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PROPOSED AVERAGE VALUES OF SOME ENGINEERING PROPERTIES OF PALM KERNELS

S.L. Ezeoha[a], **C.O. Akubuo**[b], **A.O. Ani**[c]

Department of Agricultural and Bioresources Engineering University of Nigeria, Nsukka, Nigeria.
Emails: [a]sunday.ezeoha@unn.edu.ng; [b]akubuoclem1945@yahoo.com; [c]aniozoemena@yahoo.com

Abstract

The need to know what values of engineering properties of palm kernels to use for rational design of handling and processing systems for palm kernels prompted a literature search for collation of published values. These values are presented in this work. And to manage the discrepancies observed among values published for same properties, the range of values are presented; and average values proposed for adoption in design problems pending the determination and establishment of standard values. The proposed average values include: bulk density of 711kg/m^3 and 589kg/m^3 for dura or tenera and mixtures of dura, tenera, and pisifera varieties respectively; solid density of 1.17, 1.09, 1.10, and 1.14 g/cm^3 for dura, tenera, pisifera, and their mixtures respectively; angle of repose of 33°, 32°, 29°, and 38° for dura, tenera, pisifera, and their mixtures respectively; compressive yield load of 492N and 374N for dura and tenera varieties respectively. Other proposed mean values include: sphericity of 76, 81, and 77% for dura/tenera, pisifera, and their mixtures respectively; geometric mean diameter of 12.56, 12.58, 8.84, and 13.06mm for dura, tenera, pisifera, and their mixtures respectively. The importance of determining and specifying the condition and history of experimental samples associated with published values is stressed. The need to develop or use existing standard methods and equipment for the determination of engineering properties of biological materials is recommended to reduce or limit the discrepancy among values being published for common properties.

Keywords: palm kernel, engineering properties, bulk density, processing, average values

1. Introduction

The oil palm tree (Elaeis giuneensis) is one of the most important tree crops in the tropics. The oil palm fruit is a drupe with an outer mesocarp which is rich in palm oil, and embedded hard-shelled nut containing the palm kernel which is rich in palm kernel oil (PKO). The economic importance of palm kernel is indicated by its wide use as food, traditional medicine, and in industries [1]. In order to design and develop equipment for aeration and storage of palm kernels there is need to know the various physical properties. In order to optimize the equipment design or for improvement of relevant machines and facilities for handling, storage, and processing of palm kernels, the physical properties must be known. The size and shape are important in designing of separating, sizing, and grinding machines. Bulk density and porosity affect the structural loads acting on the walls of storage structures. The angle of repose is important in designing of handling and storage structures. The coefficients of friction of palm kernels against different surfaces are important in designing of conveying, transporting, and storage structures.

The size and shape of palm kernels are important in the design of hoppers, press auger, and press barrel for efficient oil extraction using the screw press. They are also important in the design of grading or separating equipment. The solid and bulk densities are important in the design of press hoppers also, and for computing the throughput and the performance efficiencies of the screw press. The knowledge of rupture resistance, toughness, deformation, and hardness of palm kernels is important in determining the power requirement during size reduction and pressing operations, and for proper selection of construction materials. The specific heat capacity of palm kernels is useful in the determination of the amount of heat required for enhanced oil expulsion from the kernels, and hence aids in the selection of the best pressing method. Several researchers have determined some engineering properties of palm kernels. Koya et al. [1] determined some properties of the dura, tenera, and pisifera varieties of palm kernels. The properties included size, sphericity, density, and coefficient of friction. Gbadamosi [2] also determined some engineering properties of palm kernels, for the three varieties, and the parameters include size, shape, coefficient of friction, hardness, specific heat capacity, and compressive strength. Ozumba and Obiakor [3] determined the average compressive rupture force, deformation and toughness of the dura variety. Ezeoha [4] also determined the size, sphericity, bulk density, solid density, compressive yield load, hardness, angle of repose, and coefficient of sliding friction using unidentified mixture of the three varieties.

At present, there are no standard values to use when designing handling and processing systems for palm kernels. Therefore, the objective of this study is to review published values of some engineering properties of palm kernels and where discrepancies exist to establish range of values and propose average values for possible adoption for rational design and development of palm kernel handling, processing, and storage facilities.

2. Review of Published Values of some Engineering Properties of Palm Kernels

2.1. Bulk density of palm kernels

Akubuo and Eje [5] among other things determined the bulk density of unidentified mixture of varieties of palm kernels. The method used was not mentioned but a value of 568.90kg/m^3 was computed for the kernels at an average moisture content of 9.5% w.b.

Ekwulugo [6] determined the bulk density of dura and tenera varieties of palm kernels. A 95mm diameter cylindrical container of height 300mm was used to measure the volume required for the investigation. A result of 173.01kg/m^3 was computed for dura and 164.67kg/m^3 for tenera. The moisture content of the sample used was not mentioned. Koya et al. [1] measured the bulk density of dura (13.4% w.b.) and tenera (12.1% w.b.) varieties by finding the ratio of the mass of the samples to its total volume freely filling a container without compaction. Results were 710.0 kg/m^3 and 711.10 kg/m^3 for dura and tenera varieties respectively.

Ezeoha [4] used the above method by [1] and got a value of 608.05kg/m^3 for unidentified mixture of varieties of palm kernels. The average moisture content of the kernels was 10.7% w.b. The published values show a discrepancy which is attributable to varied methodology, equipment, and variety of sample.

2.2. Solid density of palm kernels

Gbadamosi [2] determined the solid or true density of dura, tenera, and pisifera varieties of palm kernels. Fifty-seed mass was measured with an electronic scale and the volume determined by water displacement method. Results were 1.31, 1.06, and 110g/cm^3 for dura, tenera, and pisifera varieties respectively. The moisture contents of the samples were not mentioned.

Koya et al. [1] got values of 1.12, 1.11, and 1.10g/cm^3 for dura (13.4% w.b.), tenera (12.1% w.b.), and pisifera (12.5% w.b.) respectively. Mijinyawa and Omoikhoje [7] after sample mass and volume measurements reported a value of 1.09g/cm^3 for the dura variety. The moisture content, however, was not mentioned. Akubuo and Eje[5] reported a value of 1.10g/cm^3 for unidentified mixture at a moisture content of 9.5% w.b. Ezeoha [4] got a value of 1.17 g/cm^3 for unidentified variety at an average moisture content of 10.7% w.b. Here, there is virtually no discrepancy in the published values.

2.3. Angle of repose of palm kernels

Gbadamosi [2] determined the angle of repose for dura, tenera and pisifera varieties. The method was that of filling a steel hollow pipe of 40cm long with palm kernels and gently lifting up the pipe from the level surface of a cardboard paper. Conical heap of the kernels formed on the paper was determined for the vertical height and for the diameter of the heap. The angle of repose was computed from the ratio of the vertical height to the true length. Values of 32.60, 31.40, and 28.50 were reported for the dura, tenera, and pisifera varieties. The moisture content of the kernels was not specified.

Akubuo and Eje [5] published a value of 38.00 for unidentified mixture of varieties of palm kernels at a moisture content of 9.5%. Ekwulugo [6] used the circular platform apparatus to determine the angle of repose and reported a value of 32.40 for a mixture of tenera and dura varieties. The kernels' moisture content was however not indicated. Ezeoha [4] also used the circular platform apparatus and found a value of 37.750 for unidentified mixture of varieties at an average moisture content of 10.7% w.b.

2.4. Compressive yield load

Gbadamosi [2] investigated the compressive yield load of palm kernels and reported values of 378.95N, 127.57N, and 162.26N for dura, tenera, and pisifera varieties. The Monsanto Tensometer testing machine was used for the investigation.

Ekwulugo [6] reported a value of 619N for a mixture of dura and tenera varieties, having used the Monsanto Tensometer. Ozumba and Obiakor [3] published a value of 475.79 N for the dura variety, using the Instrom Universal Testing Machine. Akinoso and Raji

[8] reported 5870 N and 2791.3N for dura and tenera varieties using Testometric AX Type DBBMTCL – 2500kg (Roch dale, England).

Ezeoha [4] used the Monsanto Tensometer and reported a value of 1022.44N for unidentified mixture of varieties of palm kernels.Here, there is a serious discrepancy among published values attributable to equipment sensitivity and reliability.

2.5. Hardness of palm kernels

Gbadamosi [2] carried out hardness tests on palm kernels using Rock-well hardness machine type 6402 model No 32887. The test results showed 38kN/m^2, 21.88kN/m^2, and 14.2kN/m^2 for dura, tenera, and pisifera varieties of palm kernels.

Ezeoha [4] reported a value of 10.41±0.09kN/m^2 for unidentified mixture of palm kernel varieties at average moisture content of 10.7% w.b. The Hardness testing machine model No. 174886 from Ogawa Seiki Co. Ltd., Japan was used.

2.6. Specific heat capacity of palm kernels

Gbadamosi [2] employed the method of mixtures using adiabatic drop calorimeter to determine the specific heat capacity of palm kernels. The moisture content of the kernels was not mentioned but the values published were 3.98, 4.13, and 6.55J/g°C for dura, tenera, and pisifera varieties. More researches are obviously needed here to compare these values.

2.7. Coefficient of sliding friction of palm kernels

Gbadamosi [2] determined the coefficient of sliding friction of palm kernels using a bottomless four-sided container on adjustable tilting surface of plywood, galvanized steel, and glass. The average values were 0.38, 0.45, and 0.44 for dura, tenera, and pisifera varieties respectively on plywood surface; 0.48, 0.56, and 0.57 for dura, tenera, and pisifera respectively on galvanized steel surface; and 0.35, 0.38, 0.27 for dura, tenera, and pisifera on glass surface.

Koya et al. [1] also determined the static coefficient of friction of palm kernels on plywood, galvanized steel, and jute fibre surfaces. The equipment used was the inclined plane apparatus, model 12558 (Norwood Instrument, Limited, Huddersfield). Reported values were 0.39, 0.51, and 0.68 for dura; 0.39, 0.48, and 0.68 for tenera; 0.37, 0.48, and 0.67 for pisifera on galvanized steel, plywood, and jute fibre surfaces respectively. Ezeoha [4] reported values of 0.52, 0.46, and 0.51 on plywood, glass, and galvanized steel surfaces respectively for unidentified mixture of varieties.

2.8. Sphericity of palm kernels

Ekwulugo [6] reported a sphericity value of 0.80 for a mixture of dura and tenera varieties of palm kernels. Sphericity values by other researchers include: 0.80 for unidentified variety [5]; 0.70, 0.69, and 0.77 for dura, tenera, and pisifera varieties respectively [1]; 0.78 for dura variety [7]; 0.80, 0.70, and 0.85 for dura, tenera, and pisifera respectively [2]; 0.71 and 0.85 for dura and tenera [8]; and 0.74 for unidentified mixture of varieties [4].

2.9. Size of palm kernels

The major diameter values for dura variety, as reported by several researchers were: 17.20mm [6], 17.84mm [1], 34.90mm [7], and 15.90mm [2]. For tenera variety, the reported values include: 13.90mm [6], 18.70mm [1], and 17.30 mm [2]. And for pisifera the values were: 16.21mm [1], and 6.30 mm [2]. The values of 15.70 mm were reported by [5] for unidentified mixture of varieties and 19.09mm by [4].

2.10. Geometric mean diameter of palm kernels

Akubuo and Eje [5] reported a geometric mean diameter (GMD) value of 12.00 mm for unidentified variety. Koya et al. [1] reported values of 12.47mm, 13.01mm, and 12.42mm for dura, tenera, and pisifera varieties. Gbadamosi [2] published the following values: 12.65 mm, 12.15mm and 5.25mm for dura, tenera, and pisifera varieties; whereas [4] reported a value of 14.11mm for unidentified variety.

3. Proposed mean values of some properties of palm kernels

3.1. Proposed average bulk density

Based on works done by [5, 1, 4) (Table 1): the proposed average bulk density values for oil palm kernels was computed to be 711 ± 15.0 kg/m^3 for dura (D) and tenera (T) varieties (with a range of 697 to 726kg/m^3); and 589 ± 8.0 kg/m^3 for unidentified (U) mixture of dura, tenera, and pisifera (P) (with a range of 581 to 597kg/m^3).The values given by [6] were considered doubtful and therefore were not used in the computation.

3.2. Proposed average solid density

Based on works done by [5, 1, 7, 2, and 4] (Table 2): the proposed average solid density values for oil palm kernels were computed to be 1.17 ± 0.11g/cm^3 for dura (D) variety (with average range of 1.06-1.29g/cm^3); 1.09 ± 0.04 g/cm^3 for tenera (T) (with average range of 1.05 – 1.12g/cm^3); 1.10 ± 0.05g/cm^3 for pisifera (P) (with average range of 1.08 – 1.15g/cm^3) and 1.14 ± 0.05g/cm^3 for unidentified (U) mixture (with average range of 1.09g/cm^3 - 1.19g/cm^3).

Table 1: Some bulk density values for palm kernels.

S/No.	Researchers	**Bulk density** (kg/m^3)
1	[1]	710.78(17.67)(D) 711.10 (10.9) (T)
2	[6]	173.01 (1.63) (D)* 164.67 (1.60) (T) *
3	[5]	568.90 (1.74) (U)
4	[4]	608.05 (14.08) (U)

* Doubtful values (not used)

Table 2: Some solid density values for palm kernels.

S/No.	Researchers	**Solid density** (g/cm^3)
1	[2]	1.31 ± 0.19 (D) 1.06 ± 0.04 (T) 1.10 ± 0.07 (P)
2	[1]	1.12 ± 0.08 (D) 1.11 ± 0.03 (T) 1.10 ± 0.03 (P)
3	[7]	1.09 ± 0.07 (D)
4	[5]	1.10 ± 0.02 (U)
5	[4]	1.17 ± 0.08 (U)

Table 3: Some values of static angle of repose for palm kernels.

S/No.	Researchers	**Angle of repose** (°)
1	[2]	32.6 ± 1.29 (D) 31.4 ± 2.23 (T) 28.5 ± 3.94 (P)
2	[5]	38.0 ± 0.56 (U)
3	[6]	32.3 ± 0.51 (D+T)
4	[4]	37.8 ± 1.33 (U)

Table 4: Some values of compressive yield load of palm kernels.

S/No.	Researchers	**Compressive yield load** (N)
1	[2]	378.95 (D) 127.75 (T) 162.26 (P)
2	[6]	619 (D + T)
3	[3]	475.79 ± 78.12 (D)
4	[4]	1022.44 ± 90.56 (U)
5	[8]	5870 (D) ± 2791.3 (T)

Table 5: Some hardness values for palm kernels.

S/No.	Researchers	**Hardness value** (kN/m^2)
1	[2]	38 ± 0.11 (D) 21.88 ± 0.01 (T) 14.2 ± 0.05 (P)
2	[4]	10.41 ± 0.09 (U)

3.3. Proposed average angle of repose

Table 3 presents some values of static angle of repose for palm kernels. Based on this table the proposed average angle of repose values for oil palm kernels was computed to be 33° for dura, 32° for tenera, 29° for pisifera, and 38° for unidentified (U) mixture of the three varieties.

3.4. Proposed average compressive yield load

Table 4 presents some values of compressive yield load of oil palm kernels. There is discrepancy between the values by the different researchers. And this is probably connected with the instruments used for the measurements. However, based on the works done by [6, 2, 3], the proposed average values are 492 and 374N for dura and tenera respectively. Further investigations are needed to confirm or disprove the values published by [8] and [4].

3.5. Proposed average hardness

Table 5 shows some hardness values for palm kernels. The average value ranges from 10.32 - 38kN/m^2. There is therefore need for further research work in this area using certified modern and reliable instruments and equipment.

3.6. Proposed average specific heat capacity

Table 6 contains the only value of specific heat capacity of palm kernels by [2]. The average specific heat capacity ranges from 3.98 (for dura) to 6.55 J/g°C(for pisifera). Further research works are therefore needed to confirm or improve on the estimates.

3.7. Proposed average coefficient of sliding friction

Based on Table 7, the proposed average coefficient of sliding friction for palm kernels on some surfaces were computed to be: 0.44, 0.45, and 0.35 for dura; 0.48, 0.47, and 0.38 for tenera; 0.47, 0.46, and 0.27 for pisifera; 0.51, 0.52, and 0.46 for unidentified mixture; on steel, plywood, and glass surfaces respectively.

3.8. Proposed average sphericity

Table 8 presents some values of the sphericity of palm kernels. Based on these vales the proposed average sphericity of palm kernels was computed to be 76% for dura and tenera, 81% for pisifera, and 77% for a mixture of the three varieties.

Table 6: Specific heat capacity of palm kernels.

S/No.	Researchers	Specific heat capacity (J/g°C)
1	[2]	3.98 ± 0.34 (D) 4.13 ± 0.38 (T) 6.55 ± 0.36 (P)

Table 7: Some values of coefficient of sliding friction of palm kernels.

S/No.	Researchers	Coefft. of friction values	Type of surface
1	[2]	0.38±0.04(D); 0.45±0.05(T); 0.44±0.02(P)	Plywood
		0.48±0.01(D); 0.56±0.15(T); 0.57±0.02(P)	Galvanized steel
		0.35±0.02(D); 0.38±0.01(T); 0.27±0.01(P)	Glass
2	[1]	0.39±0.01(D); 0.39±0.00(T); 0.37±0.01(P)	Galvanized steel
		0.51±0.01(D); 0.48±0.01(T); 0.48±0.01(P)	Plywood
		0.68±0.01(D); 0.68±0.01(T); 0.67±0.02(P)	Jute fibre
3	[4]	0.52±0.05(U)	Plywood
		0.46±0.06(U)	Glass
		0.51±0.03(U)	Galvanized steel

Table 8: Some sphericity values for palm kernels.

S/No.	Researchers	Sphericity values
1	[6]	0.80 (D+T)
2	[5]	0.80 (U)
3	[1]	0.70 (D) 0.69(T) 0.77(P)
4	[7]	0.78 (D)
5	[2]	0.80(D) 0.70(T) 0.85(P)
6	[8]	0.71(D) 0.85(T)
7	[4]	0.74 (U)

Table 10: Some values of geometric mean diameter of palm kernels.

S/No.	Researchers	G.M.D Estimates
1	[5]	12.00 ± 0.05 (U)
2	[1]	12.47 ± 0.98 (D) 13.01 ± 0.44 (T) 12.42 ± 0.67 (P)
3	[2]	12.65 ± 0.02 (D) 12.15 ± 0.03 (T) 5.25 ± 0.14 (P)
4	[4]	14.11 ± 0.35 (U)

3.9. Proposed average size

Table 9 shows some values of size of palm kernels. The values by [7] are obviously different and therefore were not used for the proposal. Based on the values, the following average values were computed and proposed: 16.98±0.66mm, 13.18±0.55mm, 9.87±0.48mm (major, intermediate, minor diameters) for dura; 16.63±0.54mm, 13.07±0.37mm, 8.17±0.41mm for tenera; 11.26±1.38mm, 9.13±0.57mm, 6.97±0.64mm for pisifera; and 17.40±1.12mm, 12.97±0.67mm, 10.01±0.79mm for unidentified mixture of the three varieties.

3.10. Proposed average geometric mean diameter

Some values of geometric mean diameter (GMD) of palm kernels are presented in Table 10. The following average values are therefore proposed based on the Table: 12.56mm, 12.58mm, 8.84mm and 13.06mm for dura, tenera, pisifera, and mixtures respectively.

4. Conclusion and Recommendation

Obviously, the establishment and adoption of standard values of engineering properties of palm kernels is very important for rational design and development of palm kernel handling, processing, and storage facilities. Presently, there are no established standard values in literature for these properties which include: bulk density, solid density, angle of repose, compressive yield load, hardness, specific heat capacity, coefficient of sliding friction, sphericity, geometric mean diameter, major, intermediate, and minor diameters, etc.Therefore, the only good practical option is the use of average values for design purposes. Fortunately, some research results have been published in this area, and these results are the bases of the proposed average values presented in this work. All the proposed values are shown in Table 11.

Two major difficulties were identified in this study. The first was that the conditions of the experimental samples used, especially kernel moisture content, was

Table 9: Some values of size of palm kernels.

S/No.	Researchers	Major dia.	Int. dia.	Minor dia.
1	[6]	17.20 ± 0.28 (D) 13.90 ± 0.14 (T)	14.30 ± 0.09 (D) 11.30 ± 0.11 (T)	10.90 ± 0.07 8.60 ± 0.10 (T)
2	[5]	15.70 ± 0.23 (U)	12.10 ± 0.16 (U)	9.20 ± 0.14 (U)
3	[1]	17.84 ± 1.67 (D) 18.70 ± 1.46 (T) 16.21 ± 2.62 (P)	12.25 ± 1.53 (D) 13.90 ± 0.95 (T) 12.65 ± 1.11 (P)	8.90 ± 1.36 (D) 8.50 ± 1.12 (T) 9.83 ± 1.06 (P)
4	[7]	34.90 ± 3.51 (D)	26.4 ± 2.71 (D)	21.60 ± 2.18 (D)
5	[2]	15.90 ± 0.03 (D) 17.30 ± 0.03 (T) 6.30 ± 0.13 (P)	13.00 ± 0.02 (D) 14.00 ± 0.04 (T) 5.60 ± 0.02 (P)	9.80 ± 0.02 (D) 7.40 ± 0.02 (T) 4.10 ± 0.22 (P)
6	[4]	19.09 ± 2.01 (U)	13.84 ± 1.17 (U)	10.82 ± 1.43 (U)

* D = Dura, T = Tenera, P = Pisifera, U = Unidentified mixture of varieties.

Table 11: Proposed average values of some engineering properties of palm kernels.

ITEM	**Bulk Density** (Kg/m3)	**Solid Density** (g/cm3)	**Angle of repose** (°)	**Comp. yield load** (N)	**Hadns** (N/m2)	**Spec. heat Cap.** (J/goC)	**Coefft of slid. Friction** (%)	**Sph.** (%)	**GMD** (mm)	**Maj. dia.** (mm)	**Int. dia.** (mm)	**Min. dia.** (mm)
Dura	711 (15.0)	1.17 (0.11)	33 (0.9)	492 (98.6)	-	-	44,45,35 on **S,P,G**	76	12.56 (0.50)	16.98 (0.66)	13.18 (0.55)	9.87 (0.48)
Tenera	711 (15.0)	1.09 (0.04)	32 (1.37)	374 (245.6)	-	-	48,47,38 on **S,P,G**	76	12.58 (0.24)	16.63 (0.54)	13.07 (0.37)	8.17 (0.41)
Pisifera	-	1.10 (0.05)	29 (3.94)	-	-	-	47,46,27 on **S,P,G**	81	8.84 (0.41)	11.26 (1.38)	9.13 (0.57)	6.97 (0.64)
Mixture	589 (8.0)	1.14 (0.05)	38 (0.95)	-	-	-	51,52,46 on **S,P,G**	77	13.06 (0.2)	17.40 (1.12)	12.97 (0.67)	10.01 (0.79)

* S = Steel surface, P = Plywood surface, G = Glass surface

not stated by some researchers. Secondly, the equipment and methodology used were varied. In reality, engineering properties of plant and animal materials are known to be dependent on their moisture content. Thus, property values published without stating sample moisture content and its basis have limited practical usefulness. Obviously, more and better researches are needed in this area using modern and reliable instruments and equipment in order to resolve the discrepancies existing amongst published values of some of these properties. There is a need also to determine and quantify the effect of kernel moisture content on these values as that would lead to the realization of better average values of engineering properties of palm kernels.

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