mm)	Arithmetic Dia. (mm)	Shape Index	Major Dia. (mm)	Inter Dia. (mm)	Minor Dia. (mm)	Projected Area, A_p	Aspect Ratio, R_a
Dura	540.24	13.08	13.35	1.43	16.57	10.66	12.82	167.13	0.78
Tenera	349.44	10.08	10.70	1.37	12.96	8.78	10.38	105.53	0.81

The canvas materials had significant effect at $p < 0.05$ on the coefficient of sliding friction of palm kernel. This means that the coefficient of sliding friction of at least two canvas materials are significantly different from each other. The variety tested had no significant effect at $p \geq 0.05$ on the coefficient of sliding friction of palm kernel (Table 4). The coefficient of sliding friction of the two varieties would significantly be the same on the same canvas material used. Nonetheless, the interaction of the canvas materials with the variety used was significant on the coefficient of sliding friction which means that the coefficient of sliding friction of the variety would significantly be affected by the type of the canvas materials used (Table 4).

Table 4: Analysis of Variance for the Effect of Canvas Materials, Variety and their interaction on the coefficient of sliding friction of palm kernel

Sources of variation	SS	Df	MS	F	P-value
Canvas materials	0.428	3	0.143	27.091	0.000
Variety	0.002	1	0.002	0.371	0.546
Interaction	0.167	3	0.056	10.572	0.000
Error	0.393	46	0.009		
Total	0.821	49			

Canvas materials and their interaction with the variety tested had significant effect at $p < 0.05$ on the coefficient of sliding friction of palm shell but the variety had no significant effect at $p \geq 0.05$ (Table 5). This means that the coefficient of sliding friction of at least two canvas materials were significantly different from each other. The coefficient of sliding friction of the two varieties would significantly be the same on the same canvas material used. Nevertheless, the interaction of the canvas materials with the variety was significant on the coefficient of sliding friction which means that the coefficient of sliding friction of the variety would significantly be affected by the type of the canvas materials used (Table 5).

Table 5: Analysis of variance for the effect of the canvas materials, variety and their interaction on coefficient of sliding friction of palm shell

Sources of variation	SS	Df	MS	F	P-value
Canvas materials	3.129	3	1.043	355.593	0.000
Variety	0.004	1	0.004	1.335	0.254
Interaction	0.060	3	0.020	6.872	0.001
Error	0.123	42	0.003		
Total	3.317	49			

The means of the coefficient of sliding friction for canvas materials were significantly different from each other except for urethane foam and fibre which were insignificantly different from each other for palm kernel (Table 6). The means of the coefficient of sliding friction for the canvas materials were significantly different from each other. This means that all the canvas materials were statistically different from each other in terms of their coefficient of sliding friction.

Table 6: Summary of the least significant differences of the canvas materials for palm kernel and palm shell

	Canvas materials	Coefficient of sliding friction
Palm kernel	Leather tarpaulin	0.568^{a}
	Jute	0.853^{b}
	Urethane foam	0.761^{c}
	Fibre	0.745^{c}
Palm shell	Leather tarpaulin	0.558^{a}
	Jute	1.141^{b}
	Urethane foam	0.947^{c}
	Fibre	1.219^{d}

means with different letters are significant but means with the same letter are insignificant at 0.05

CONCLUSIONS

This study obtained values for physical properties of palm kernel and shell sequential to the development of an inclined draper separator for palm kernel and shell following standard operational procedure. The following conclusions were drawn from the study:

The physical properties of the two varieties are different from each other. This would help in designing machines, especially a separator, for palm kernel and shell mixtures by considering their physical properties independently.

The analysis carried out on the effect of canvas materials and variety on the coefficient of sliding friction of palm kernel and that of shell showed that they were similar in terms of significance of the factors. This means that irrespective of the component (palm kernel or palm shell) used to determine coefficient of sliding friction, the result would be the same always.

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