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SELECTED PROPERTIES OF OIL PALM KERNEL

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ABSTRACT

Selected physical properties of oil palm kernel are required for its drying studies. The effect of moisture content on physical properties of oil palm kernel was determined in the moisture range of 28-2% (d.b). These include physical dimension, shape, surface area, specific surface area, bulk density and true bulk density. Length, width, thickness of the palm kernel ranged from 16-14 mm, 12-11 mm, 10-9 mm respectively and these dimensions did not vary over the various moisture contents. However, the bulk density, surface area and specific surface area of palm kernel increased linearly as the moisture content increased. There was reduction in porosity and true density as the moisture content increased. A study on equilibrium moisture content of local variety of palm kernel was conducted. At temperature of 50˚C and relative humidity of 50 %, EMC value obtained from other studies was found to be 1 to 3 times higher compared to current study. EMC is found to decrease with increasing temperature and, at constant temperature, EMC increased with increasing relative humidity, which is consistent generally with established EMC behavior. The experimental drying data on single kernel available in the literature was utilized to develop thin layer drying model by fitting the data with several common thin layer drying equations available in the literature. It was found that Lewis model could be fairly used (R^2=0.86) to represent thin layer drying of oil palm kernel; however, further study is needed to obtain more suitable thin layer drying model for palm kernel.

Keywords: *Palm kernel, physical properties, Equilibrium moisture content, thin layer drying, moisture content.*

INTRODUCTION

Oil palm (*Elaeis guineensis*) is grown extensively in Southeast Asia and Equatorial Africa and it produces more oil per area than any other plants. There are two types of oil that can be obtained from the oil palm: palm oil from the mesocarp layer and Palm kernel oil from palm kernel which differ greatly in their characteristics and properties. Palm oil is rich in palmitic acid (C_{16}) containing about 44% and about 36% $C_{18:1}$. Other major fatty acids of palm oil are stearic acid ($C_{18:0}$) and linoleic acid ($C_{18:2}$). Palm kernel oil is rich in lauric acid (C_{12}), containing about 50% C_{12} and the remaining major fatty acids are myristic (C_{14}) and oleic acids ($C_{18:1}$) [1]. In the world of oils and fats, the lauric oils are the aristocrats. There are very few of them, they move in they own higher price. Among the 17 major oils and fats in the world trade, there are only two lauric oils, coconut oil and palm kernel oil and they called lauric because lauric acid is the major fatty acids in their composition at about 50% [2]. Palm kernel on a wet basis, contains about 45–50% oil [1] which is used in food and pharmaceutical industries [2].

The efficient processing and storage of palm kernel requires that the moisture content be reduced to appropriate levels by drying. The initial moisture content of palm kernel is about 28 % (d.b) and it is required to be dried until final moisture content of 7% (d.b).Food drying involves simultaneous heat and mass transfer. This makes the theoretical treatment complex, and engineering calculation of process becomes complicated. Mathematical modeling is valuable for the study of drying process [3]. The proper modeling of the drying process required knowledge of physical properties, equilibrium moisture content and thin layer drying equation of the palm kernel. Knowledge of relationship between the air relative humidity, temperature and moisture content of test material is essential to drying study. There were few studies on equilibrium moisture content (EMC) of oil palm kernel conducted by Hakimi [4] and Ajibola [5]. The comparison between these studies showed differences in the values of equilibrium moisture content. This variation of equilibrium moisture content might be as a result of differences in palm variety, the palm maturity, and equilibrium moisture content determination method [6]. Information on physical properties and thin layer drying model of palm kernel are not sufficiently available. This study hence investigates these important properties for palm kernel.

MATERIALS AND METHODS

Preparation of sample

The palm kernels for this study were obtained locally. The samples were brought to the agricultural process engineering laboratory, UPM. In order to prevent moisture content loss from the sample during transportation, they were packed and sealed into plastic bag. Prior to experiment, the kernels were stored in the refrigerator until used.

Physical properties

The physical properties experiments were conducted in the moisture content of 28-2% (d.b). The initial and final moisture content was determined according to standard MPOB test method [7]. 10 g of sample was weighted in aluminum Petri dishes. Samples were kept for 4 hour in oven, the operating temperature was maintained at 103°C, and then samples were taken out of the oven, cooled in a desiccator and weighed. In order to calculate the moisture content of the samples, the fresh and dried weight were used as outlined in Equation 1, which was expressed as g water/g dry matter. The experiments were done in triplicates and the average data were reported.

$$Mc = \frac{\mathrm{Wi - Wf}}{\mathrm{Wf}} \qquad (1)$$

Where, Mc is moisture content in g water/ g dry matter; Wi is Initial sample weight in g; Wf is Final sample weight in g.

The samples of lower moisture content were obtained by drying in a oven at 45 ˚C [8]. The desired moisture content was obtained by drying to give a sample mass as calculated by Equation 2.

$$B = \frac{\mathrm{A(100 - a)}}{\mathrm{(100 - b)}} \qquad (2)$$

Where, A is initial mass of the sample in kg; B is final mass of the sample after drying in kg; a is initial moisture content of sample in %; b is final (desired) moisture content of sample in %.

Determination of size

Size of kernels was measured according to Gbadam [9]. From the samples, 50 palm kernels were selected at random for determining the physical axial characteristics. For each kernel, three linear dimensions were measured, that is length (L), width (W), and thickness (T) using a Vernier caliper reading to 0.01 mm as shown in Fig. 1. Hence measurements of all size indices were replicated fifty times.

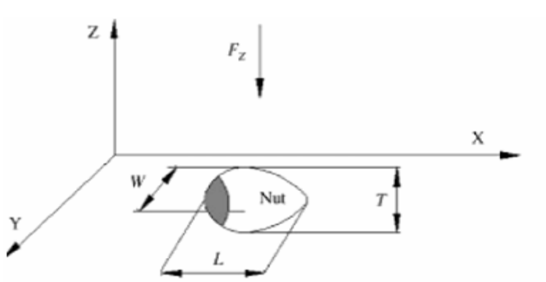

Fig. 1: Dimensions of a Palm kernel size [5].

Determination of shape

The kernel shape was expressed in terms of its sphericity index which expresses the shape character of the kernel relative to that of a sphere of the same volume. For the sphericity index γ. the dimensions obtained for the 50 palm kernel selected at random above were used to calculate the index based on Equation 3 [10]:

$$\gamma = \frac{GMD}{L} \qquad (3)$$

Where, GMD = $(LWT)^{1/3}$ is the geometric mean diameter in mm ; T, W, L , is the length, width and thickness of the nut in mm as shown in Fig. 1.

Surface area and specific surface area

Surface area refers to the kernel surface area per unit volume of kernel that exchange energy and moisture with the air during the drying process [9].

Surface area S_K and specific surface area a were estimated by the formula corresponding to the geometrical shape similar to the shape of kernel. The specific surface area is defined to be the surface area of one kernel multiplied by number of kernels in given mass and divided by bulk volume. Bulk volume itself is found by multiplying mass of one kernel by the number of kernels in given mass and dividing by the bulk density [11].

Thus, the surface area is obtained from Equation 4.

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

Where, GMD = $(LWT)^{1/3}$ is the geometric mean diameter in mm ; T, W, L , is the length, width and thickness of the nut in mm as shown in Fig 1.

And the specific surface area is obtained from Equation 5.

$$Ss = \left(\frac{\rho b}{mu}\right) \qquad (5)$$

Where: $m_{u,}$ is the mass of one unit of palm kernel, in g; and $\rho_{b,}$ is the bulk density of kernel, in g/cm^3.

Bulk density and true density of palm kernel

Bulk density and true density were measured according to Chandrasekar [12]. The palm kernel was put into a container with known weight and volume and it was weighed. Bulk density is equal to mass of bulk material divided by volume containing the mass.

For true density measurement, the mass of individual material (20 unit sampling) was measured according to Mohsenin [10]. The volume of individual material was determined by weighing the material in toluene. The volume V was calculated via the principle of buoyance force by Equation 6:

$$V = \frac{mt}{\rho to} \qquad (6)$$

Where: mt is the mass weighed in toluene in g; and ρto is the density of toluene (0.86 g/cm^3).

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Porosity of palm kernel

Porosity of palm kernel was calculated using the relationship between bulk density and true density of palm kernel shown in Equation 7 [13]:

$$\varepsilon = 1 - \frac{\rho b}{\rho t} \times 100 \qquad (7)$$

Where: ε is porosity in %, ρb is bulk density of palm kernel in kg/m^3, and ρt is true density of palm kernel in kg/m^3.

Equilibrium Moisture Content Determination

The equilibrium moisture content (EMC) of palm kernel was determined by gravimetric method which is based on using saturated salt solution to maintain a fixed relative humidity when the equilibrium is reached. Seven saturated salt solutions (Table 1) were prepared corresponding to a wide range of relative humidity ranging from 11 to 80 [14].

Table 1: Relative humidity of the saturated salt solutions at the four temperatures used in the experiment

Salt solution	**50˚C**	**60˚C**	**70˚C**	**80˚C**
LiCl	11.10	10.95	10.75	10.51
KF	20.80	20.77	21.74	22.85
$MgCl_2$	30.54	29.26	27.77	26.05
NaBr	50.93	49.66	49.70	51.43
NaNO3	69.04	67.35	66.04	62.22
NaCl	74.43	74.5	75.06	76.29
KCl	81.2	80.25	79.49	78.9

For each experiment three sealed glass bottles were used. Each bottle was provided with a sample holder that was hanged up in there. Sample holder was kept above saturated salt solution to avoid contact of the solution with it. 15 g of palm kernel was measured for each experiment. To inhibit microbial growth a small quantity of thymol was also placed inside the jar for relative humidity higher than 70% [15]. The samples were weighed every ten days. Equilibrium was acknowledged when three consecutive weigh measurements showed a difference less than 0.001 g. The moisture content of the sample was determined by standard MPOB Test Method [7]. Three replications were kept for each temperature and the EMC were determined by calculating the mean of triplicate measurements.

Thin Layer Drying Characteristics

In an attempt to establish the drying characteristics of palm kernel, it is important to model the drying behavior effectively. In this study, the experimental drying data of palm kernel obtained from Hakimi [4] were fitted into commonly used thin-layer drying equations that are mentioned in Table 2.

Table 2: Thin-layer drying equations

No	**Equation**	**Expression**
1	Lewis	$M_R = \exp(-kt)$
2	Page	$M_R = \exp(-kt^n)$
3	Henderson and Pabis	$M_R = a \exp(-kt)$

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Statistical Analysis

To find a suitable mathematical model, the moisture content data at different drying conditions were converted to moisture ratio (MR) expression by using Equation 8.

$$MR = (M - M_e) / (M_0 - M_e) \qquad (8)$$

Where, MR represents the dimensionless moisture ratio; M is the moisture content of the product at each moment; M_0 is the initial moisture content of the product; M_e is the equilibrium moisture content.

The software package SAS 9.2 was used in the numerical calculation. The parameters were evaluated non-linearly. The goodness of fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE). Higher R^2 values and lower χ^2 and RMSE values implies better goodness of fit .The reduced chi-square (χ^2) and the root mean square error (RMSE) were calculated based on Equations 9 and 10 respectively:

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{\exp,i} - MR_{pre,i})^2}{N - z} \qquad (9)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{\exp,i})^2} \qquad (10)$$

Where, $MR_{\exp,i}$ is the ith experimental moisture ratio; $MR_{pre,i}$ is the ith predicted moisture ratio; N is the number of observation; z is the number of constants [16].

RESULTS AND DISCUSSIONS

Mean values of the physical properties of palm kernel at different moisture contents are presented in Table 3.

Table 3: Physical properties of palm kernel

Moisture content [%. dry basis]	Length [mm]	Width [mm]	Thickness [mm]	Bulk density [kg/m^3]	True density [kg/m^3]	Surface area [cm^2]	Specific surface area [m^2/m^3]	Porosity [%]
28%	16.63 ±2.67	11.553 ±1.52	9.34 ±1.21	629,3 ±1.0	860,9 ±1.20	202,12 ±1.32	131,6	26,90
20%	14.58 ±2.64	11.49 ±1.37	10.25 ±1.59	617,02 ±1.1	861,4 ±1.98	182,9 ±1.44	123,20	28,37
17%	14.3 ±2.38	12.49 ±1.50	9.21 ± 1.27	611,29 ±1.53	862 ±1.84	164,2 ±2.0	116,08	29,08
9%	14.22 ±2.04	11.40 ±1.59	9.19 ±1.757	598,6 ±1.48	863,5 ±2.01	152,4 ±1.01	112,76	30,67
5%	14.20 ±2.1	11.37 ±1.2	9.18 ±12	591,18 ±1.30	863,7 ±1.88	150,0 ±0.98	112.,2	31,55
2%	14.17 ±2.3	11.24 ±1.08	9.18 ±1.05	584,6 ±1.37	864,2 ±1.01	148,07 ±1.11	111,18	32,35

As can be seen from the Table 3, the dimensions of palm kernel did not vary over various moisture content. Similar result was found by Chandrasekar [12]. The palm kernel mean length, width and thickness were found to be 16-14 mm, 12-11 mm, 10-9 mm, respectively and these dimensions did not vary over the various moisture contents.

In current study the calculated mean value of palm kernel sphericity was 78 %. The high sphericity of palm kernel is indicative of the tendency of the shape towards a sphere. The kernels are considered as spherical when the sphericity value is more than 70% [17]. Values for sphericity of palm kernel as 64 % and 70 % have been reported by Owolarafe [18] which is quite close to the results of this investigation.

Table 3 indicates an increment for bulk density with increasing the moisture content. Positive relationships between the bulk density and the moisture content have also have been reported in literature [19-20]. However, the true density of the palm kernel generally decreased as the moisture content increased. The negative relationships between true density and the moisture content have also been reported in some studies [19-21].
Surface area and specific surface area of palm kernel also increased with the increase of moisture content. Increment in surface area by moisture content was reported in literature [22-23]. Porosity of palm kernel was found to decrease with increasing moisture content. This is in agreement with Kibar [23].

The experimental data on equilibrium moisture content of palm kernel at temperature ranging from 50-80 ˚C and relative humidity of 10-80 % are shown in Fig. 2.

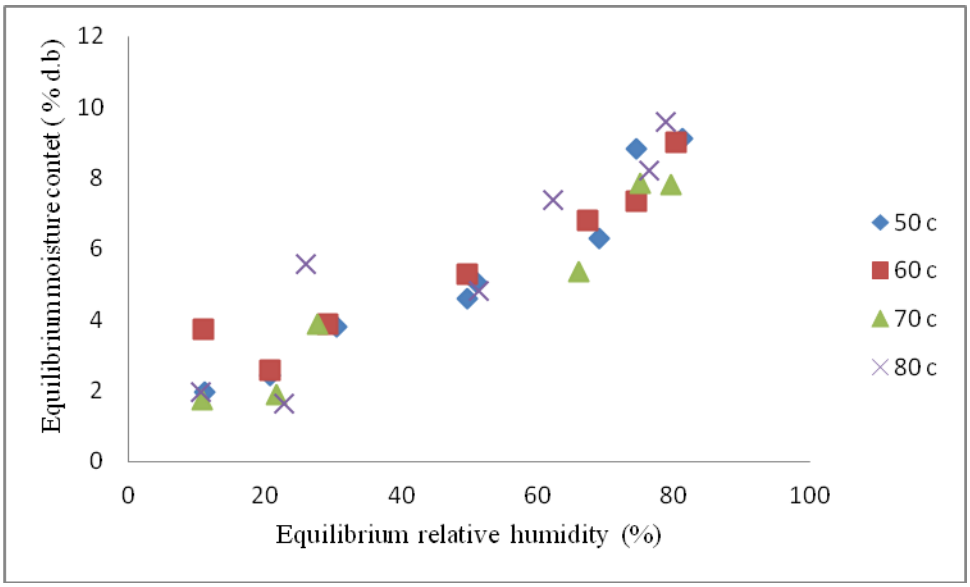

Fig .2: Experimental values of equilibrium moisture content at different temperature.

Equilibrium moisture content is found to decrease with increasing temperature and, at constant temperature, equilibrium moisture content increased with increasing relative humidity, which is consistent generally with established equilibrium moisture content behavior. A constant temperature of 50˚C and relative humidity of 50 %, EMC value obtained from studies by Hakimi [4] and Ajibola [5] was found to be1 to 3 times higher compare to current study. As explained by Brooker [6] this variation of equilibrium moisture content might be as a result of differences in palm variety, the palm maturity and equilibrium moisture content determination method. Vapour pressuring and oven method were used by Ajibola [5] and Hakimi [4] to measure equilibrium moisture content of palm kernel while in current study saturated salt solution method was used.

The experimental drying data on single kernel available in the literature [4] was utilized to develop thin layer drying model by fitting the data with several common thin layer drying equations available in the literature. The moisture content data at selected drying conditions were converted into moisture ratio (MR) and fitted to the three equations and Table 4 lists the selected drying conditions and model constants obtained by application of three equations as mentioned in Table 2.

All models were good enough to represent the experimental data since the overall R^2 ranged from, 0.90 to 0.99, χ^2ranged from 0.00019 to 0.01967 and RMSE ranged from 0.01974to 0.12901 respectively.

Table 4: Values of equation constants and statistical results for selected drying condition

Drying Condition	Constant				Coefficients		
T= air temperature V= air velocity	Equation	k	n	a	R^2	χ^2	RMSE
T=49 V=2.5	Lewis	0.50920			0.99381	0.00123	0.03376
T=49 V=2.5	Page	0.5608	0.8921		0.99235	0.00097	0.02863
T=49 V=2.5	Henderson & Pabis	0.48796		0.95964	0.99486	0.00111	0.03075
T=32 V=2.69	Lewis	0.44875			0.99512	0.00109	0.03172
T=32 V=2.69	Page	0.47421	0.94362		0.99289	0.00109	0.03033
T=32 V=2.69	Henderson & Pabis	0.43625		0.97335	0.99556	0.00108	0.030255
T=33 V=2.45	Lewis	0.52806			0.9944	0.00109	0.03166
T=33 V=2.45	Page	0.58542	0.88029		0.99405	0.00072	0.02463
T=33 V=2.45	Henderson & Pabis	0.5057		0.95917	0.99548	0.00095	0.028432
T=59.3 V=2.33	Lewis	0.61333			0.99546	0.00079	0.027
T=59.3 V=2.33	Page	0.66821	0.8849		0.99533	0.00046	0.01974
T=59.3 V=2.33	Henderson & Pabis	0.5902		0.96279	0.99639	0.00068	0.024069
T=66.3 V=2.38	Lewis	0.69698			0.99625	0.0006	0.02351
T=66.3 V=2.38	Page	0.75493	0.87		0.99778	0.00019	0.01252
T=66.3 V=2.38	Henderson & Pabis	0.67417		0.96797	0.99695	0.00053	0.021203
T=20.1 V=2.42	Lewis	0.39855			0.994	0.00152	0.03746
T=20.1 V=2.42	Page	0.3711	1.0675		0.99176	0.00153	0.03597
T=20.1 V=2.42	Henderson & Pabis	0.39822		0.99919	0.994	0.00165	0.037464
T=57.6 V=1.2	Lewis	0.57843			0.99616	0.0007	0.02549
T=57.6 V=1.2	Page	0.61434	0.9241		0.99454	0.0006	0.02244
T=57.6 V=1.2	Henderson & Pabis	0.5288		0.9559	0.99542	0.0005	0.03
T=65.2 V=0.77	Lewis	0.58004			0.99072	0.00165	0.039
T=65.2 V=0.77	Page	0.38772	1.9299		0.90858	0.01967	0.12901
T=65.2 V=0.77	Henderson & Pabis	0.54575		0.94359	0.99286	0.00138	0.034213

Based on three thin layer drying models studied, moisture ratio was estimated using each model which are shown in Fig. 3. All models yielded results in good agreement with the experimental ones, indicated by high correlation coefficients and low root mean square errors (RMSE) in Table 4.

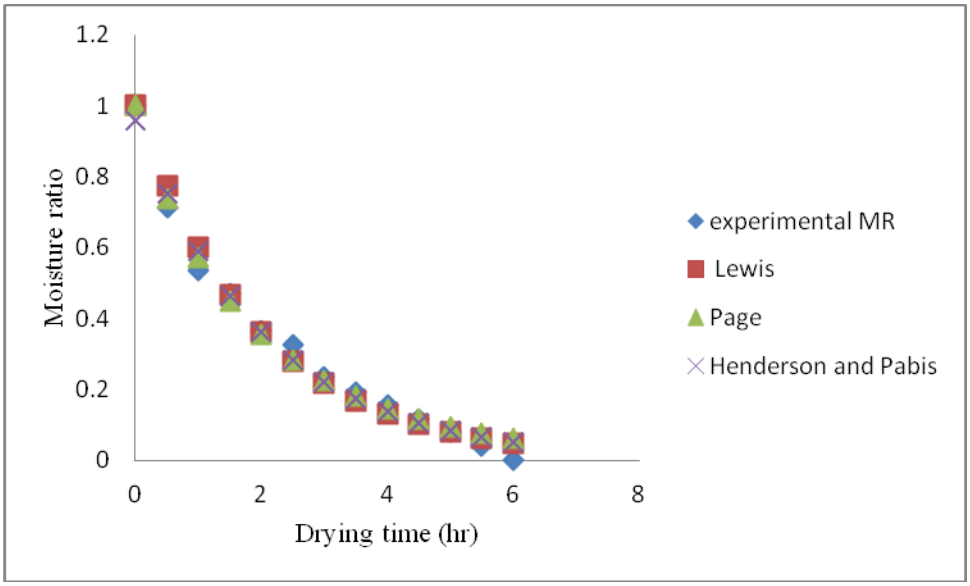

Fig. 3: Comparison of experimental moisture ratio for palm kernel (air temperature of 49 ˚C and air velocity of 2.5 m/s) with the moisture ratio predicted by various equations.

In order to take into account the effect of air temperature and air velocity on the constants of different models, the regression analysis was used to set up relations between these parameters and the accepted models are as follows:

Lewis :$M_R = \exp(-kt)$

Where, for palm kernel,

k= 0.20110+ 0.00580T+ 0.03350V R^2=0.86

Page:$M_R = \exp(-kt^n)$

Where, for palm kernel,

k= -0.29326+ 0.00748T+ 0.21521V R^2= 0.8167

n= 3.06177-0.00401T -0.77527 V R^2=0.7427

Henderson and Pabis: $M_R = a \exp(-kt)$

Where, for palm kernel,

k= 0.18790+ 0.00540 T+ 0.03881V R^2= 0.8295

a= 0.97175 -0.00052089+ 0.00840 R^2= 0.5994

The comparison criteria used to evaluate goodness of fit, i.e, R^2 among different models showed that Lewis model could be fairly used to represent thin layer drying of oil palm kernel; however, further study is needed to obtain more suitable thin layer drying model for palm kernel.

CONCLUSIONS

The investigation of various properties of palm kernel revealed the following:

1. Length, width, thickness of the palm kernel ranged from 16-14 mm, 12-11 mm, 10-9 mm respectively and these dimensions did not vary over the various moisture contents.
2. The sphericity of palm kernel is found to be 78%.
3. The bulk density, surface area and specific surface area of palm kernel increased linearly as the moisture content increased. There was reduction in porosity and true density as the moisture content increased.
4. Equilibrium moisture content is found to decrease with increasing in temperature and at constant temperature, equilibrium moisture content increased with increasing relative humidity.
5. Based on limited data Lewis model could be fairly used to represent thin layer drying of oil palm kernel. However more study is needed to obtain more suitable thin layer drying model.

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