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Empirical Model For Predicting Volume Of Palm Nut With Respect To Its Moisture Content

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Abstract: *After drying of palm nut, it is necessary to store it properly to avoid wastage either by pest attack or other environmental factors. In an attempt to design an efficient storage system for palm nuts, basic physical property such as volume of the fresh and dried palm nut must be known at different moisture levels; and should be articulated and modelled for easy prediction. In this study three varieties (Dura, Tenera and Pisifera) of fresh palm nuts were sourced, classified and mixed based on their minor diameter (d_1), into three size ranges. A total of 1680 nuts were sampled. Nut masses were noted before drying in a hot air convection oven at 105 ^{0}C. At 4 hourly intervals during drying, 180 nuts per size range were taken out; and their moisture content (%db), geometric diameter (D_G), volume and the ratio of nut volume at any drying time to its initial volume were determined. Mean and standard deviation of each parameter were calculated. Model based on basic drying theory was generated, verified and validated. Technical analysis revealed that the value of coefficient of determination (R^2) was approximately equal the coefficient of correlation ($r \approx 1$), and was higher than the values of reduced Chi-square (χ_c^2), mean bias error (MBE) and root mean square error (RMSE). The values of modelling efficiency (EF) and coefficient of residual mass (CRM) were almost perfect. Therefore, the model developed is reasonably good for predicting instantaneous volume of palm nut with respect to its moisture content.*

Keywords: *Modelling, Storage system, Drying, Nut moisture content, Nut volume.*

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I. INTRODUCTION

The oil palm tree, also known as *Elaeis guineensis*, is a very important economic and perennial plant. Its origin could be traced from Africa, but grown commercially in Southern America and Southeast Asia (Kheiri, 1985). It is classified based on endocarp (shell thickness) and mesocarp content (Etawau, 2017). Dura have large sized kernel and a very thin pericarp; Tenera have medium sized kernel with a thick pericarp, while Pisifera have about 95% mesocarp and with little or no kernel (Stephen and Emmanuel, 2009). Products derived from the plant include palm oil, kernel oil, kernel cake, palm wine, etc. Palm kernel oil can be used for making glycerin, margarine, etc (Stephen and Emmanuel, 2009; Antia *et al.*, 2012). Shell fragments are used as domestic fuel, decorating houses, key biomass material, etc (Oyejobi *et al.*, 2012). The kernel cake is used in making livestock feed (Emeka and Olomu, 2007). In order to harness the above mentioned products, palm fruits are stripped, sterilized, digested and oil extracted. The residues such as palm nuts and fibres are left (Ologunagba *et al.*, 2010). The nuts are dried and could be stored in silos properly to avoid wastage either by pest attack or other environmental factors such humidity, temperature, etc. or cracked thereafter into a mixture of kernels and shell fragments; and followed by kernels separation. These kernels are crushed and separated into crude palm kernel oil (CPKO), palm kernel meal (PKM) and water (FAO, 2004). However, accurate modelling of nut volume with respect to its moisture content (% db) could aid in storage system design. Models allow for quick and easy performance test of different alternatives that may lead to optimal solution. They allow room for system efficiency improvement and overall performance of engineering design, even before equipment construction (Assian *et al.*, 2021). Many researchers have developed several models which could be used in food and crop processing machines design and process optimization which recognize some food and crop physical properties (Alonge and Oje, 2003; Ndukwu and Asoegwu, 2011; Alonge and Onwude, 2013; Antia and Assian, 2018a & 2018b; Antia *et al.*, 2019a, 2019b and 2019c; Assian, *et al.*, 2021). These physical properties may include nut geometric mean diameter, nut surface area, nut moisture content, nut initial mass and nut mass at any drying time given as (Irtwange and Igbeka, 2000; Antia *et al.*, 2015; Antia and Assian, 2018b; Antia *et al.*, 2019c, Antia *et al.*, 2021):

$$D_G = (d_1 \times d_2 \times d_3)^{1/3} \quad (1a)$$

$$d_2 = (d_1 \times d_3)^{1/2} \quad (1b)$$

$$V_n = 76.548\, e^{(0.196 \times D_G)} \quad (2)$$

$$S_n = \frac{V_n}{D_G} \quad (3)$$

$$\%\ MC_{db} = \left[\left(\frac{1}{F\frac{M_0}{M_t}}\right) - 1\right] \quad (4)$$

$$M_0 = \rho V_0 \quad (5)$$

$$M_t = \rho V_t \quad (6)$$

Where, D_G = nut geometric mean diameter (cm), d_1 = nut minor diameter (cm), d_2= nut intermediate diameter (cm), d_3 = nut major diameter (cm), V_n= nut volume (cm^3), S_n= nut surface area (cm^2), $\%\ MC_{db}$ = percent moisture content dry basis, F = drying mass constant, M_0 = nut initial mass (g), M_t = nut mass at any drying time (g), ρ = nut density (g/cm^3), V_0 = nut initial volume (cm^3) and V_t = nut volume at any drying time (cm^3)
Therefore, the key objective of this study would be to develop a model that could predict the volume of palm nut with respect to its moisture content at any drying time. The model could find application in the design of palm nut storage system.

II. MATERIALS AND METHODS

2.1 Materials

In this study, the materials used were fresh palm nuts, hot air convection oven, clean cloth, containers (crucibles), polyethene bags, digital vernier calipers and desiccator**.**

2.2 Sourcing of Palm nuts

In this study, a mixture of three varieties of fresh palm nuts (the Tenera, Pisifera and Dura) was sourced from a palm oil processing mill along Abak Road, Uyo, Nigeria.

2.3 Methods

The nuts were mopped with a clean cloth and wrapped in black polyethene bags. The bulk nuts were grouped based on nut minor diameter (d_1), into three size ranges: small size ($d_1 \leq 1.4$ cm), medium size ($1.4\ \text{cm} < d_1 \leq 2.0$ cm) and large size ranges ($d_1 > 2.0\ cm$) using digital vernier calipers. 420 nuts, from each size range, were picked at random, and mixed to form a total of 1260 bulk nuts. The nut initial masses were weighed as M_0 , and introduced into a hot air convection oven at a temperature of 105^0C. At 4 hourly intervals, 60 palm nuts per size range were removed, cooled in a desiccator for 5 minutes, re-weighed as M_t and their corresponding axial dimensions taken and recorded. The process continued until bone dry mass was obtained. The experiment was conducted in triplicates.

2.4 Moisture Content Determination

The nut moisture content was found using oven drying method as described by ASAE (2000) and Antia *et al.* (2014) using Equation 7.

$$\%\ MC_{db} = \frac{M_t - M_{bd}}{M_{bd}} \times 100\% \quad (7)$$

Where, M_{bd} = nut mass at bone dry condition (g)

2.5 Nut Geometric Mean Diameter and Volume Determinations

The nut geometric mean diameter and volume were found using Equations 1 and 2. Since seven (7) groups of nuts were used, it was necessary to standardize the values of nut volume using V_t / V_0 .

2.6 Data Analysis

Mean and standard deviation of each parameter were calculated through the aid of Data Acquisition Template powered by Microsoft Excel ™. Based on Equations 4, 5 and 6, Equation 8 was obtained as:

$$\frac{V_t}{V_0} = F\frac{\rho_t}{\rho_0}(\%\ MC_{db}) + F\frac{\rho_t}{\rho_0} \quad (8)$$

Where, ρ_t = nut density at any moisture content level and initial nut density.

A plot of $\frac{V_t}{V_0}$ against $\%\ MC_{db}$ based on Equation 8 was carried out and model that fits the curve was determined.

The model obtained based on data was evaluated using Statistical Package for Social Scientists (SPSS) Version 20. The model, its regression coefficient and constant were found.

2.7 Model Verification and Validation

The experiment was repeated with 20 nuts per size range from the bulk nuts, giving a total of 420 nuts. The model was verified and validated using the following statistical computations and analyses:

(i) The correlation coefficient (r) and coefficient of determination(R^2) found by employing regression analysis (Frank and Altheon, 1995);

(ii) Scattered plot of experimental and predicted values; and determination of the extent to which the predicted and experimental values are associated (Spiegel and Stephens, 2006); and

(iii) Reduced Chi-square (χ_c^2), mean bias error (MBE), coefficient of residual mass (CRM), root mean square error (RMSE) and modelling efficiency (EF) analyses (Loague and Green, 1991; Legates and McCabe Jr., 1999; Dermir *et al.*, 2004; Arumuganathan *et al.,* 2009).

These values were obtained using Equations 9 to 13:

Reduced Chi-square (χ_c^2)

$$(\chi_c^2) = \frac{\sum_{i=1}^{\hat{T}} (MR_{exp} - MR_{pre})}{\hat{T} - P} \quad (9)$$

Mean bias error (MBE)

$$MBE = \frac{1}{\hat{T}} \sum_{i=1}^{\hat{T}} (MR_{exp} - MR_{pre})^2 \quad (10)$$

Root mean square error (RMSE)

$$RMSE = (MBE)^{1/2} \quad (11)$$

Coefficient of residual mass (CRM)

$$CRM = \frac{\sum_{i=1}^{\hat{T}} MR_{exp} - \sum_{i=1}^{\hat{T}} MR_{pre}}{\sum_{i=1}^{\hat{T}} MR_{exp}} \quad (12)$$

Modelling efficiency (EF)

$$EF = 1 - \frac{\sum_{i=1}^{\hat{T}} (MR_{exp} - MR_{pre})^2}{\sum_{i=1}^{\hat{T}} (MR_{exp} - MR_{exp.mean})^2} \quad (13)$$

Where, MR_{exp}= experimental values, MR_{pre} = predicted values, $MR_{exp.mean}$ = mean experimental values, $\hat{T}$ = total number of observation, and P = number of constants. For precise goodness of fit, the value of r should be equal to R^2, and also greater than the values of χ_c^2, RMSE and MBE. Besides, the value of CRM must be close to zero and EF roughly equal to 1.

III. RESULTS AND DISCUSSIONS

The result of the research is shown in Table 1.

Table 1: The mean values of geometric mean diameter, moisture content, nut volume and standardized nut volume

Drying Time, t (hr)	D_G [cm]	MC_{db} [%]	Nut Volume (V_n) [cm^3]	$\frac{V_t}{V_0}$
0	2.290	23.66	119.912	1.0000
4	2.210	15.83	118.394	0.9873
8	2.182	8.71	117.411	0.9791
12	2.173	7.91	117.193	0.9773
16	2.165	6.08	117.010	0.9758
20	2.155	1.88	116.781	0.9739
24	2.150	0.00	116.666	0.9729

The plot of $\frac{V_t}{V_0}$ versus % MC_{db} is given in Figure 1.

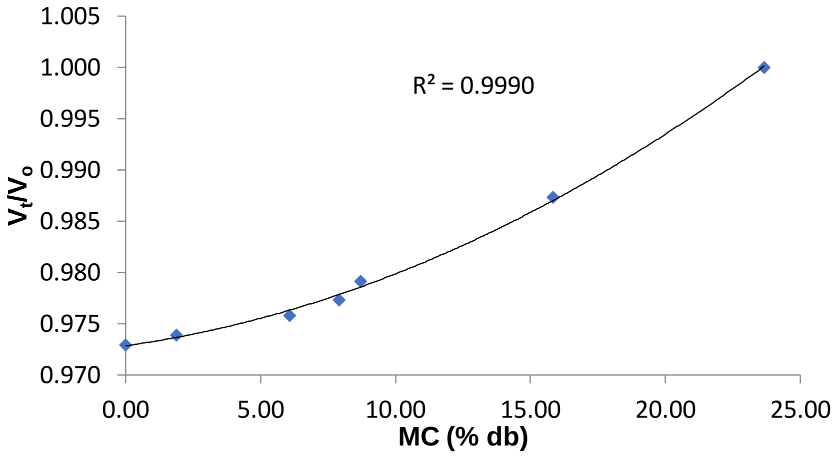

Figure 1: Plot of $\frac{V_t}{V_0}$ versus % MC_{db}

As seen in Figure 1, as ratio $\frac{V_t}{V_0}$ decreased, the nut moisture content also decreased. The model that best described the curve is the linear-power model and could be expressed in the form given in Equation 14 as:

$$\frac{V_t}{V_0} = c(MC_{db})^g + f \quad (14)$$

Where, c = constant = 0.00017, g = index = 1.565 and f = constant = 0.973

The predicted values of nut volume ratio using the model Equation 14 are presented in Table 2.

Table 2: Mean Experimental and Predicted Values of Bulk Palm Nut Volume Ratio at Various Moisture Contents

Bulk Sample % MC (db)	Exp.	Pred.
23.66	1.0000	1.0000
15.83	0.9873	0.9873
8.83	0.9791	0.9785
7.91	0.9773	0.9778
6.08	0.9758	0.9761
1.88	0.9739	0.9735
0.00	0.9729	0.9731

Note: Exp. = experimental values and Pred. = predicted values

Besides, curve fitness of the model Equation 14 computed by plotting mean predicted $\frac{V_t}{V_0}$ against mean experimental $\frac{V_t}{V_0}$ from Table 2, is shown in Figure 2.

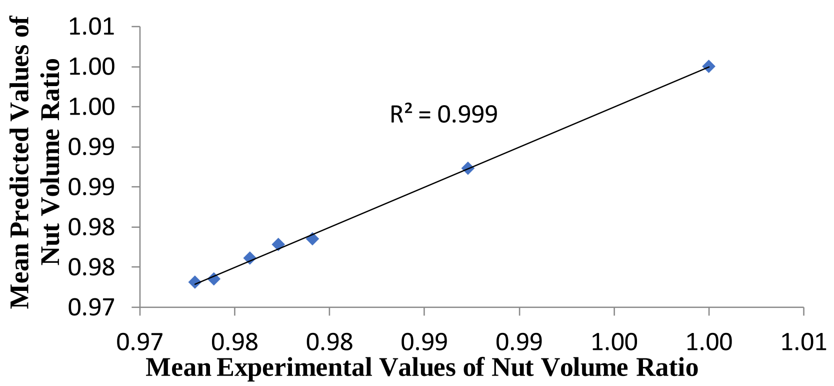

Figure 2: Mean predicted values of nut volume ratio versus experimental values

The plot, in Figure 2, clearly shows that the points for predicted and experimental values have positive relationship and r $\approx$ 1. The line in which the slope equal one is the one for which predicted values would equal experimental values. Arranging Equation 14, we have

$$V_t = V_0\,[c(MC_{db})^g + f] \quad (15)$$

Also, from Figure 2, the calculated statistical parameters for goodness of fit are presented in Tables 3.

Table 3: Statistical parameters for goodness of fit for the model Equations 14

Parameters	Values
Coefficient of correlation, r	0.9995
Coefficient of determination, R^2	0.9990
Reduced Chi-square, χ_c^2	0.0002
Mean bias error, MBE	0.0000
Root mean square error, RMSE	0.0004
Coefficient of residual mass, CRM	0.0000
Modelling efficiency, EF	0.9978

From Table 3, the value of coefficient of determination (R^2) was approximately equal the coefficient of correlation (r), which showed that $R^2 \approx 1$, and were higher than the values of reduced Chi-square (χ_c^2), root mean square error (RMSE) and mean bias error (MBE). The value of coefficient of residual mass (CRM) was zero and modelling efficiency (EF) approximately equal one. These are good properties of a satisfactory quality fit. Therefore, the empirical Equations 14 could be used to predict the volume of palm nut with respect its moisture content dry basis.

IV. CONCLUSION

The model Equation 14 was developed using empirical approach. It was statistically validated and also found to be reasonably good for predicting palm nut volume with respect its moisture content dry basis. It could also be employed in the design of silo capacity for storage of palm nut after drying operation.

Conflict of interest

None is declared.

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