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Empirical Modeling Of 4-Dimensional Relationship For Dried Palm Nut Of Dura Variety

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ABSTRACT: The dried and ready to cracked palm nuts of the Dura variety was investigated for dimensional relationship existing between its minor axis, intermediate axis, major axis and shell thickness. The relationship can assist in predicting the nut shell thickness of un-cracked nuts; hence possible to monitor and prevent water from penetrating into kernels to cause rancidity of oil extracted from kernels of over-dried nuts soaked in water to attain the required range of moisture level that would enhance nuts cracking to release whole kernels. In this study, the minor axis (d_1), intermediate axis (d_2) and major axis (d_3) of each nut were measured using vernier caliper, and then classified into twenty-one size ranges based on the minor axis. Each of the nuts in each classified size ranges was cracked and the shell thickness measured. Data of minor axis, intermediate axis, major axis and shell thickness size ranges were generated. An empirical relationship between the three axes and thickness of the nuts was developed. The model equation was tested for goodness of fit; and was found to have reasonable degree of accuracy.

KEYWORDS: Model, Nut axis, Dura variety, Shell thickness, Size ranges.

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I. INTRODUCTION

Palm trees are grown abundantly in Nigeria especially the Dura variety. The major varieties are the Dura, the Tenera and the Pisifera. The Tenera is hybrid of the Pisifera and the Dura. The Dura Variety has generally wider range of shell thickness when compared to the Tenera and the Pisifera variety (NIFOR, 1981; Badmus, 2002; FAO, 2009).

The nuts shape are more elliptical and have three dimensions namely: the major axis (d_3), the intermediate axis (d_2) and the minor axis (d_1) (Oje et al., 2001; Akubuo and Eje, 2002).

These three dimensions has relationship given approximately as (Antia et.al., 2015):

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

The palm nuts are obtained when palm fruits are processed to produce the fibres and palm oil. The nuts obtained are then dried and the release of whole kernels are guaranteed if nuts moisture content range of 2.5 to 8.6 % wb are subjected to cracking by application of impact energy in a nut cracker machine or with stone (Gbadam et. al., 2009; Antia, 2011; Antia et. al., 2013;). The thickness of the shell contributes to the overall mass of the nut of which mass is generally a function of energy. Therefore, estimation of energy required to crack nuts could be related to the nut size vis-a-vis nut mass (Asoegwu and Ndukwu, 2010; Antia, 2013). Nuts that are under dried are likely not to release kernels from shells; hence when cracked, the kernels might split and still get attached to the shell fragments. However, overdried nuts crack and most of the kernels released are split; thereby losing more kernels during separation because the split kernels are sometimes smaller or have approximately the same size as the shell fragments.

The averagely dried nuts do release high percentage of whole kernels. This may be because a certain ratio of quantity of water and oil in the kernel would contribute to cause kernels to be plastic in nature; and so can absorb shock and cannot easily split if appropriate impact energy is applied during nut cracking (Koya, 2006; Antia, 2013). Also, for overdried nuts meant for cracking, the absorption of water by the nuts to have the required moisture content for whole kernel release is important and has to be carried out with care. This is because the time it takes water to travel across the shell thickness must be monitored; since the water if absorbed beyond the inner shell thickness will wet the kernel inside the nuts. This might possibly lead to rancidity of oil if such kernels are processed to obtain palm kernel oil following nut cracking and separation (Okoli, 2003; Antia et al., 2014).

The rancidity of oil could also result if more split kernels are obtain following nut cracking; because the split surface is exposed to environmental influence such as moist from air, mould, etc. This would cause lowering of the quality of marketable oil hence limited usage and lower sales cost of the oil.

II. MATERIALS AND METHODS

Dried and ready to cracked palm nuts of the Dura variety having moisture content of 5.81 % wb was obtained from palm oil processing mill. The nuts were randomly picked and measured using vernier caliper into three size ranges based on the nut minor axis (d_1) as follows: small size: $d_1 \leq 12$ mm ; medium size: 12 mm < $d_1 \leq 20$ mm and large size: 20 mm $< d_1 \leq 30$ mm. Six hundred (600) nuts were sampled per size range and then mixed together to form bulk representative of the nuts. The nuts from the bulk sample were then classified into twenty-one size ranges based on its minor axis (d_1). Eighteen classified size ranges had 1mm interval classification between size ranges of 6 to 24 mm. Three size ranges had: $d_1 < 6$ mm, 24 mm $\leq d_1 < 25\,mm$ and 25 mm $\leq d_1 < 30\,mm$ as these three size ranges are limited in bulk nuts. Sixty nuts were classified into each of the twenty-one size ranges. Twenty nuts from each size range were picked out randomly and the minor axis d_1, intermediate axis d_2 and major axis d_3 were measured. Each nut picked and measured was cracked and the thickness of the shell measured. Three replicates were carried out totaling one thousand five hundred and twenty (1520) nuts for this study. The possible relationships of the three measured axis that may likely predict the thickness of the nuts from the data generated were proposed as:

$t_s = \frac{d_1 d_2}{d_3}$, $t_s = \frac{d_1 d_3}{d_2}$ and $t_s = \frac{d_2 d_3}{d_1}$

Each of these relationship was investigated using Statistical Software (called Microsoft Excel for curve fittings) to obtain a suitable model equation. The model equation was tested for validation by carrying out the following statistical computation and analysis:

(i) Regression analysis to compute the coefficient of determination (R^2) and coefficient of correlation (r) (Frank and Altheon, 1995)

(ii) Plot of scatter diagram of predicted values; and determine the degree to which the predicted and experimental values are related (Spiegel and Stephens, 2006).

(iii) Analysis based on reduced Chi-square (χ_c^2), mean bias error (MBE) and root mean square error (RMSE) (Dermir et. al.,2004; Arumuganathan et. al., 2009).

These values are obtained using the following relationships:

(a) Reduced Chi-square (χ_c^2)

$$(\chi_c^2) = \frac{\sum_{i=1}^{\hat{N}}(MR_{exp} - MR_{pre})}{\hat{N} - Z}$$

(b) Mean bias error (MBE)

$$MBE = \frac{1}{\hat{N}} \sum_{i=1}^{\hat{N}} (MR_{exp} - MR_{pre})$$

(c) Root mean square error (RMSE)

$$RMSE = [\frac{1}{\hat{N}} \sum_{i=1}^{\hat{N}} (MR_{exp} - MR_{pre})^2]^{1/2}$$

where, MR_{exp} = *Experimental values*

MR_{pre} = *Predicted values*

$\hat{N}$ = *Number of observations*

Z = *Number of constants*

χ_c^2 = *Chi-square*

III. RESULTS AND DISCUSSION

The data generated from the twenty-one classification size ranges based on the nut minor axis is presented in Table 1. From Table 1, the values for dimensions of d_2, d_3 and t_s showed overlapping values within any dimensional classification of d_1. This may be due to morphological variations. The dimensional relationship that correlates the shell thickness was found to depend on the minor axis d_1 size ranges as:

$$t_s = k_1 [A]^{n_1} + k_2 [A]^{n_2} + k_3 \quad (1)$$

where, for size range:

(i) $6\ mm \leq d_1 < 17.0\ mm$

$n_1 = 1$, $n_2 = 0$, $k_1 = 0.0099$, $k_3 = 0.4662$, $A = \frac{d_2\, d_3}{d_1^a}$ *and* $a = 0.23$

Equation 1 becomes:

$$t_s = 0.0099\left[\frac{d_2\,d_3}{d_1^{0.23}}\right] + 0.4662 \qquad (2)$$

(ii) 17 mm $\le d_1 \le$ *20.0 mm*

$n_1 = 1,\ n_2 = 0,\ k_1 = 0.0104,\ k_3 = 0.0986,\ A = \frac{d_2\,d_3}{d_1^a}$ and $a = 0.23$

Equation 1 becomes:

$$t_s = 0.0104\left[\frac{d_2\,d_3}{d_1^{0.23}}\right] + 0.0986 \qquad (3)$$

(iii) 20.0 mm $\le d_1 \le$ *30.0 mm*

$n_1 = 2,\ n_2 = 1,\ k_1 = -0.00003,\ k_2 = 0.0347,\ k_3 = -3.254,\ A = \frac{d_2\,d_3}{d_1^a}$ and $a = 0.23$

Equation 1 becomes:

$$t_s = -0.00003\left[\frac{d_2\,d_3}{d_1^{0.23}}\right]^2 + 0.0347\left[\frac{d_2\,d_3}{d_1^{0.23}}\right] - 3.254 \qquad (4)$$

The curve fitness of model equation 1 was plotted as presented in Figure 1 to 3.

From Figure 1 to 3, the following parameters were obtained as presented in Table II to Table IV.

Based on Table II to IV, the coefficient of determination, R^2 showed that R^2 = 0.9611, 0.9895 and 0.9571. The coefficient of correlation, r is approximately equal to R^2. The goodness of fit was further evaluated based on reduced Chi-square (χ_c^2), mean bias error (MBE) and root mean square error (RMSE) values. These values are as presented in Table 2 to 4. The values of R^2 were higher than χ_c^2, MBE , RMSE. These are attributes of good quality fit. Therefore, the empirical Equation 1 vis-a-vis Equation 2, 3 and 4 are considered to be reasonably good. A plot of experimental values against predicted values for the model equation 1 vis-a-vis Equation 2 to 4 are presented in Figure 4 to 6.These plots clearly show that the points for experimental and predicted values have positive correlation and r = 1. The line for the slope equal one is the one for which predicted values will equal experimental values. Therefore, the model could be used with reasonable degree of accuracy.

IV. CONCLUSION

The empirical equation 1 vis-à-vis equation 2, 3 and 4 developed to relate the palm nuts minor axis d_1, intermediate axis d_2, major axis d_3 and shell thickness t_s could be used to predict with reasonable degree of accuracy the nut shell thickness.

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TABLES/FIGURES

Table I: Dura nut variety dimensions of minor axis (d_1), intermediate axis (d_2), major axis (d_3) and shell thickness (t_s)

d_1 (mm)	d_2 (mm)	d_3 (mm)	t_s (mm)
$d_1 < 6.0$	$6.0 \le d_2 \le 9.0$	$7.0 \le d_3 < 13.5$	$0.4 \le t_s < 1.5$
$6.0 \le d_1 < 7.0$	$6.5 \le d_2 \le 10.5$	$8.0 \le d_3 < 16.0$	$0.5 \le t_s \le 1.8$
$7.0 \le d_1 < 8.0$	$7.5 \le d_2 \le 11.5$	$9.0 \le d_3 < 16.5$	$0.5 \le t_s \le 1.8$
$8.0 \le d_1 < 9.0$	$8.5 \le d_2 \le 12.5$	$10.0 \le d_3 < 17.0$	$0.6 \le t_s \le 2.0$
$9.0 \le d_1 < 10.0$	$9.5 \le d_2 \le 13.0$	$11.0 \le d_3 < 17.5$	$0.6 \le t_s \le 2.0$
$10.0 \le d_1 < 11.0$	$10.5 \le d_2 \le 14.0$	$12.0 \le d_3 < 18.0$	$1.0 \le t_s \le 2.5$
$11.0 \le d_1 < 12.0$	$11.5 \le d_2 \le 15.0$	$12.5 \le d_3 < 19.0$	$1.0 \le t_s \le 2.5$
$12.0 \le d_1 < 13.0$	$12.5 \le d_2 \le 16.0$	$15.0 \le d_3 < 20.0$	$1.0 \le t_s \le 2.5$
$13.0 \le d_1 < 14.0$	$13.5 \le d_2 \le 17.0$	$16.0 \le d_3 < 21.0$	$1.0 \le t_s \le 3.0$
$14.0 \le d_1 < 15.0$	$14.5 \le d_2 \le 18.0$	$17.0 \le d_3 < 22.0$	$1.0 \le t_s \le 3.5$
$15.0 \le d_1 < 16.0$	$15.5 \le d_2 \le 19.0$	$18.5 \le d_3 < 23.0$	$1.0 \le t_s \le 3.8$
$16.0 \le d_1 < 17.0$	$16.5 \le d_2 \le 20.0$	$19.0 \le d_3 < 24.0$	$1.0 \le t_s \le 3.8$
$17.0 \le d_1 < 18.0$	$17.5 \le d_2 \le 22.0$	$20.0 \le d_3 < 27.0$	$1.2 \le t_s \le 4.0$
$18.0 \le d_1 < 19.0$	$18.5 \le d_2 \le 23.0$	$20.0 \le d_3 < 28.0$	$1.3 \le t_s \le 4.2$
$19.0 \le d_1 < 20.0$	$19.5 \le d_2 \le 24.0$	$20.0 \le d_3 < 29.0$	$1.3 \le t_s \le 4.5$
$20.0 \le d_1 < 21.0$	$20.5 \le d_2 \le 24.5$	$23.0 \le d_3 < 29.0$	$2.5 \le t_s \le 5.0$
$21.0 \le d_1 < 22.0$	$22.0 \le d_2 \le 25.0$	$23.0 \le d_3 < 29.0$	$2.5 \le t_s \le 6.0$
$22.0 \le d_1 < 23.0$	$23.0 \le d_2 \le 26.0$	$24.0 \le d_3 < 30.0$	$3.0 \le t_s \le 6.0$
$23.0 \le d_1 < 24.0$	$24.0 \le d_2 \le 28.0$	$25.0 \le d_3 < 33.0$	$3.5 \le t_s \le 6.0$
$24.0 \le d_1 < 26.0$	$25.0 \le d_2 \le 31.0$	$26.0 \le d_3 < 37.0$	$4.0 \le t_s \le 6.5$
$26.0 \le d_1 \le 30.0$	$26.5 \le d_2 \le 36.0$	$28.0 \le d_3 < 45.0$	$4.0 \le t_s \le 7.0$

Table II: Statistical parameters for goodness of fit for Model Equation 2

Parameters for Goodness of fit for model equation 3 for $6\ mm \le d_1 < 17.0\ mm$	*Values*
Coefficient of correlation, r	0.9800
Coefficient of determination, R^2	0.9611
Reduced Chi-square, χ_c^2	0.0088
Mean bias error, MBE	0.0155
Root mean square error, RMSE	0.0663

Table III: Statistical parameters for goodness of fit for Model Equation 3

Parameters for Goodness of fit for model equation 3 for $17\ mm \le d_1 < 20.0\ mm$	*Values*
Coefficient of correlation, r	0.9882
Coefficient of determination, R^2	0.9895
Reduced Chi-square, χ_c^2	0.0272
Mean bias error, MBE	0.0143
Root mean square error, RMSE	0.0371

Table IV: Statistical parameters for goodness of fit for Model Equation 4

Parameters for Goodness of fit for model equation 4 for $20\ mm \le d_1 \le 30.0\ mm$	*Values*
Coefficient of correlation, r	0.9612
Coefficient of determination, R^2	0.9517
Reduced Chi-square, χ_c^2	0.0262
Mean bias error, MBE	0.0505
Root mean square error, RMSE	0.0809

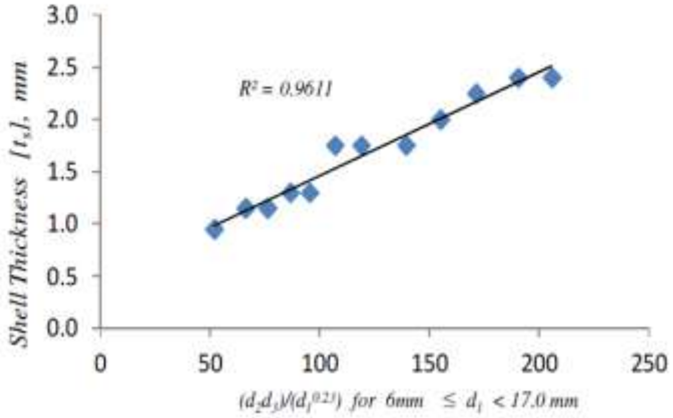

Figure 1: Curve fitness of $t_s = 0.0099\left[\frac{d_2\,d_3}{d_1^{0.23}}\right] + 0.4662$ **for nut size range, 6mm ≤** d_1 **< 17.0 mm**

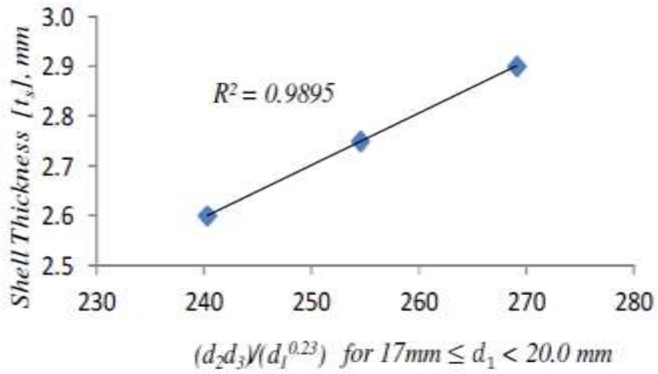

Figure 2: Curve fitness of $t_s = 0.0104\left[\frac{d_2\,d_3}{d_1^{0.23}}\right] + 0.0986$ **for nut size range, 17mm ≤** d_1 **< 20.0 mm**

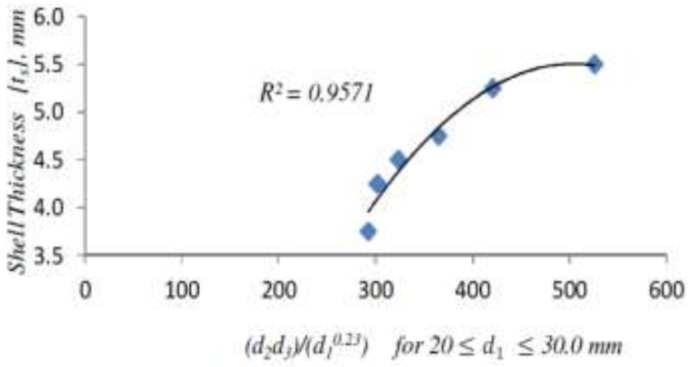

Figure 3: Curve fitness of $t_s = -0.00003\left[\frac{d_2\,d_3}{d_1^{0.23}}\right]^2 + 0.0347\left[\frac{d_2\,d_3}{d_1^{0.23}}\right] - 3.254$ **for nut size range, 20.0 mm ≤** d_1 **≤ 30.0 mm**

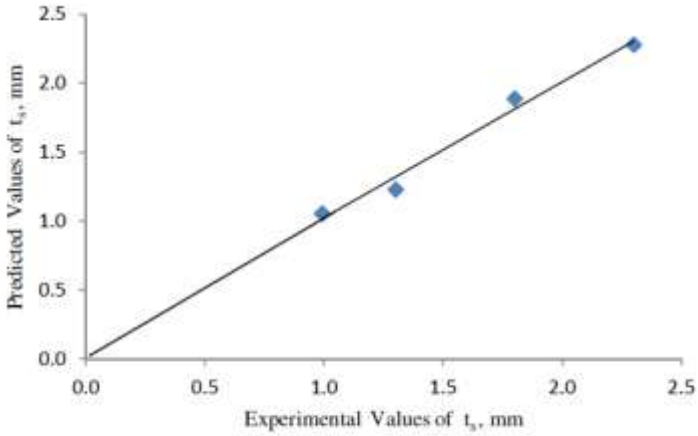

Figure 4: Predicted values of t_s against experimental values of t_s for equation 2

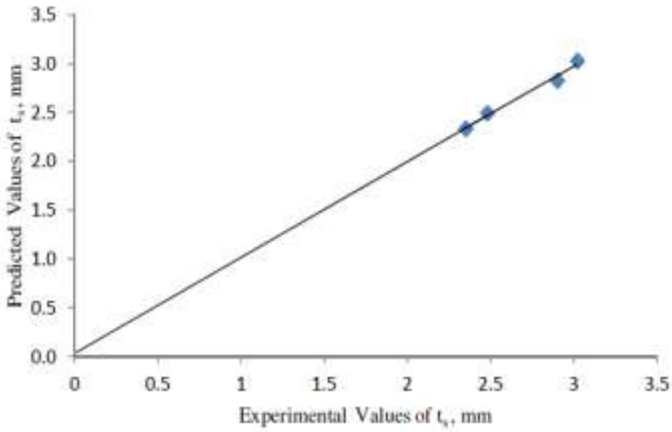

Figure 5: Predicted values of t_s against experimental values of t_s for equation 3

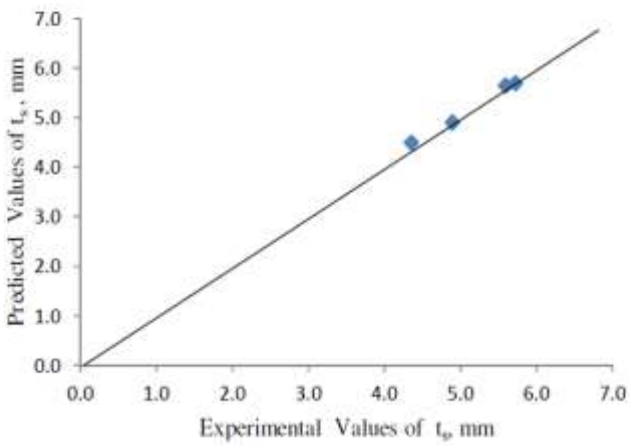

Figure 6: Predicted values of t_s against experimental values of t_s for equation 4

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