SELECTED ENGINEERING PROPERTIES OF PALM NUT (*ELAEIS GUINEENSIS)* REQUIRED IN THE DESIGN OF PALM KERNEL-SHELL SEPARATOR

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ABSTRACT

Based on high dependence of many companies on palm kernel products for soap making vegetable oil and body cream, an efficient palm kernel-processing machine is therefore not only necessary but also important to regenerate the production of palm kernel oil in order to meet up with the ever increasing demand for the industries. Therefore, the knowledge of engineering properties becomes very important in the design of suitable and appropriate palm kernel-shell separator. The parameters investigated were linear dimensions, arithmetic mean and geometric mean diameters, surface area, sphericity, true and bulk densities, angle of repose, drag coefficient and terminal velocity of palm nut and kernel at 7.19 % and 9.5 % (d.b.) moisture content, respectively. The results revealed that average arithmetic mean diameter, geometric mean diameter, sphericity, surface area, angle of repose, drag coefficient and terminal velocity were 20.88/12.55 mm, 20.08/12.41 mm, 0.69/0.84 %, 104.67/485.31 mm^2, 19.33/19.17 °, 1.93/1.22 and 5.72/3.21s m/s, respectively for nuts/kernel seeds. Some of the properties of the palm nut have been determined and found useful in the design and construction of palm kernel shell separator. These properties were needed as input to models or predicting the behaviour of agricultural produce in pre-harvest, harvest, and post-harvest conditions, to aid better understanding of processing and design of machines.

Keywords: Palm nut, Kernel, Engineering properties, Moisture content, Shell separator

1. Introduction

Nigeria was one of the major exporters of palm oil in the world in the early sixties, producing about 400,000 metric tons which amount to about 65% of the world palm trade. Nigeria palm kernel oil export started reducing drastically in the late seventies, from 65% to 15% when there was an oil boom (Ndegwe, 1987). Oke (2007) reported that based on high dependence of many companies on palm kernel oil for soap making, vegetable oil and body cream, an efficient palm nut and kernel-processing machine is therefore not only necessary but also important to regenerate the production of palm kernel oil in order to meet up with the ever increasing demand from the industries and other domestic uses of palm oil. Kheiri (1985) reported that palm kernel is the most favoured vegetable oil plant and many products can be derived from the oil palm, these includes; palm oil, palm kernel oil, palm kernel cake, fibre, palm wine, fatty alcohol, broom and wood plank. Harvested fresh fruit bunches undergo processing stages of palm oil extraction. Palm nuts and fibres are left as residues. The nuts are dried and cracked to get palm kernel and shell as the by-products (Ndukwu and Asoegwu, 2010).

Palm kernel separation has been the most challenging aspect of palm kernel oil production in that the fibres, palm nuts and cracked nuts are all produced before other activities are performed on it. The separation of the palm kernel from other by-products is therefore said to be time consuming, stressful and less effective. This problem has caused the low supply of palm kernel to the market for the production of palm kernel oil and other products. The separation of the kernels from the shells is a very difficult process and an issue which continues to be of great concern within the industry. In the developing nations, small scale palm mills make use of manual labour for the separation of the kernels. The local methods of cracking palm nuts involved using stones and separation of kernels by hand picking from the cracked shells which is associated with drudgery, cumbersome and very sluggish to meet the demand of the growing industries (Oke, 2007).

Therefore, the knowledge of engineering properties becomes very important in the design of a suitable or appropriate palm kernel-shell separator. Koya *et al.* (2004) reported that some engineering properties of agricultural seeds and kernels are considered very important for the rational design of tools and equipment for seeds processing, handling and storage systems. The seeds properties require are true density, bulk density, hardness, specific heat capacity, compressive strength and toughness, angle of repose, co-efficient of sliding friction, size and shape. These properties of biomaterials (crops/seeds) are essential parameters in the design of equipment/tools, development of processing methods and utilization (Akinoso and Raji, 2011; Bagherpour *et al*., 2010; Ogunsina *et al*., 2008).

The engineering properties which are significant for machine design must be known and determined under laboratory conditions as reported by Gürsoy and Güzel (2010). Agricultural materials especially food products are of important and been transformed into different products with great economic importance. These food products are greatly increasing with the complexity of new technology for production, handling, preservation and storage. In addition, Kachru *et al*. (1994) reported that it is necessary to determine the engineering properties of oilseeds for proper design of equipment for drying, separation, handling, aeration and conveying, hulling and mechanical extraction of oil from these seeds.

Machines efficiency, capacity, quality and the yield of oil depends on design considerations, variables under consideration and necessary assumptions (Akinoso *et al*., 2009). Improvement on the processing of palm fruit, nut and kernel requires accurate information of the physical and mechanical properties of the crop as affected by primary processing (Akinoso and Raji, 2011). Engineering properties will guide manufacturers/fabricators in the design of appropriate processing machines and modify the components of the existing machine which entails progress of technology transfer and adoption to produce palm nut- fibre separator from small to medium scale level. Figures 1 and 2 showed palm nut and palm kernel, respectively. The developed or modified new machine will drastically reduce the drudgery associated with farm works and the cost involved in the production of palm oil in a more hygienic way and under good environmentally friendly conditions (Adzimah, and Seckley, 2009). This work was therefore carried out to study some selected engineering properties of palm nut (*Elaeis guineensis)* required in the design of palm kernel-shell separator.

Figure 1: Kernel Seed/Nut

Figure 2: Palm Kernel

2. Material and Methods

2.1 Sample preparation

The bulk of the palm nut used for the study was procured directly from a local palm nut producing farmer at Iresa-Adu, a village in the suburb of Ogbomoso, Oyo State, Nigeria. The laboratory study of the nuts was conducted at the processing laboratory of the Agricultural Engineering Department, Faculty of Engineering and Technology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. The procured nuts were sun dried for some days to reduce their moisture content and then cracked to free the kernels from the shells. The moisture content of the shells and the kernels were also determined. For the determination of the physical properties of the nuts and kernels, 150 samples of the nuts and kernels were randomly selected for processing and measurements.

2.2 Determination of the Physical Properties of Palm Nut and Kernel

2.2.1 Arithmetic Mean Diameter

The arithmetic mean diameter of the nuts and kernels was determined from the three-principle diameters using eqn. 1 (Busari and Olaoye, 2016).

$$AMD = \frac{l+b+t}{3} \quad (1)$$

Where:

AMD = Geometric mean diameter, mm
I = *T*hickness of the nut/kernel, mm
b = Width of the nut/kernel, mm
t = *L*ength of the nut/kernel, mm.

2.2.2 Geometric Mean Diameter

The geometric mean diameter was determined from the thickness of the nut/kernel, width and length using the relationship in eqn. 2 (Mohsenin, 1986)

$$GMD = (lbt)^{\frac{1}{3}} \qquad 2$$

Where:

GMD - Geometric mean diameter, mm
l, *b and t* are as defined in eqn. 1.

2.2.3 Sphericity Determination

Sphericity is a function of the basic dimensions of seeds/nuts under consideration (length, width and thickness) and can be calculated/determined using the relationship in eqn. 3 as reported by Erica *et al*. (2006); Garnayak *et al*. (2008); Davies and Zibokere (2011).

$$(\emptyset) = \frac{(lbt)^{\frac{1}{3}}}{l} \qquad 3$$

Where:

$\emptyset$ = Sphericity measured, %

2.2.4 Surface Area

Surface area can be estimated by the formula corresponding to the geometrical shape similar to the shape of kernel using eqn. 4.

$$S = \pi(GMD)^2 \qquad 4$$

Where:

GMD = Geometric mean diameter, mm

2.2.5 Specific Surface Area

The specific surface area is obtained from eqn. 5 (Davies, 2012)

$$S_S = \frac{\rho b}{mu} \qquad 5$$

Where:

mu = *M*ass of one unit of palm kernel, g.
ρb = *B*ulk density of kernel, g/cm^3.

2.3.6 Bulk density and true density of palm nut/kernel

Bulk and true densities were measured according to Chandrasekar *et al.* (1999). A container with known weight and volume was used for volume measurement. Bulk density is equal to mass of bulk material divided by volume containing the mass. To determine the true density, the mass of individual material was measured according to Mohsenin *et al.* (1986). The true and bulk densities were calculated using relationships in eqn.s 6 and 7.

$$TrueDensity = \frac{weight\ of\ the\ sample\ (\frac{nuts}{kernel})}{volume\ of\ distilled\ water\ displaced} \qquad 6$$

$$BulkDensity = \frac{weight\ of\ sample\ (\frac{nuts}{kernel})}{volume\ occupied} \qquad 7$$

2.3.7 Determination of angle of repose

A regular cylindrical container opened at both ends and placed on a galvanized steel surface was filled with the palm kernel to the brim. Afterwards the container was lifted gradually and finally emptied to form a conical heap with the seeds. The tangent of the angle of inclination to the horizontal ($\tan\theta$) was calculated from the height (h) and base radius (r) of the formed heap as reported by

Busari and Olaoye (2016). The angle of repose was calculated using the relationship in eqn. 8

$$\theta = tan^{-1}\left(\frac{h}{r}\right) \qquad 8$$

Where:

θ = the angle of repose, degree
h = height of the pile, mm and
r = radius of the pile, mm.

2.3.8 Coefficient of friction

Coefficient of static friction was calculated using the method described by Solomon and Zewdu (2009). The Coefficients of static friction of the nuts/kernels was determined on three different surfaces; plywood, galvanized iron sheet and glass. The nuts/kernels were placed on the surfaces each at a time of an inclined apparatus. The plane portion of the apparatus was raised. The angle of inclination to the horizontal, as soon as the nuts/kernels began to slide, was measured from a protractor attached to the inclined plane. The coefficient of friction was calculated from eqn. 9 (Mohsenin, 1986)

$$\mu = tan\,\alpha \qquad 9$$

Where:

μ = the coefficient of friction and
α = the angle of tilt, degree.

2.3.9 Determination of Aerodynamic Properties using Sphericity Method

The drag coefficient and terminal velocities of both un-cracked palm nuts and palm kernel nuts samples were computed using sphericity method using the relationship reported by Olayanju *et al.* (2008), Ayman Hafiz (2009), Salah *et al*. (2011) and Oloyede (2015) as given in equations 10 and 11.

$$C_d = 5.31 - 4.884S_{ph} \quad (10)$$

$$Vt = \sqrt{2Mg/ApSfCd} \quad (11)$$

Where:

Vt = Terminal velocity, m/s

M = Weight of the sample, kg,

A_p = Area of the sample (LW), m^2 S_f = Air density, kg/m^3,

Cd = Drag coefficient, S_{ph} = Sphericity of the sample.

3. Result and Discussion

The selected engineering properties of the palm nut and palm kernel are shown in Tables 1 and 2, respectively. The required physical properties of the nuts and kernel were determined at 7.19 and 9.5 % dry basis moisture content, respectively. The highest axial dimensions of 35.07, 22.25 and 17.72 mm for length, width and thickness, respectively were obtained for the palm nut and the corresponding values for the kernel were 17.07, 13.28 and 12.38 mm, respectively. These values were significantly different at 5 % level. While the minimum values of the length, width and thickness were respectively 23.40, 16.00 and 12.32 mm for the palm nut and 13.46, 11.25 and 8.97 mm for the kernel. The corresponding mean values were 29.17, 18.06 and 15.43 mm for the palm nut and 15.27, 12.27 and 10.68 mm for the kernel. The results are similar to that obtained by Owolarafe *et al*. (2007), they reported mean size of the fresh dura palm kernel to be 30.25, 19.94 and 15.66 mm for length, width and thickness, respectively. The significant of these dimensions is in the determination of aperture size of machines, particularly in materials separation (Ali, 2012; Busari and Olaoye, 2016). Davies (2012) reported that the engineering properties are essential for the design of appropriate equipment for postharvest processing and handling such as cleaning, sorting and packaging.

The results of the weight values of the samples as presented in the Tables showed that the mean weight of the palm nut is 4.51 g, while that of the kernel is 1.08 g. The terminal velocity of the palm nut and kernel are 5.73 and 3.21 m/s, respectively. These properties are very important in the design of the blower by achieving a velocity less than 3.21 m/s of the kernel, which will allow the kernel to fall and the shell blown off. The mean arithmetic and geometric mean diameters and the sphericity of the palm nut are 20.88 mm, 20.08 mm^3 and 69 %, respectively, while the corresponding values for the palm kernel are 12.55 mm, 12.41 mm^3 and 84 %.

The mean value of the drag coefficient and terminal velocity for the nut and kernel were 1.93, 5.72 m/s and 1.22, 3.21 m/s, respectively at moisture content of 7.19 % (db). The drag

Table 1: Physical Properties of the Palm Nut

Physical Property	Unit	Minimum Value	Maximum Value	Mean	Standard Deviation	Sample Variation	Confidence Level
Weight	g	2.22	8.67	4.15	2.04	4.18	1.46
Length	mm	23.40	35.07	29.17	3.90	15.24	2.79
Width	mm	16.00	22.25	18.06	1.86	3.46	1.33
Thickness	mm	12.32	17.72	15.43	1.69	2.88	1.21
Sphericity	%	0.64	0.77	0.69	0.04	0.002	0.03
AMD	mm	17.9	25.01	20.88	2.25	5.09	1.61
GMD	mm^3	17.17	24	20.08	2.10	4.41	1.5
SA	mm^2	70.59	151.33	104.67	25.36	643.33	18.14
AR	(°)	17	23	19.33	3.21	10.33	7.98
DC		1.54	2.21	1.93	0.22	0.048	0.15
TV	m/s	4.74	6.94	5.72	0.69	0.48	0.49

Table 2: Physical Properties of the Palm Kernel

Physical Property	Unit	Minimum value	Maximum value	Mean	Standard Deviation	Sample Variation	Confidence Level
Weight	g	0.83	1.19	1.08	0.12	0.014	0.08
Length	mm	13.46	17.07	14.88	1.22	1.48	0.87
Width	mm	11.25	13.28	12.17	0.69	0.49	0.50
Thickness	mm	8.97	12.38	10.62	0.97	0.93	0.69
Sphericity	%	0.75	0.95	0.84	0.06	0.004	0.04
AMD	mm	11.35	13.16	12.55	0.59	0.34	0.42
GMD	mm^3	11.18	12.99	12.41	0.59	0.35	0.42
TD	g/cm^3	35.10	39.10	37.10	2.83	8.00	25.4
BD	g/cm^3	266.86	277.27	272.07	7.36	54.18	66.10
SA	mm^2	392.77	530.08	485.31	45.00	2025.34	32.19
AR	(^{o})	16.5	24	19.17	4.19	17.58	10.41
DC		0.67	1.66	1.22	0.31	0.09	0.22
TV	m/s	3.04	3.46	3.21	0.11	0.01	0.08

AMD = Arithmetic Mean Diameter, GMD = Geometric Mean Diameter, SA = Surface Area
AR = Angle of Repose, DC = Drag Coefficient, TV = Terminal Velocity
TD = True Density BD = Bulk Density

coefficient and terminal velocity for the nut were higher than that of the kernel. This may be due to the lower unit mass of the kernel compared to the nut. This implies that when designing the aspiration unit of the separator, the terminal velocity of the nut should be lower than that of the kernel for easy separation of the shells from the kernels. The results of the terminal velocity obtained are comparable to 2.46 m/s at 8 % db moisture content and 1.7 m/s at 9.80 % db moisture content reported by Ayman (2009) and Pandiselvam *et al.* (2013), respectively. The unique dimensions of the nuts and kernels as identified by the values obtained for the size distribution pattern and sphericity can be employed and utilized for the selection of sizes and shapes of aperture screens in mechanical separation of kernels from shells. While the angle of repose would be useful in hopper and chutes design as well as material handling of the seeds.

The bulk density of palm nut ranges from 35.10 to 39.10 g/cm^3, while the true density of kernel varied from 266.86 g/cm^3 to 277.27 g/cm^3. Owolarafe *et al.* (2006) reported that, the true and bulk densities characteristics are useful in the estimation of load and hence in the design of load shafts for processing machine. These properties are needed as input to models or predicting the behaviours of agricultural biomaterials in pre-harvest, harvest and postharvest conditions, to aid better understanding of processing and design of machines. Optimization and prediction in process control, design of appropriate process flow and process models are useful tools in new product development. These can be achieved through engineering properties of seeds (Nesvadba, *et al.,* 2004; Tagawa *et al.,* 2007).

4 Conclusion

This research has successfully identified some selected engineering properties of palm nut and kernel. These properties would be of help in the design of post-harvest processing and handling machines for palm nut. Both the physical and the aerodynamic properties (drag coefficient and the terminal velocity) that were obtained from the experiment are parameters that can be used to design a separator for a palm kernel cracked nut.

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