Determination of Design-Related Physical and Mechanical Properties of Palm Nut

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Abstract- The knowledge of the physical dimensions and mechanical strength of agro-material/bio-materials is needed in the design and development of agricultural processing and handling machines. The physical properties were determined with help of oven dryer, vernier calliper and electronic weighing sale while the mechanical properties were determined with the help of 1000 KN Universal Materials Testing Machine (Enerpac), Cat.Nr.261, with reading accuracy of 0.01 KN. The physical properties of palm nuts determined in this study were geometric mean diameter, sphericity, projected area, surface area, arithmetic mean diameter, square mean diameter, flakiness ratio, and elongation ratio. These measurements were investigated at moisture content dry basis (17.42%) The mean value of geometric mean diameter is 18.84 mm, sphericity (0.758), projected area (366.7 m^2), square mean diameter (19.19 mm), arithmetic mean diameter (19.48 mm), flakiness ratio (0.81), elongation ratio (1.36) and volume (3808.5 mm^3). The average crushing force for ten samples of palm nuts under vertical loading conditions is higher than the average crushing for ten samples of palm nuts under horizontal loading conditions. The average crushing force and compressive strength under vertical loading were 1765 N and 3.79 N/$mm^2$and the average crushing force and the compressive strength under horizontal loading was found to be 1428 N and 2.71 N/mm^2. The values of mechanical and physical properties will guide a palm nut cracker designer is selecting the appropriate speed of a beater, fan's speed, hopper's inclination, screening sizes. The overall objective of this study is to present adequate data that will enable machine developers to develop efficient palm nut/palm fruits processing machines.

Keywords- crushing, compressive strength, mechanical, materials, speed

1 INTRODUCTION

The manual methods of processing palm fruits are stressful. The processes involved include cutting of palm heads, size reduction, and picking of the palm fruits in preparation for boiling. Thereafter, pounding, sieving followed and finally re-boiling for the extraction of palm oil. After the extraction of palm oil another useful product that still demands attention is the palm nut. The palm nuts need to be cracked in order to separate the palm kernel from the shell. This process of cracking palm nuts is laborious which over the years it has been done manually. This made it difficult to satisfy the expectation of the industrialist thereby forcing them to resort to alternative sources.

Since all the products of palm trees are highly needed both at the domestic and industrial levels, it is advisable that mini machines that are affordable and compatible are developed locally and introduced to the local processors so that it can facilitate their rate of production and work rate. To develop functional processing machines, adequate knowledge of the physical and mechanical properties of the intended crop to be processed needs to be ascertained so that it will guide in speed selection and the required force to apply for the benefit of quality enhancement of the finished product.

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Some of these physical properties include the linear dimension, bulk density, true density, sphericity, porosity, volume, surface area, angle of repose, weight, coefficient of internal friction and terminal velocity. The mechanical properties to be determined include bio-yield, rupture strength, shear strength, deformation modulus, tensile and compressive strength (Akaaimo and Raji, 2006). According to Irtwange (2002), the physical characteristics and mechanical features of agro-materials are pertinent in solving problems related with the design of machines and the study of the behaviour of the product during pre-planting and post agricultural process operations. Such operations include handling of farm produce, harvesting of crops, threshing of grains, cleaning and winnowing of grains, sorting and drying of crops. Davies and El-Okene (2009) asserted the importance of physical dimensions and mechanical features of agricultural products in machine design where they stated that to develop appropriate equipment for handling, conveying, cleaning, packing, separation, storing, drying, and managing of crops, comprehensive information of crops physical features and mechanical strength need to be known. It thus became necessary to carry out research work on the mechanical strength and physical features of palm-nuts.

Adequate knowledge of the engineering properties of palm nuts will enable agricultural machinery designers to design functional machines like palm nuts crackers, palm kernel and shell separator, palm fruit pounder, and a sterilizing machine that performs its work without compromising efficiency. The objective of this research work is to ascertain the physical features and mechanical strength of palm nuts that will guide in developing palm nut /palm fruits processing equipment/machine.

2 Materials and Methods

2.1 Sample preparation

A sample of palm nuts was bought from Ebonyi state and was soaked in water for 24 hours so that so that it can assume the and managing condition of a newly processed palm nuts. After 24 hours, the sample was removed from water and allowed to dry for one hour, weighed with electronic scale and recorded as W_i. The sample was oven dried at 105^0C for 24 hours. At the end of drying, the sample was reweighed and recorded as W_f. the moisture content was calculated on dry basis (MC_{db}) and moisture content of the sample was calculated and found to be 17.42 %. The moisture content was calculated by the equation given by (Ndirika and Oyeleke, 2006) as stated in equation (1).

$$MC_{db} = \frac{W_i - W_f}{W_i} \qquad (1)$$

Where: W_i is the initial weight before drying (g), W_f is the final weight after drying (g), MC_{db} is the moisture content (%)

2.2 Dimensional Properties

2.2.1 Size and shape

The major (a), intermediate (b) and minor (c) diameters were measured using a digital vernier calliper with accuracy of 0.001mm in the Processing Laboratory of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria. The values of a, b and c were recorded and used to calculate the geometric mean diameter, arithmetic mean diameter, square mean diameter, sphericity, volume, surface area, specific surface area.

2.2.2 Geometric Mean diameter, D_g

According to Ciro (1997), D_g can be determined using the equation stated in equation (2).

$$D_g = (abc)^{\frac{1}{3}} \qquad (2)$$

2.2.3 Arithmetic Mean Diameter, D_a

According to Mohsenin (1986), the D_a was calculated by the equation given in equation (3).

$$D_a = \frac{a+b+c}{3} \qquad (3)$$

2.2.4 Square Mean Diameter, S_{da}

Square mean diameter was calculated with equation given by Asoegwu *et al.* (2006) as stated in equation (4).

$$S_{da} = \left(\frac{ab + bc + ac}{3}\right)^{\frac{1}{2}} \qquad (4)$$

2.2.5 Volume, V

The volume of palm nuts was determined based on the equation (5) given by Pabis *et al.* (1998).

$$V = \frac{(\pi \times abc)}{6} \qquad (5)$$

2.2.6 Surface Area and Specific Surface Area

The surface area (SA) was determined by the equation given by Siqueira *et al.* (2013) as stated in equation (6).

$$S_A = \pi D_g \qquad (6)$$

Specific surface area (SFA) was determined using the equation (7) given by Nivedithat *et al.* (2013),

$$S_{sp} = \frac{S \times \rho_b}{M_n} \qquad (7)$$

2.2.7 Sphericity, ∅

Sphericity was determined using the formula given by Mohsenin (1970) as stated in equation (8).,

$$\emptyset = \left(\frac{b}{a}\right) \times 100\% \qquad (8)$$

2.2.8 Flakiness Ratio, F_R and Elongation Ratio, E_R

These properties were calculated using equation reported by Mora and Kwan (2000) as stated in equation (9). Flakiness and elongation ratio are physical properties for they calculated from the measurement made on physical dimension of palm nuts.

$$F_R = \frac{c}{b} \qquad (9)$$

$$E_R = \frac{a}{b}$$

2.2.9 Projected Area, P_A

P_A was calculated based on equation given by Ebrahimzadeh *et al.* (2013).

$$P_A = \frac{\pi \times a \times b}{4} \qquad (10)$$

2.4 Mechanical Properties of Palm Nuts

The mechanical features (compressive strength) of palm nut were determined using 1000 KN Universal Materials Testing Machine (Enerpac), Cat.Nr.261, with reading accuracy of 0.01 KN. Ten samples were crushed with the machine under vertical condition and the force required to crush each sample was recorded under vertical condition was determined. Similarly, ten samples were crushed with machine while the sample were in horizontal condition, each force required to crush each sample under horizontal condition were observed and recorded. The essence of crushing it under different orientation is to ascertain the best position in which palm nut can be placed when cracking.

3 Results and Discussions

3.1 Results

Table 1 displays the physical properties of palm nuts; Table 2 shows the forces required in crushing palm nuts under vertical loading and Table 3 shows the force required to crush palm nuts under horizontal loading. Table 1 illustrates the values of palm nuts' sphericity, minor diameter, major diameter and intermediate diameter, maximum and minimum values of different physical properties.

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Table 1. Physical Properties of Palm Nuts at 17.42 %, dry basis

	Major Diameter (a)	Intermediate Diameter (b)	Minor Diameter (c)	Axbxc	Geometric Mean Diameter	Arithmetic Mean Diameter	Sum	Surface Area (SA)	Volume (V)	Square Mean Diameter	Aspect Ratio	Sphericity	Flakiness Ratio	Elongation Ratio	Projected Area (PA)
Mean	25.12	18.39	14.92	7270.69	18.84	19.48	58.45	1144.47	3808.46	19.19	75.88	.75	.812	1.36	366.76
Std. Error of Mean	.75	.28	.48	484.11	.43	.43	1.29	51.41	253.58	.42	2.18	.02	.02403	.03	14.52
Median	24.12	18.28	14.710	6380.86	18.49	18.96	56.9	1074.9	3342.35	18.73	75.84	.75	.80	1.31	348.10
Mode	20.130	17.680	3.000[a]	1071.78[a]	10.21[a]	13.64[a]	40.92[a]	327.62[a]	561.41[a]	12.53[a]	46.91[a]	.47[a]	.17[a]	.84[a]	195.24[a]
Std. Deviation	5.33	1.99	3.45	3423.17	3.05	3.06	9.18	363.58	1793.09	3.01	15.43	.15	.16	.26	102.72
Variance	28.41	3.98	11.96	11718157.81	9.34	9.37	84.38	132190.54	3215186.15	9.08	238.20	.02	.02	.07	10551.93
Range	20.01	9.310	18.93	13570.07	14.18	11.54	34.63	1541.39	7108.13	12.12	71.62	.72	1.10	1.29	365.66
Minimum	15.32	13.72	3.00	1071.78	10.21	13.64	40.92	327.62	561.41	12.53	46.91	.47	.17	.84	195.24
Maximum	35.33	23.03	21.93	14641.86	24.39	25.18	75.55	1869.01	7669.54	24.65	118.53	1.19	1.27	2.13	560.90

Table 2. The force required to crush each sample of palm nut in a vertical loading

Sample	**Diameter Vertical axis (mm)**	**Diameter Horizontal Axis (mm)**	**Area (mm^2)**	**Force (N)**	**Compressive strength (N/mm^2)**
1	32.4	22.2	585.43	1230	2.1
2	28	18.8	430.1	1590	3.4
3	29	20.6	483.1	1550	3.2
4	30	15.3	403	2260	5.6
5	24.4	24	460	1940	4.2
6	28	21.2	475.4	2430	5.1
7	34	21.6	607.1	2040	3.4
8	21.8	19.5	335	2480	7.4
9	33.5	21	583.3	1510	2.5
10	32.2	23.2	602.7	620	1
Mean	29.33	20.74	496.5	1765	3.79

Table 3. The force required to crush each sample of palm nut in a horizontal loading

Sample	**Area (mm^2)**	**Force (N)**	**Compressive Strength (N/mm^2)**
1	481.2	2320	4.82
2	602.7	1920	3.18
3	624.7	910	1.46
4	514.8	1270	2.46
5	647	810	1.25
6	461.9	1340	2.9
7	581.1	1800	3.9
8	498.9	1500	3
9	535.9	1060	1.97
10	624.7	1350	2.16
Mean	**557.9**	**1428**	**2.71**

3.2 Discussions

The physical dimensions and mechanical strength of palm nuts were shown in Tables 1, 2, 3. The properties were determined at a specific moisture content of 17.42 %. From Table 1, the major diameter, intermediate diameter, and minor diameter have the following as the maximum values (35.33, 23.03, and 21.93) while the minimum values were (15.32, 13.72, and 3.00) respectively. These values were not far from the results given by Davies (2012) at 10.7 % moisture content (dry basis) where the maximum and minimum values of major, intermediate and minor diameters were given as follows (33.29, 24.02, 20.04) and (25.19, 14.33 and13.05), respectively.

Geometric mean diameter was calculated to be 24.39 mm (maximum), 10.21 mm (minimum); Standard deviation was found to be 3.056 and variance was 9.343. The arithmetic mean diameter was calculated to be 25.18 mm (maximum), 13.64 mm (minimum); the Standard deviation was observed to be 3.06 and the variance was 9.276. From tables 1 the maximum value of sphericity was 1.19 and minimum was 0.47, with a mean of 0.758 (75.8%) and standard deviation and variance of 0.1543 and 0.024 respectively. Davies (2012), reported the sphericity of palm nuts, to range from 66.5% to 75.7% and mean of 70.0%. Galedar *et al.* (2008) reported sphericity for pistachio nut at a moisture content of 5.83% and kernel at a moisture content of 6.03% were 69.34% and 72.59% respectively. According to Garnayak *et al.* (2008), they considered any grain, fruit, and seed as spherical when the sphericity value is above 80 and 70% respectively. Therefore, palm nut can be described as being spherical if the sphericity values obtained are above 70-80%.

From the study, the mean crushing force, area, and compressive strength in a vertical loading were observed to be 1765 N (1.765 KN), 496.513 mm², and 3.79 N/mm². In a horizontal loading, the mean crushing force, area, and compressive strength were found to be 1428 N (1.428 KN), 557.29 mm², and 2.71 N/mm². The mean fracture force required breaking the palm fruit, kernel, and nut on the horizontal position were 0.39, 2.83, and 0.80 KN, respectively. The mean fracture force required to break the palm fruit, kernel, and nut vertical position were 0.39, 11.00, and 0.92 KN. The average force required to break the *dura* and *tenera* palm kernel according to (Owolarafe et al, 2007) were 2301N and 1149N, respectively. The results of mechanical properties of palm nut are not quite different from the results/values presented by (Owolarafe et al, 2007).

4 Conclusion

The values of physical properties of palm nuts measured do not vary significantly from the values other researchers have reported. The force required to crush ten samples of palm nuts in vertical loading condition is higher than the forces required in crushing the ten samples of palm nuts in horizontal condition. The average crushing force required to crush ten samples in vertical loading position is 1765 N and that of horizontal loading condition is 1428 N. The average compressive strength of ten samples of palm nut in vertical loading condition is 3.79 N/mm² and that of ten samples under horizontal loading is 2.71 N/mm².

Based on these results, any palm nut cracking machine should not exert a force that is below 1428 N or above 1765 N. It will also guide in speed selection so that that the palm kernel will not break during the time of cracking. Similarly, it serves as a guide in selecting data in designing a palm kernel and chaff separator and the angle of inclination of a hopper.

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