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DEVELOPMENT OF AN EMPIRICAL MODEL RELATING PALM NUT MOISTURE CONTENT, SHELL THICKNESS AND SOAKING TIME

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ABSTRACT: *This paper attempts to offer the use of shell thickness and soaking time to obtain any desired moisture content of dried palm nuts soaked in water at room temperature. In this study nuts were categorized into three size ranges based on its minor axis dimension* (d_1) *and then dried to dry bone mass. The nuts for each experimental run were subjected to soaking per size range per vessel containing water. The experimental data were obtained at 3 –hourly intervals for parameters (nut axial dimension, thickness and mass) considered. Moisture content was computed and statistical analysis carried out. Result revealed that dried palm nut shell thickness and soaking time, apart from any other possible parameter(s) influence water absorption by the nuts vis-à-vis moisture content. The empirical equation developed was tested, validated and found to be useful in estimating soaking time for dried palm nut to attain any desired moisture content.*

KEYWORDS: Moisture Content, Shell Thickness, Soaking Time, Dried Palm Nut, Size Range, Soaking Time

INTRODUCTION

The oil palm fruits are well known for their economic importance and nutritive values. There are three (3) major varieties namely: The Dura, Tenera and Pisifera. The Dura has large size nuts, very thin pericarp and 2 – 5 mm shell thickness. The Tenera has medium size nuts, thick pericarp and 1 – 2.5 mm shell thickness while Pisifera has thicker pericarp with small or no shell (The Tropical Agriculturalist, 1989; Hartmann, Kester and Davis, 1993). Antia, Aniekan and Olosunde (2015) developed a mathematical relationship that enveloped palm nut dimensions as:

$$d_2 = (d_1 d_3)^{1/2} \tag{1}$$

Where d_1= nut minor axis, d_2 = nut intermediate axis and d_3= nut major axis.

The Equation 1 can be used with other relevant engineering formulae to design silo.

To obtain kernels which could be further processed to palm kernel oil and cake, the nuts are usually dried, cracked and kernels separated from the cracked mixture. The kernel oil, cake and shell fragments find various industrial applications (Stephen and Emmanuel, 2009; Emeka and Olomu, 2007). The kernels are preferred to be released wholly as split kernel would expose the oily surface to environmental influence to cause rancidity of the oil when extracted. Since the factors that might affect palm nut processing includes moisture content vis-a-vis rate of moisture evaporation and absorption for under-dried and over-dried nuts respectively, nut soaking time for over-dried nuts, nut shell thickness and axial dimensions, etc; it is therefore necessary to develop a model expressing moisture content as a function of soaking time and shell thickness for efficient processing. The model would assist in estimating nut soaking time to achieve the desired moisture content; and thereby minimize the production of split kernels and occurrence of kernel oil rancidity.

LITERATURE/ THEORETICAL UNDERPINNING

Generally, the crackability of palm nut to release whole kernel depends on a number of factors such as size, shell thickness, mass, nut moisture content, etc (Eric *et al.*, 2009; Antia and Aluyor, 2018). A model relating nut axial dimensions $(d_{1,}\ d_2 \text{ and } d_3)$ and shell thickness (t_s) has been developed and is given (Antia and Assian, 2018) as:

$$t_s = k_1 [A]^{n_1} + k_2[A]^{n_2} + k_3 \qquad (2)$$

where, $A = \left[\frac{d_2\, d_3}{d_1^{0.23}}\right]$; and n_1, n_2, k_1, k_2 and k_3 are constants.

For small size range (5.0 mm$\leq d_1 <$ 17.0 mm):

n_1= 1, n_2 = 0, k_1= 9.9 × 10^{-3}, k_2= 0 and k_3= 0.4662;

For medium size range (17.0 mm $\leq d_1 <$ 20.0 mm):

n_1= 1, n_2 = 0, k_1= 10.4 × 10^{-3}, k_2= 0 and k_3= 0.0986;

For large size range (20.0 mm $\leq d_1 \leq$ 30.0 mm):

n_1= 2, n_2 = 1, k_1= -0.03× 10^{-3}, k_2= 0.0347 and k_3= -3.254

The moisture content of a material is usually determined as described by ASAE (2000). The moisture content (MC) wet basis (wb) is given as:

$$\%\ \text{MC (wb)} = \frac{\text{Initial mass} - \text{final mass}}{\text{Inital mass}} \times 100 \qquad (3)$$

Dehulling/ cracking of some seeds/nuts is enhanced by soaking in water (Shittu *et al.*, 2012; Shafaei and Masoumi, 2013a). The water absorbed by dried seeds/ nuts when soaked depends mainly on water temperature and soaking time (Zhang and Brusewitz, 1993). Several works have been carried out on water absorption of seed during soaking and several models such as Pilosof-Boquet-Bartholomai (1985), Singh-Kulshrestha (1987) and (Jideani and Mpotokwana, (2009) models respectively have been proposed with respect to soaking time and moisture content (Turhan *et al.*, 2002; Kashaninejad *et al*., 2009).

METHODOLOGY

The Dura and the Tenera varieties of palm nut were gotten from an oil processing mill and moisture content determined. Grizzly screen was used to classify each variety of the nuts, based on nut minor diameter (d_1), into three size ranges namely: small size range ($d_1 <$

$12\ mm$), medium size range ($12\ \text{mm} \leq d_1 < 17\ mm$) and large size range ($d_1 \geq 17$ mm). Three hundred nuts per size range per variety were randomly picked; and re-dried in a hot air convection oven at 105 ^{0}C to dry bone mass (ASAE, 2000; Aviara *et al.,* 2005). The nuts were removed, kept in desiccators for 5 minutes and thereafter packed per size range per variety into 6 polyethene bags. Ten nuts were randomly selected from the polyethene bags per size range, weighed using electronic weighing balance as M_{ni}, axial dimensions taken using vernier calipers, numbered with permanent marker and then mixed together to have 20 nuts as a fair representation of mixed nut variety for that size range for each experimental run. Each experiment was carried out in three replicates, and total number of nuts used was 1800.

A preliminary study to determine the soaking period of the nuts in water at room temperature per each size range without soaking the kernel(s) was estimated by soaking 20 nuts of mixed variety per size range per water vessel. At 1-hourly interval, two nuts were picked per size range per vessel and cracked to examine visually the depth of water penetration through the shell thickness using magnifying lens. This experiment was discontinued when the time required for water to penetrate completely through the shell thickness was observed per size range. These times were established as the maximum soaking time for each size range.

At soaking time, T = 0 hour, 20 nuts of mixed variety per size range were selected, weighed, axial dimensions taken using vernier calipers, cracked using static nut cracker and shell fragments measured using vernier caliper one after the other. Mean and standard deviation of percent moisture content (% MC) and shell thickness were calculated. Each size range of the mixed nut variety was immersed respectively into three different vessels containing water at room temperature. At 3 hourly intervals, the same procedure and readings were repeated. The best combination of shell thickness (t_s) and soaking time (T) was determined using SPSS (2011). Plot of average % MC against the corresponding average best combination of t_s and T was carried out to obtain the trend of the curve that fitted the data. The model goodness of fit was carried out using statistical computation and analysis followed by validation of the model using different sets of the nuts (Frank and Altheon, 1995; Spiegel and Stephens, 2006; Arumuganathan *et al.,* 2009; Dermir *et al*., 2004).

RESULTS/ FINDINGS

The data generated were computed based on the nut minor diameter (d_1). The best combination of shell thickness (t_s) and soaking time was determined as $\left(\frac{t_s}{T}\right)^{-0.5}$. The plots of average % MC versus average $\left(\frac{t_s}{T}\right)^{-0.5}$ for the three size ranges and bulk sample gave the curves as presented in Figures 1 to 4.

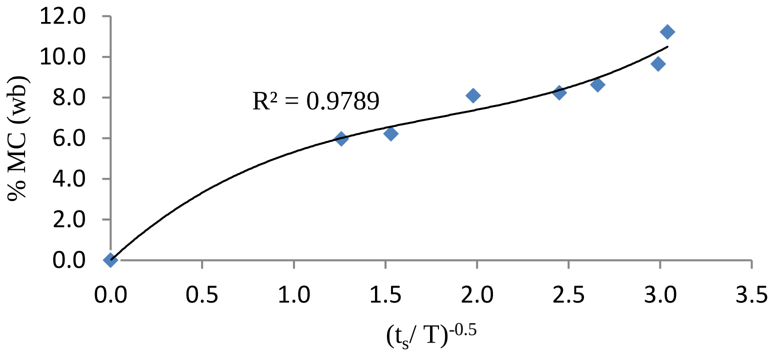

Figure 1: A Plot of % MC (wb) vs $\left(\frac{t_s}{T}\right)^{-0.5}$ for Small Size Range, 12.0 mm < d_1.

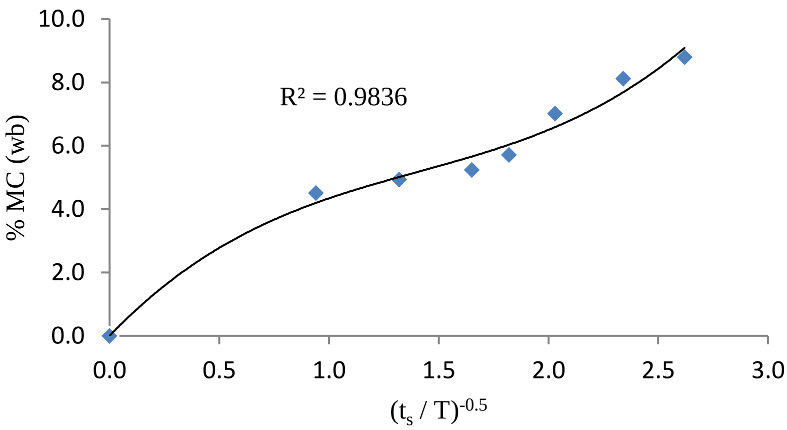

Figure 2: A Plot of % MC (wb) vs $\left(\frac{t_s}{T}\right)^{-0.5}$ for Medium Size Range, 12.0 mm $\leq$ d_1< 17.0mm.

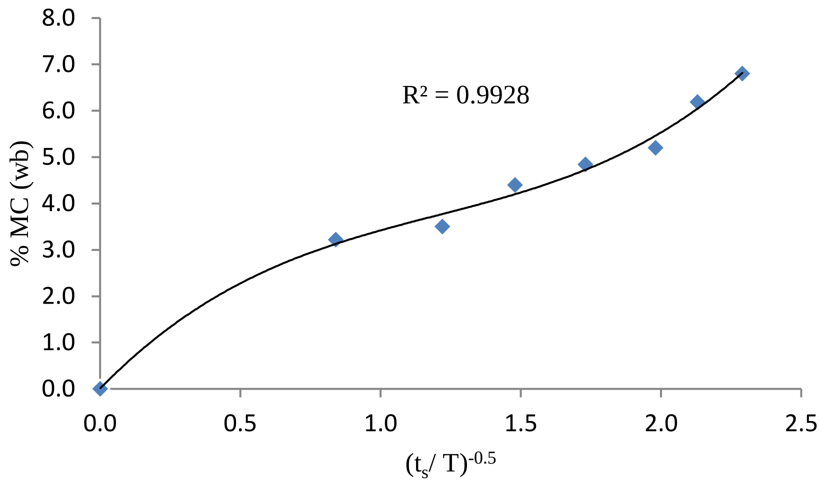

Figure 3: A Plot of % MC (wb) vs $\left(\frac{t_s}{T}\right)^{-0.5}$ for Large Size Range, 17.0 mm $\leq$ d_1.

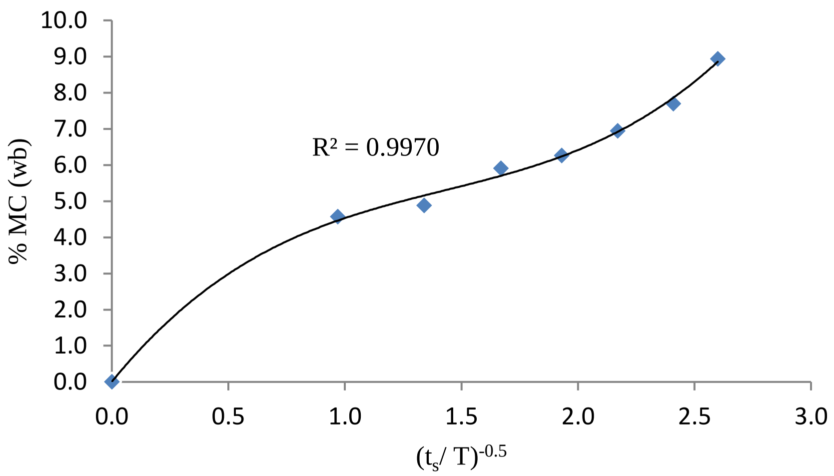

Figure 4: A Plot of % MC (wb) vs $\left(\frac{t_s}{T}\right)^{-0.5}$ for Bulk Sample

The equation that best fits these curves was obtained and is given as:

$$\% \text{ MC} = C_1[Q]^3 - C_2[Q]^2 + C_3[Q] \quad (4)$$

where, for size range:

(i) $12.0 \text{ mm} < d_1$

$C_1 = 0.6758$, $C_2 = 3.6445$, $C_3 = 8.2868$, $Q = \left[\left(\frac{t_s}{T}\right)^{-0.5}\right]$

(ii) $12.0 \text{ mm} \leq d_1 < 17.0 \text{ mm}$

$C_1 = 0.8895$, $C_2 = 3.7575$, $C_3 = 7.2067$, $Q = \left[\left(\frac{t_s}{T}\right)^{-0.5}\right]$

(iii) $17.0 \text{ mm} \leq d_1$

$C_1 = 1.069$, $C_2 = 3.8577$, $C_3 = 6.2018$, $Q = \left[\left(\frac{t_s}{T}\right)^{-0.5}\right]$

(iv) Bulk sample

$C_1 = 0.9770$, $C_2 = 4.231$, $C_3 = 7.706$, $Q = \left[\left(\frac{t_s}{T}\right)^{-0.5}\right]$

($R^2 = 0.9970 \pm 0.023$, standard error = 0.9 %)

where T= soaking time (hr), t_s= shell thickness (mm), $C_1, C_2,$ and C_3 are constants and R^2 = coefficient of determination.

The curve fitness of the specific model equation for each size range of nuts based on Equation 4 was carried out by plotting average predicted % MC (wb) against average experimental % MC (wb) and are shown in Figures 5 to 8.

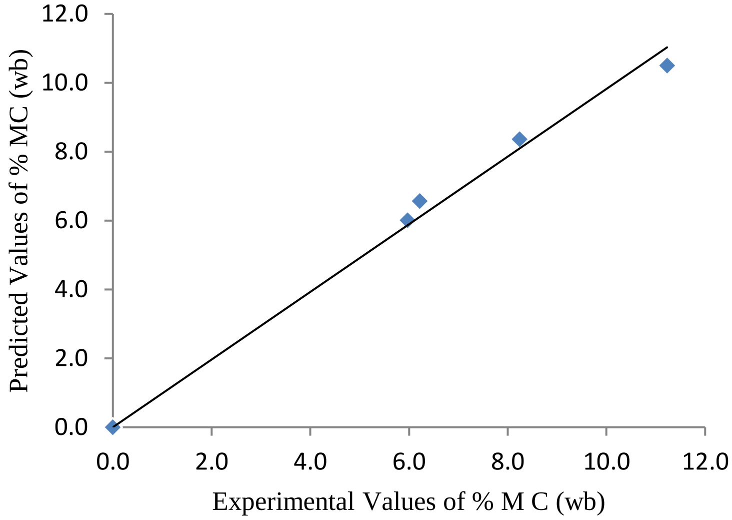

Figure 5: Predicted Values of % MC Against Experimental Values of % MC for Small Size Range.

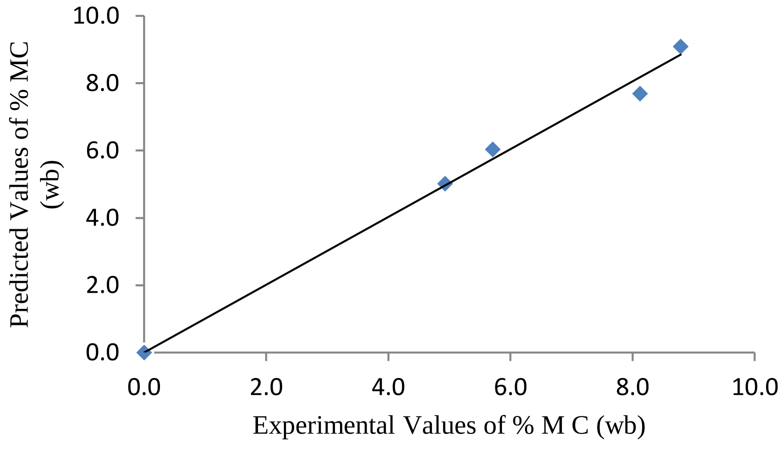

Figure 6: Predicted Values of % MC Against Experimental Values of % MC for Medium Size Range.

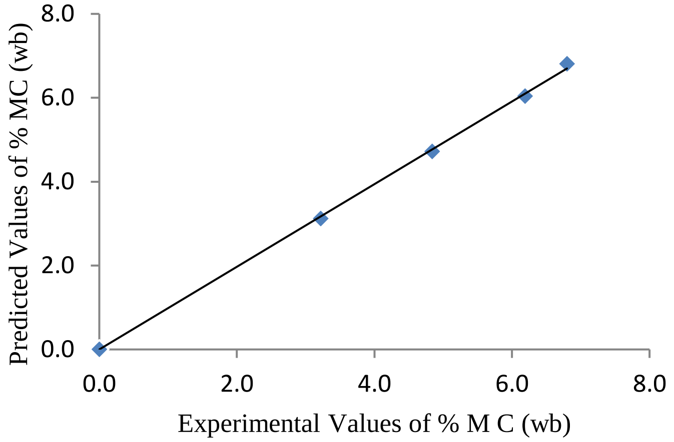

Figure 7: Predicted Values of % MC Against Experimental Values of % MC for Large Size Range

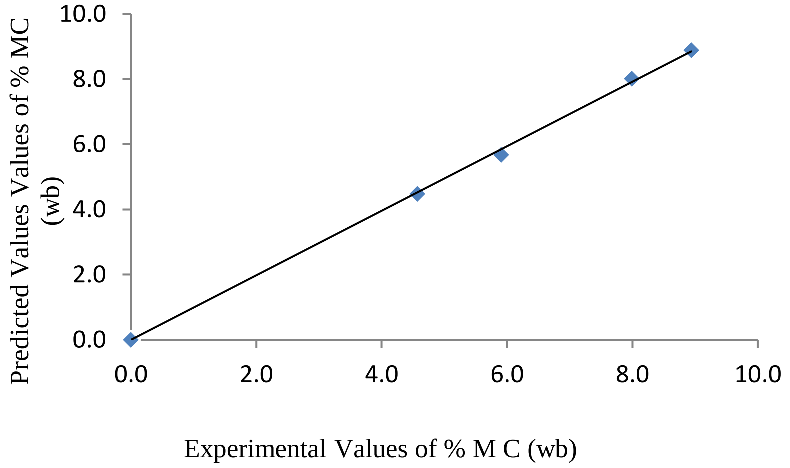

Figure 8: Predicted Values of % MC Against Experimental Values of % MC for Bulk Sample.

From Figures 5 to 8, statistical parameters for goodness of fit were calculated and presented in Table 1

Table 1: Statistical parameters for goodness of fit for model Equation 3.

Parameters	Values			
	Small	**Medium**	**Large**	**Bulk**
Coefficient of correlation, r	0.9894	0.9918	0.9964	0.9985
Coefficient of determination, R^2	0.9789	0.9838	0.9924	0.9970
Reduced Chi-square, χ_c^2	0.1100	-0.1350	0.1800	0.1700
Mean bias error, MBE	0.0440	-0.0540	0.0720	0.0680
Root mean square error, RMSE	0.3660	-0.2770	0.0990	0.1130

Different sets of nuts were used for validation of the model Equation 4. The mean experimental and predicted values of required parameters are presented in Table 2.

Table 2: Validation of model Equation 4 by using different sets of nuts.

Size Range	**Nut Initial Axial Dimensions (mm)**			**Mean Predicted Values**					**Mean Experimental Values**				
								% MC	**Nut Mass (g)**			**% MC**	
	d_1	**d_2**	**d_3**	**t_s**	**G**	G^2	T	**(wb)**	**M_{ni}**	**M_{nf}**	**W_{ab}**	**(wb)**	**t_s**
Small	10.76	13.19	18.56	1.88	2.74	7.51	14.08	9.20	1.44	1.58	0.14	9.17	1.83
Medium	13.88	18.13	22.88	2.70	2.64	6.97	18.79	9.20	3.16	3.50	0.33	9.60	2.50
Large	18.51	21.34	25.67	3.02	2.64	6.97	21.02	9.20	5.60	6.17	0.58	9.27	3.39
Bulk	14.38	17.55	22.37	2.53	2.67	7.15	17.56	9.20	3.40	3.75	0.35	9.35	2.57
	3.90	*4.11*	*3.58*	*0.59*	*0.06*	*0.31*	*3.54*	*0.00*	*2.09*	*2.31*	*0.22*	*0.23*	*0.78*

Italicized values are standard deviations. $G = \left(\frac{t_s}{T}\right)^{-0.5}$ = reciprocal of the square root of velocity of water absorbed $\left[\frac{mm}{hr}\right]^{-0.5}$, M_{ni} = nut mass before immersion [g] , M_{nf} = nut mass after immersion [g] and W_{ab} = amount of water absorbed [g]. t_s predicted using Equation 2.

T-test was carried out on predicted and experimental values of moisture content and shell thickness. The values are presented in Table 3.

Table 3: T-test comparing experimental values of % moisture content/ shell thickness and predicted values of % moisture content /shell thickness.

Size Range	**Parameter**	**Mean Values**		**Probability level @ 5%**			**Significance?**
		Experimental Values	**Predicted Values**	**df**	**T_c**	**T_{tab}**	
Small:	% MC	9.17	9.20	118	0.8310	1.981	No
	t_s	1.83	1.88	118	0.1111	1.981	No
Medium:	% MC	9.60	9.20	118	0.0110	1.981	No
	t_s	2.50	2.70	118	0.0002	1.981	No
Large:	% MC	9.27	9.20	118	0.6040	1.981	No
	t_s	3.39	3.02	118	0.0001	1.981	No

DISCUSSION

From Figures 1 to 4, the curve fitness that best described the trend of % moisture content, shell thickness and soaking time relationship was found to be a polynomial of degree 3, i.e., a cubic curve as presented in Equation 4. The expression $\left(\left[\frac{t_s}{T}\right]^{-0.5}\right)$ may be described as the reciprocal of square root of velocity of water absorbed into the nut/shell. The generalized model Equation 4 with respect to the nut size ranges computed as the bulk sample had the following coefficients: $C_1 = 0.977 \pm 0.350$, $C_2 = 4.231 \pm 0.59$ and $C_3 = 7.706 \pm 1.58$, and $R^2 = 0.9970 \pm 0.023$ with standard error of 0.9%. Generally, the plots in Figures 5 to 8 vividly show that the points for experimental and predicted values have positive correlation and $r \approx 1$. The line for the slope equal one is the one that the predicted values would be equal to the experimental values. Based on Table 1, the coefficient of determination (R^2) show that R^2 = 0.9789, 0.9838, 0.9924 and 0.9970 for small, medium, large size ranges and bulk sample respectively. The coefficient of determination, R^2 is approximately equal to r. The values of root mean square error (RMSE), mean bias error (MBE) and reduced Chi-square (χ_c^2) obtained were lower than R^2 values. These are characteristics of good quality fit. The validation of the model Equation 4 was carried out using 20 nuts of bone-dry mass selected randomly per size range per replicate, making a total of 180 nuts. The nut moisture content of 9.20% was required for attainment when soaked in water for certain time (T). These nuts when subjected to soaking in water were removed at the estimated soaking time using specific expressions based on Equation 4 for small, medium, large size range and bulk sample. The mean experimental and predicted values of required parameters as presented in Table 2 confirmed the validity of the model Equation 4. From Table 3, it is seen that the mean experimental values of % moisture content and shell thickness for the three size ranges do not differ statistically from that of mean predicted values of % moisture content and shell thickness at 118 degree of freedom (df) at 5% level of probability since $T_c < T_{tab}$. This indicates that the model Equation 4 vis-à-vis its specific expressions for small, medium, large size ranges and bulk sample could be reasonably good for estimating either the moisture level or nut soaking time if the nut axial dimensions are known.

Implication to Research and Practice

The time required for attainment of nuts moisture content desired during soaking in water to enhance whole kernel production and minimize production of split kernel vis-à-vis kernel oil rancidity was achieved by using the model Equation 4 coupled with Equation 2.

CONCLUSION

The empirical model (Equation 4) expressing moisture content as a function of shell thickness and nut soaking time was developed.

Future Research

The effect of moisture content on palm nut shell fragmentation for effective separation of kernel is expected to be carried out.

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