PRACTICAL MODEL FOR ESTIMATING TARO COCOYAM VOLUME BASED ON ITS AXIAL DIMENSIONS

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Abstract: Taro Cocoyam is prone to attack by rodents, insect pests and environmental elements. After drying, it is stored to evade wastage. In an effort to efficiently develop storage system, fundamental physical parameter such as volume of the fresh cocoyam with respect to its axial dimensions should be well expressed and modelled for easy estimation. In this study, fresh Taro Cocoyam samples were sourced, cleaned and packaged. Ten unpeeled samples were used in determining initial moisture content (% w.b). The axial dimensions of fifty unpeeled samples were measured and used to compute arithmetic mean diameter ($D_A$). Corresponding true volume ($V_T$) was found using water displacement approach. The bulk samples were grouped based on $D_A$, into seven (7) size ranges. Mean and standard deviation of each parameter were computed. The model was established, verified and validated. Statistical analysis showed that the value of coefficient of determination ($R^2$) was almost equals correlation coefficient ($r \approx 1$). The values of reduced Chi-square ($\chi^2$), root mean square error (RMSE) and mean bias error (MBE) were not that high. The values of coefficient of residual mass (CRM) and modelling efficiency (EF) were almost perfect.

Therefore, the model established is practically good for estimating volume of Taro Cocoyam which could find application in the design of feed hopper and storage system.

Key words: Model, estimation, Taro Cocoyam, volume, storage system

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INTRODUCTION

The demand for fresh Taro Cocoyam today has progressively been on the increase in our locality (Nigeria). After harvest, it is allowed to naturally undergo dehydration to reduce the moisture level and stored properly to avoid attack by rodents / insect pests or other environmental elements. Poorly designed storage facility, processing equipment for cocoyam or other factors may contribute to the wastage or loss in its quality.

Some physical properties such as axial dimensions (length, width and thickness), arithmetic mean diameter, geometric mean diameter, moisture content, surface area, initial mass, static frictional coefficient, angle of repose, etc. are relevant in the development of a good storage facility and processing equipment [1, 2, 3, 4, 5]. Models could be established amongst these properties for easy prediction or equipment development. However, precise modelling of Taro Cocoyam volume with respect to its axial dimensions could assist in the development of feed hoper and storage systems. Model permits possibility for improving the system, process or equipment efficiency and total engineering design performance, before fabrication. It enhances rapid and simple evaluation of various options that could result in a desired solution. It helps in the elimination of wastage in the design and results testing [5]. Several researchers have established many models which could find application in food and crop processing / process optimization as well as equipment development [6, 7, 8, 9, 10, 11, 12, 5]. Thus, the main objective of this research was to establish a model that could be used in estimating Taro Cocoyam volume with respect to its axial dimensions for efficient development of storage system.

MATERIALS AND METHODS

Exactly one hundred and fifteen (115) sets of fresh Taro Cocoyam (Colocassia esculenta) were bought from Akpan Andem Market, Uyo, Akwa Ibom State. Taro Cocoyam samples were chosen at random, mopped and scrapped with a clean cloth and knife to eliminate foreign materials such as dust, dirt, wounded or blemished samples, stones, and stored in black polyethene bags. The initial moisture content of 10 unpeeled samples was found using gravimetric method as described by [13], [14], [15] using Equation 1. Seventy (70) unpeeled samples were chosen and their axial dimensions (length \(L\), width \(W\) and thickness \(T\)) measured using digital vernier calipers of 0.01 mm calibration and tape rule as shown in Figure 1, and documented. The corresponding true volume of each sample was determined by water displacement as described by [2] and recorded. The axial dimensions were used to compute arithmetic mean diameter (\(D_A\)) using Equation 2. The bulk samples were categorized based on \(D_A\) into seven (7) size ranges: I \((D_A < 3.0 \text{ cm})\), II \((3.0 \text{ cm} \leq D_A < 3.5 \text{ cm})\), III \((3.5 \text{ cm} \leq D_A < 4.0 \text{ cm})\), IV \((4.0 \text{ cm} \leq D_A < 4.5 \text{ cm})\), V \((4.5 \text{ cm} \leq D_A < 5.0 \text{ cm})\), VI \((5.0 \text{ cm} \leq D_A < 5.5 \text{ cm})\) and VII \((D_A \geq 5.5 \text{ cm})\).

Mean and standard deviation of each parameter were computed using Data Acquisition Template powered by Microsoft Excel ™.
Fig. 1: The principal dimensions of Taro Cocoyam sample

**Moisture Content Determination**

The sample moisture content in percent wet basis ($\% \text{ M}_{\text{wb}}$) was found using Equation 1.

$$\% \text{ M}_{\text{wb}} = \frac{M_i - M_{bd}}{M_i} \times 100\%$$ (1)

Where, $M_i$ = initial mass of the sample (g) and $M_{bd}$ = sample mass at bone dry condition (g).

**Arithmetic Mean Diameter Determination**

The sample arithmetic mean diameter ($D_A$) was found using Equation 2.

$$D_A = \left( \frac{L + W + T}{3} \right)$$ (2)

**Sample True Volume Determination**

The sample true volume ($V_T$) was found using Equation 3 [2].

$$V_T = V_f - V_i$$ (3)

Where, $V_i$ = initial volume of water in the measuring cylinder or beaker (ml) and $V_f$ = final volume of water in the measuring cylinder or beaker (ml). Note: 1.0 ml = 1.0 cm$^3$

**Data Analysis**

A. **Model Formulation**

From the data generated, the following in form of exponential model, linear-power model, quadratic model, polynomial of degree 3 and hyperbolic model were suggested as given in Equation 4 to 8 [16].

$$Y = ae^{bX}$$ (4)

$$Y = a(X)^b + c$$ (5)

$$Y = a(X)^2 + b(X) + c$$ (6)

$$Y = a(X)^3 + b(X)^2 + c(X) + d$$ (7)

$$Y = \frac{1}{a + b(X)}$$ (8)

Where,

- $Y$ represents $V_T$ in (cm$^3$),
- $X$ denotes $D_A$,
- and $a$, $b$, $c$ and $d$ are constants of the suggested model equations.
**B. Model Development**

The measured data obtained were fitted into the proposed model Equation 4 to 8 using Non-Linear Regression Statistics embedded in Statistical Package for Social Scientists (SPSS) Version 20. Each model and its respective constants were found.

The model(s) with reasonable and highest value of coefficient of determination ($R^2$) were selected and subjected to verification and validation.

**C. Model Verification and Validation**

The experimental run was repeated with 5 samples per size range from the bulk sample, giving a sum of 35 samples. The model was verified and validated using statistical computations and analyses namely: coefficients of correlation ($r$) and determination ($R^2$), scattered graph of measured and predicted values, reduced Chi-square ($\chi^2_c$), mean bias error (MBE), coefficient of residual mass (CRM), root mean square error (RMSE) and modelling efficiency (EF) [5, 17].

Where,

Reduced Chi-square ($\chi^2_c$)

\[
(\chi^2_c) = \frac{\sum_{i=1}^{\hat{T}} (MR_{mea} - MR_{pre})}{\hat{T} - G}
\]

(9)

Mean bias error (MBE)

\[
MBE = \frac{\frac{1}{\hat{T}} \sum_{i=1}^{\hat{T}} (MR_{mea} - MR_{pre})^2}{\hat{T} - G}
\]

(10)

Root mean square error (RMSE)

\[
RMSE = (MBE)^{1/2}
\]

(11)

Coefficient of residual mass (CRM)

\[
CRM = \frac{\sum_{i=1}^{\hat{T}} MR_{mea} - \sum_{i=1}^{\hat{T}} MR_{pre}}{\sum_{i=1}^{\hat{T}} MR_{mea}}
\]

(12)

Modelling efficiency (EF)

\[
EF = 1 - \frac{\sum_{i=1}^{\hat{T}} (MR_{mea} - MR_{pre})^2}{\sum_{i=1}^{\hat{T}} (MR_{mea} - MR_{mea.mean})^2}
\]

(13)

Where,

- $MR_{mea}$ = measured values,
- $MR_{pre}$ = predicted values,
- $MR_{mea.mean}$ = mean measured values,
- $\hat{T}$ = total number of observation,
- $G$ = number of constants.

For exact goodness of fit, the value of $r$ should be equal to $R^2$. Besides, the value of CRM must be close to zero and EF roughly equal to 1.
RESULTS AND DISCUSSIONS

The results of the study are shown in Table 1.

Table 1. The mean values of axial dimensions, arithmetic mean diameter and true sample volume

<table>
<thead>
<tr>
<th>Group</th>
<th>Axial Dimensions</th>
<th>Volume of Liquid in the Cylinder</th>
<th>( V_d = V_T ) (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( L ) (cm)</td>
<td>( W ) (cm)</td>
<td>( T ) (cm)</td>
</tr>
<tr>
<td>I</td>
<td>3.806</td>
<td>2.275</td>
<td>2.505</td>
</tr>
<tr>
<td></td>
<td>0.556</td>
<td>0.191</td>
<td>0.021</td>
</tr>
<tr>
<td>II</td>
<td>5.587</td>
<td>2.218</td>
<td>2.415</td>
</tr>
<tr>
<td></td>
<td>0.303</td>
<td>0.098</td>
<td>0.083</td>
</tr>
<tr>
<td>III</td>
<td>5.470</td>
<td>2.820</td>
<td>3.088</td>
</tr>
<tr>
<td></td>
<td>0.766</td>
<td>0.502</td>
<td>0.481</td>
</tr>
<tr>
<td>IV</td>
<td>6.006</td>
<td>3.264</td>
<td>3.498</td>
</tr>
<tr>
<td></td>
<td>0.889</td>
<td>0.479</td>
<td>0.508</td>
</tr>
<tr>
<td></td>
<td>0.625</td>
<td>0.206</td>
<td>0.196</td>
</tr>
<tr>
<td>VI</td>
<td>8.248</td>
<td>3.700</td>
<td>3.915</td>
</tr>
<tr>
<td></td>
<td>0.702</td>
<td>0.129</td>
<td>0.157</td>
</tr>
<tr>
<td>VII</td>
<td>8.917</td>
<td>3.873</td>
<td>4.110</td>
</tr>
<tr>
<td></td>
<td>0.091</td>
<td>0.078</td>
<td>0.036</td>
</tr>
<tr>
<td>Overall Mean</td>
<td>6.367</td>
<td>3.188</td>
<td>3.427</td>
</tr>
<tr>
<td>Overall S.D</td>
<td>1.291</td>
<td>0.599</td>
<td>0.612</td>
</tr>
</tbody>
</table>

Note: \( L \)= length, \( W \)=width, \( T \)=thickness, \( D_A \)= arithmetic mean diameter, \( V_i \) and \( V_f \) are initial and final volume of liquid, \( V_d \) = volume of liquid displaced equals true volume of Taro Cocoyam (\( V_T \)).

The plot of true volume of Taro Cocoyam (\( V_T \)) against its arithmetic mean diameter (\( D_A \)) is given in Figure 1.

Fig. 2. Plot of true volume of Taro Cocoyam against its arithmetic mean diameter.
As observed in Figure 2, increase in \( D_A \), led to increase in the true volume of taro cocoyam. The model that could reasonably describe the relationship is the polynomial of degree 3 and is stated in Equation 14 as:

\[
V_T = a(D_A)^3 + b(D_A)^2 + c(D_A) + d
\]

Where,
\[
\begin{aligned}
a &= -3.87, \\
b &= 55.453, \\
c &= -232.11, \\
d &= 319.76
\end{aligned}
\]

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

<table>
<thead>
<tr>
<th>Volume of Taro Cocoyam (cm³)</th>
<th>Measured Values</th>
<th>Predicted Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.50</td>
<td>18.96</td>
<td></td>
</tr>
<tr>
<td>20.33</td>
<td>19.60</td>
<td></td>
</tr>
<tr>
<td>26.67</td>
<td>25.99</td>
<td></td>
</tr>
<tr>
<td>38.06</td>
<td>38.02</td>
<td></td>
</tr>
<tr>
<td>48.92</td>
<td>52.51</td>
<td></td>
</tr>
<tr>
<td>75.50</td>
<td>70.76</td>
<td></td>
</tr>
<tr>
<td>78.00</td>
<td>80.15</td>
<td></td>
</tr>
</tbody>
</table>

Besides, a graph of mean predicted against mean measured value of Taro Cocoyam volume from Table 2 is presented in Figure 3 to examine its curve fitness.

Fig. 3: Plot of mean predicted and measured value of Taro Cocoyam volume

The graph, in Figure 3, evidently shows that the points for predicted and measured values have positive correlation and \( R^2 \approx 1 \). The line where the slope is equivalent to one is that which the predicted values would be equal the measured values. Moreover, the computed statistical parameters for goodness of fit from Figure 3 are shown in Tables 3.
Table 3: Statistical parameters for goodness of fit for the model Equation 14

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of correlation, r</td>
<td>0.9945</td>
</tr>
<tr>
<td>Coefficient of determination, $R^2$</td>
<td>0.9890</td>
</tr>
<tr>
<td>Reduced Chi-square, $\chi^2$</td>
<td>0.7050</td>
</tr>
<tr>
<td>Mean bias error, MBE</td>
<td>5.2000</td>
</tr>
<tr>
<td>Root mean square error, RMSE</td>
<td>2.2900</td>
</tr>
<tr>
<td>Coefficient of residual mass, CRM</td>
<td>0.0000</td>
</tr>
<tr>
<td>Modelling efficiency, EF</td>
<td>0.9900</td>
</tr>
</tbody>
</table>

From Table 3, the value of $R^2$ was almost equal to $r$, which indicated that $R^2 \approx 1$. The values of $\chi^2$, RMSE and MBE were too high. The value of CRM was zero and EF almost equal one. These are good characteristics of an acceptable quality fit. Therefore, the empirical model as described in Equation 14 could be employed in estimating the volume of Taro Cocoyam with respect its axial dimensions.

CONCLUSION

The model Equation 14 was established using experimental approach. It was validated and found to be rationally good for estimating Taro Cocoyam volume if its axial dimensions are measured. Besides, the model could also be used in efficient design of feed hopper, silo and bin capacity for storing dried Taro Cocoyam samples.

CONFLICT OF INTEREST

None is declared.

REFERENCES


PRAKTIČNI MODEL ZA PROCENU ZAPREMINE TARO KOKOYAM NA OSNOVU NJEGOVIH AKSIJALNIH DIMENZIJA

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Sažetak: Taro Cocoyam (Colocassia esculenta) plod je podložan napadima glodara, insekata i elemenata iz životne sredine . Nakon sušenja plod Taro Cocoyam, se čuva kako bi se izbegli gubici. U nastojanju da se efikasno razvije sistem skladištenja, osnovni fizički parametar kao što je zapremina svežeg ploda (zrna) Taro Cocoyam u odnosu na njegove aksijalne dimenzije treba da bude dobro izražena i modelovana zbog lake procene.
U ovoj studiji, sveži uzorci zrna Taro Cocoiam su nabavljeni, očišćeni i upakovani. Za određivanje početnog sadržaja vlage (%) korišćeno je deset (10) neoljuštenih uzoraka. Aksijalne dimenzije pedeset (50) neoljuštenih uzoraka su izmerene i korišćene za izračunavanje srednjeg aritmetičkog prečnika \((D_A)\). Odgovarajuća stvarna zapremina \((V_T)\) je određena korišćenjem postupka sušenja. Veliki uzorci su grupisani na osnovu pri \((D_A)\), u sedam (7) različitih veličina. Izračunate su srednja vrednost i standardna devijacija svakog parametra. Model je uspostavljen, verifikovan i validiran. Statistička analiza pokazuje da je vrednost koeficijenta determinacije \((R^2)\) skoro jednak koeficijentu korelacije \((r=1)\). Vrednosti redukovanog hi-kvadrata testa \((\chi^2)\), srednje kvadratne greške (RMSE) i srednje greške pristrasnosti (MBE) nisu bile tako visoke. Vrednosti koeficijenta preostale mase (CRM) i efikasnost modeliranja (EF) bile su skoro savršene.

Zato je uspostavljeni model praktično dobar za procenu zapremine ploda Taro Cocoiam i može da nade uspešnu primenu kod projektovanja oblika rezervoara za hranu i sistema za skladištenje.

**Ključne reči:** Model, procena, Taro Cocoiam, zapremina, sistem skladištenja.

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