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Development of an Empirical Model for Palm Nut Volume Determination

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ABSTRACT

Palm nut volume is tedious to obtained using mathematical method. The development of model equation to easily predict nut volume is essential as it can find applications in the design of palm nut silos, bins, hopper and some related engineering properties of nut. In this study, empirical approach was carried out by using grizzly screens to classify nuts into six (6) size ranges, measuring nut dimensions and determining its volume by water displacement in a glass measuring cylinder. The nuts average geometric mean diameter (GMD) per nut classified size range were computed and values per size range plotted against corresponding average displaced volume of palm nuts per size range. The trend of the plotted points was observed to be exponential, and exponential curve fitted using Statistical Software (Microsoft Excel) to give a model equation for data generated. The developed model was tested for its validity. Result revealed that the coefficient of determination (R^2) and coefficient of correlation (r) are approximately equal 1 and the value of R^2 is greater than the values of Chi square (χ_c^2), mean bias error (MBE) and root mean square error (RMSE). This implies that the model equation could be used for predicting palm nut volume.

Key words: Palm nut, Model, Volume, Geometric mean diameter, Exponential

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Notation

V_{av} = Average volume of palm nut per size range (ml)
$\sum$ = Sum
L_f = Final level of water immediately after immersion (ml)
L_i = Initial level of water of before immersion of palm nut (ml)
N_n = Number of palm nuts used per size range (100)
GMD_{av} = Average geometric mean diameter of the palm nuts per size range (mm)
GMD = Geometric mean diameter of palm nuts per size range (mm)
MBE = Mean bias error
RMSE = Root mean square error
MR_{exp} = Experimental values
MR_{pre} = Predicted values
$\hat{N}$ = Number of observations
Z = Number of constants
χ_c^2 = Chi-square
Y= Volume of palm nut (mm^3)
a and b are coefficients
x = Geometric mean diameter of nut (GMD)
r = Coefficient of correlation
R^2 = Coefficient of determination

INTRODUCTION

Oil palm is a monocotyledonous tree plant. The oil palm is believed to have originated in the tropical rain forest region of West Africa. Additional perspective is that oil palms were found in wild, semi-wild and cultivated conditions in Africa, South-East Africa and America [1]. The oil palm is a tall straight branchless truck with leaves clustered at the top. It bears fruits; and these fruits are oval-shaped sessile drupes. The fruits shape and size vary considerably and each fruit consists of three major layers: an outer epicarp; a middle fibrous mesocarp from which oil is extracted and a hard breakable endocarp called nut which encloses the kernel [2-4]. An oil palm nut is hard and oval shaped. It is obtained after the removal of soft oily mesocarp during palm oil extraction. The shape and size of the oil palm nut vary and the sphericity of the nut ranges from 0.6 to 0.8 [5-7]. Study of some physical properties of palm nuts have been carried out in relation to the design of nut cracker and kernel separator. Some of these parameters include: the angle of repose, sphericity, density, coefficient of friction for nuts, shell particles and kernel [8-10]. The size of agricultural seeds such as grains, pulses and oil seeds have been described by measuring their principal axial dimensions. Palm nuts have three axial dimensions namely: minor axis (d_1), intermediate axis (d_2) and major axis (d_3). The geometric mean of the axial dimensions have been shown to be adequate for calculating Reynold number, projected areas and drag coefficient of food grains. These parameters are basically required in the design of machine for pneumatic conveying, fluidization, etc [11-13]. The nut dimensions expressed in terms of geometric mean diameter (GMD) are given as [7]:

$$GMD = [d_1 d_2 d_3]^{1/3} \quad (1)$$

The palm nuts can be processed to obtain kernels following nut drying, cracking and shell fragments separation from the kernels. The kernel, shell fragment and oil are of economic importance as the kernel can be further processed to obtain palm kernel oil and cake. The oil can be used for production of soap, edible vegetable oil, cosmetics, drugs, etc. The cake can be used as animal feeds while shell fragments could be used for decoration of premises; coarse aggregate in road binder coarse with emphasis on strength of the asphalt concrete as single fuel or blended with other low quality fuel for boiler use to generate power/ electricity [14-16]. The nuts are therefore of enormous economic importance. In processing of nuts for cracking to release whole kernels, it is necessary that the nuts be stored well as moisture content plays a role in the cracking of nuts and rancidity of oil produced from kernels if not properly stored. The nut could be stored in silos and bins; and are also made to pass through hopper into the cracking chamber of a nut cracker. The effective design of these storage vessels and some engineering properties of nuts for efficient processing, therefore, require a contributory knowledge of nuts volume for proper design of the palm nut processing plant. In this study, the use of Archimedes Principles [17] for solid volume displacement in a liquid was employed together with other engineering principles and methods to obtain an empirical model equation for predicting palm nut volume.

METHOD

Palm nuts of the Dura and the Tenera varieties were obtained from an oil processing mill. Fresh palm nuts were used in order to minimize if any, the rate of absorption of water into the nut when immersed in water. The grizzly screens with aperture sizes [P] of 12 mm, 14 mm, 16 mm, 18 mm, 20 mm were used to classify each of the nuts varieties into six (6) sizes within the range of $P \leq 12$ mm, $12\ mm < P \leq 14$ mm, $14\ mm < P \leq 16$ mm, $16\ mm < P \leq 18$ mm, $18\ mm < P \leq 20$ mm and $P > 20$ mm. Fifty (50) nuts from each size range per variety were randomly picked and for each size range, the two varieties were mixed together to obtain a fair representation of the bulk nuts of mixed varieties. The minor axis (d_1), intermediate axis (d_2) and major axis (d_3) of each nut in each size range of the mixed varieties were measured using vernier caliper; and its geometric mean diameter calculated. A 50 ml measuring cylinder containing water was used to measure water displacement level caused by each nut when immersed into the water. The level of water before and after each nut immersion was read and recorded. The level of water displaced for each nut immersion was taken immediately to avoid incorrect volume reading that may arise due to water absorption by the nut shell before reading is taken. A total of 100 nuts were used for each size range and the experiment was carried out in triplicates. A total of 1800 nuts of mixed varieties were used. The difference in the level of water displacement was taken as equivalent of the volume of the palm nuts; and was calculated as:

$$V_{av} = \frac{\sum[L_f - L_i]}{N_n} \quad (2)$$

The average geometric mean diameter of palm nuts in each size range was computed as:

$$GMD_{av} = \frac{\sum[GMD]}{N_n} \quad (3)$$

A plot of geometric mean diameter (GMD) and volume was carried out using a Statistical Software (Microsoft Excel) to observe the trend of the curve whether it was linear, parabolic, exponential, etc in nature. The best curve fitting tool for the trend under the "Trendline" option was selected, which gave the appropriate 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) [18].
(ii) Plot of scatter diagram of predicted values; and determine the degree to which the predicted and experimental values are related [19].
(iii) Analysis based on reduced Chi-square (χ_c^2), mean bias error (MBE) and root mean square error (RMSE) [20], [21].

These values are obtained using the following relationships:

(a) Reduced Chi-square (χ_c^2)

$$(\chi_c^2) = \frac{\sum_{i=1}^{\hat{N}}(MR_{exp} - MR_{pre})}{\hat{N} - Z} \quad (4)$$

(b) Mean bias error (MBE)

$$MBE = \frac{1}{\tilde{N}}\sum_{i=1}^{\tilde{N}}(MR_{exp} - MR_{pre}) \quad (5)$$

(c) Root mean square error (RMSE)

$$RMSE = [\frac{1}{\tilde{N}}\sum_{i=1}^{\tilde{N}}(MR_{exp} - MR_{pre})^2]^{1/2} \quad (6)$$

RESULTS AND DISCUSSION

The plot of data generated for average GMD corresponding to average experimental volume of the nuts is presented in Figure 1.

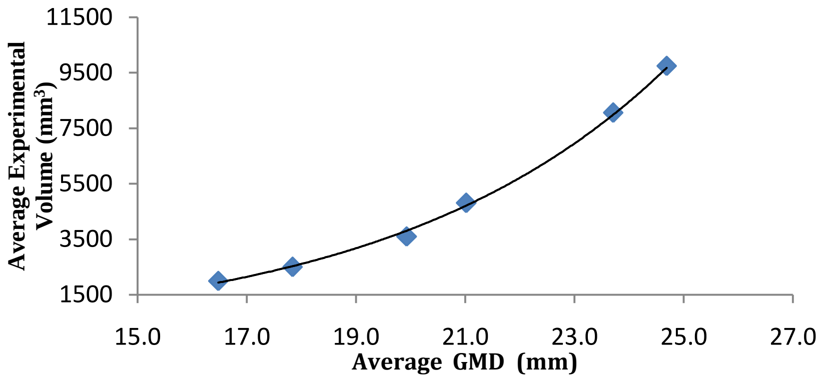

Fig. 1 Plot of average GMD against average experimental volume of nuts

The points on Figure 1 indicate that an exponential curve would fit into the data generated. The curve fitting to the data was carried out using Microsoft Excel. A model equation with coefficients was obtained as:

$$Y = ae^{bx} \quad (7)$$

The coefficient values were obtained as:

a= 76.548

b = 0.196

The model equation was tested using palm nuts of mixed varieties (Tenera and Dura). A plot of experimental values and predicted values from the model Equation 7 was carried out using another set of nuts of mixed varieties (Dura and Tenera). The plot is presented in Figure 2.

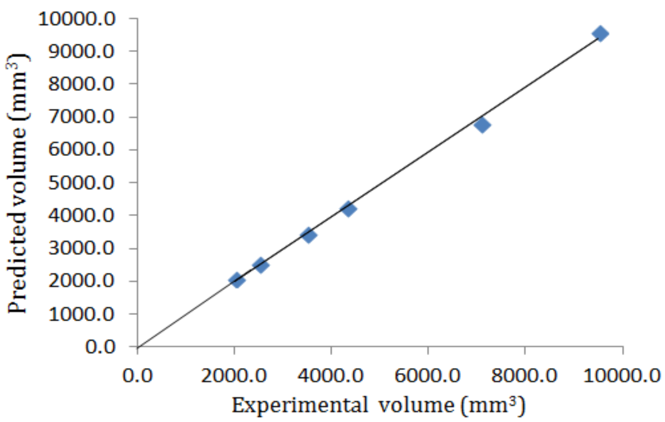

Fig. 2 Plot of experimental volume against predicted volume of nut

The plot showed that the experimental values and predicted values fall within the line where slope is equal to 1. This implies that the predicted values are in close consonance with the experimental values.

Further statistical analyses such as coefficient of correlation (r), coefficient of determination (R^2), reduced Chi square (χ_c^2), mean bias error (MBE) and root mean square error (RMSE) were carried out to investigate the validity of the Equation7. The values are presented in Table 1.

Table -1 Statistical parameters for goodness of fit for Model Equation 7

Parameters for Goodness of fit for model equation 7	**Values**
Coefficient of correlation, r	0.9988
Coefficient of determination, R^2	0.9976
Reduced Chi-square, χ_c^2	0.074
Mean bias error, MBE	0.049
Root mean square error, RMSE	0.141

It is observed that the coefficient of correlation (r) is approximately equal to the value of R^2. Also, the values of χ_c^2, MBE and RMSE are small compared to the value of R^2. This implies that the model Equation 7 could be used to predict reasonably the values of palm nut volume.

CONCLUSION

The model equation developed could be used to predict palm nut volume.

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