FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE
JOURNAL OF ENGINEERING AND ENGINEERING TECHNOLOGY

DEVELOPMENT OF PREDICTIVE MASS AND VOLUME MODELS FOR AFRICAN BUSH MANGO (Irvingia gabonensis)

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Oyefeso, B. O., Yusuff, O. A. and Fadele, O. K. (2025): Development of Predictive Mass and Volume Models for African Bush Mango (Irvingia gabonensis). *FUTA Journal of Engineering and Engineering Technology /19(1), 108-113*

Received Date: 10.11.24 **Accepted Date: 30.4.25**

Abstract
Allometric properties of fruits such as physical properties are indispensable in design of equipment and processing systems. This study aimed to develop mathematical models in relation to some selected physical properties of bush mango. The axial dimensions, equivalent mean diameter (EMD), geometric mean diameter (GMD), arithmetic mean diameter (AMD), criterion area (CPA), projected areas (perpendicular to the length, width and thickness), mass, and volume of African bush mangoes were determined. The mean values obtained for length, width, thickness, EMD, GMD, AMD, CPA, projected areas (perpendicular to the length, width and thickness), mass, volume, surface area, sphericity, aspect ratio, shape index, eccentricity and elongation ratio were 63.39 mm, 53.93 mm, 49.46 mm, 55.59 mm, 55.27 mm, 55.32 mm, 2292.50 mm2, 2691.48 mm2, 2101.29 mm2, 2361.77 mm2, 92.67 g, 86.96 mm3, 9626.18 mm2, 0.87, 0.85, 1.23, 0.52 and 1.18, respectively. The mathematical relationship between the mass and volume was found to have a coefficient of determination of 0.988. Thus, the developed models can be employed in the automated machine for sorting and packaging of African bush mango fruit.

Keywords: *Bush mango, Models, Mass, Volume and dimension.*

Introduction

African bush mango (Irvingia gabonensis, Tailfert.) is a tropical tree indigenous to the regions of West and Central Africa. It is renowned for its valuable fruits and seeds, and it goes by several common names, reflecting its significance in various cultures. Some of these common names include wild mango, African mango, bush mango, bread tree, dika nut, odika, kaka, and etima. The fruit and seeds are widely consumed and processed into various products (Iyilade et al., 2019). The fresh fruits, which are similar to small mangoes, have a green-yellow color and since their taste varies between sweet and bitter, they are divided into two groups, the edible type and the cooking type (Alonge and Idung, 2015). The edible type comprises the species Irvingia gabonensis which is fibrous, has a mesocarp characterized by a sweet taste, and is yellow to orange in colour while the cooked type is the Irvingia wombolu species whose seeds are widely processed across West Africa but the mesocarp is bitter and non-edible (Ogundahusi et al., 2016). The fruit is a broad, ellipsoid drupe with a thin epicarp, an edible fleshy mesocarp (pulp) (when ripe) and a hard, stony, nut encasing a soft, oil-rich, dicotyledonous kernel wrapped inside a brown seed-coat (Ogunsina et al., 2012). This kernel, which is also referred to as seed, is widely used as food (Omoniyi et al., 2017). The seeds, sometimes referred to as dika nuts, can be processed to make edible oil, margarine, soap, thickening agents, cattle feed, and cosmetics. They can also be eaten raw or roasted. Gabonese cuisine makes use of nuts, and the wood is used for building and fuel. Processing of African bush mango is mostly done manually in many developing countries where it is consumed. However, there is a need for mechanization of these processing operations through the development of various machines for their handling and processing (Ogunsina et al., 2008). The design of processing machines for agricultural materials or products relies on a good understanding of its engineering properties, including physical properties such as mass, volume, density, and particle size distribution (Moradi et al., 2019; Shahbazi and Rahmati, 2013). Engineering properties such as physical properties (viz. sizes and shapes), play a major role in fruits separation processes which include cleaning, sorting, and grading (Khoshnam et al., 2007). Development of predictive models from these properties are essential in automation of fruit separation processes for bush mango fruit, having been established in the literatures (Oyefeso and Raji, 2024; Shahbazi and Rahmati, 2014). There is dearth of information on the development of accurate and efficient models for estimating mass and volume of African bush mango based on its geometrical attributes, which will help in developing automated systems for sorting and grading the fruits. This study aims to develop predictive models for the mass and volume of African bush mangoes.

Materials and Methods

Materials

Fresh African bush mango fruits used for this study were sourced from Ipokia, Ipokia Local Government, Ogun State, Nigeria. One hundred African bush mangoes were used in the study. Each mango was properly labelled to enable precise identification and recording of the research findings.

Determination of Mass and Volume of Bush Mango

The mass of the bush mango fruit was determined using an electronic weighing balance with an accuracy of 0.1g (METRA, model TL-5000). The volume of the fruit was determined using liquid displacement method (Lorestani et al., 2014; Aremu and Fadele, 2011). This was carried out by measuring the quantity of liquid displaced when the fruit was immersed in an eureka can as shown in Figure 1 (Jaliliantabar et al., 2013). The volume of water displaced was collected and measured using a measuring cylinder.

Determination of Geometrical Attributes of Bush Mango

The geometrical attributes (viz. length, breadth and thickness) of the fruit were measured using a digital vernier caliper (Carrera Precision model CP8812-T 12-inch digital caliper, with an accuracy of 0.01mm). The projected areas along the three mutually perpendicular axes were calculated using Equations 1 to 3 (Rafiee et al., 2007; Panda et al., 2020; Ahemen and Raji, 2017).

$$PA_L = \frac{\pi \times L \times W}{4} \quad (1)$$

$$PA_W = \frac{\pi \times W \times W}{4} \quad (2)$$

$$PA_T = \frac{\pi \times T \times W}{4} \quad (3)$$

where; PA_L - Projected area perpendicular to the length (mm^2); PA_W - Projected area perpendicular to the width (mm^2); PA_T - Projected area perpendicular to the thickness (mm^2); L - length or longest diameter of the Tuber (mm); W - width or the axial dimension perpendicular to the length (mm); T - thickness or diameter which is perpendicular to both length and width (mm).

The criterion area (CPA) was determined by evaluating the average of all projected areas. The GMD, AMD, and EMD were computed using Equations 4 – 6, respectively (Tulagha and Raji, 2011; Panda *et al*., 2020)

$$AMD = \frac{L+W+T}{3} \quad (4)$$

$$GMD = \sqrt[3]{L \times W \times T} \quad (5)$$

$$EMD = \left[L \times \frac{(W+T)^2}{4}\right]^{\frac{1}{3}} \quad (6)$$

where; AMD - Arithmetic Mean Diameter (mm); GMD - Geometric Mean Diameter (mm); EMD - Equivalent Mean Diameter (mm)

Model Development

Mathematical models were developed using statistical package such as Microsoft Excel (2013 version). Regression analysis was carried out to develop multiple and simple mathematical models to

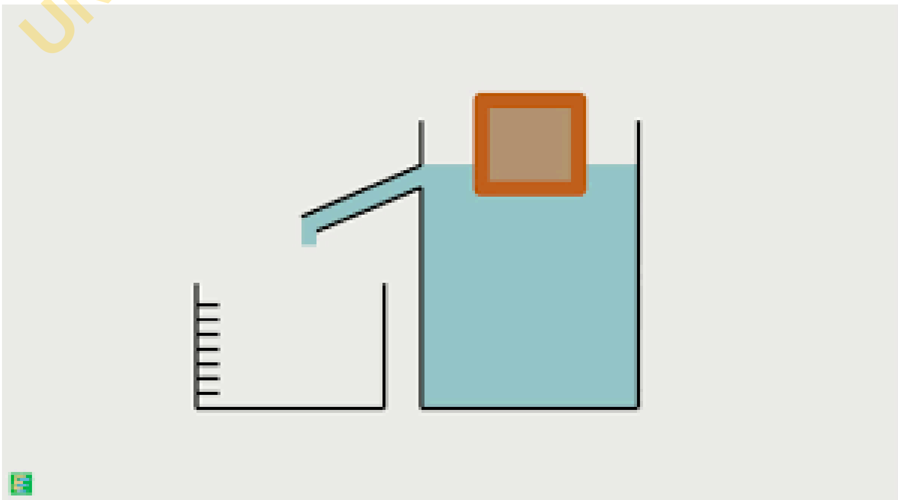

Table 1: Water displacement method (Jaliliantabar et al., 2013)

establish the relationship between mass and volume of African bush mangoes (Panda *et al*., 2020).

Model Validation

The models developed were validated by comparing the predicted values with the calculated values of mass and volume of African bush mangoes. The models were further evaluated through the coefficient of determination (R^2) which indicates the measure of goodness of fit (Lorestani *et al*., 2014; Azman *et al*., 2020). The value of R^2 values range from 0.00 to 1.00 for a regression analysis. The coefficient of determination value closer to 1.00 was selected in this study (Oyefeso and Raji, 2021).

Results and Discussion

Geometrical Attributes of Bush Mango Fruit

Some physical properties of bush mango fruits such as length, breadth and thickness as well as other geometrical properties such Arithmetic Mean Diameter (AMD), Geometric Mean Diameter (GMD), Equivalent Mean Diameter (EMD), projected areas in various axis, mass and volume were obtained as shown in Tables 1. The mean value for length, breadth and thickness were found to be 63.39, 53.93 and 49.46mm while the Arithmetic Mean Diameter (AMD), Geometric Mean Diameter (GMD), Equivalent Mean Diameter (EMD) were 55.59, 55.27 and 55.32 mm, respectively. The

Table 1: Physical properties of African bush mango fruits

Physical properties	Numbers of Samples	Mean	Range	Standard Deviation
L (mm)	100	63.39	54.79 – 72.33	3.58
W (mm)	100	53.93	43.74 – 59.93	3.28
T (mm)	100	49.46	41.84 – 58.06	3.30
AMD (mm)	100	55.59	47.53 – 61.52	3.01
GMD (mm)	100	55.27	47.13 – 61.11	3.02
EMD (mm)	100	55.32	47.13 – 61.13	3.02
$PA_L (mm^2)$	100	2691.48	1942.92 – 3292.65	288.82
$PA_W (mm^2)$	100	2292.50	1502.81 – 2821.21	272.61
$PA_T (mm^2)$	100	2101.29	1453.68 – 2645.09	245.63
CPA (mm^2)	100	2361.77	1633.14 – 2832.27	261.03
Mass (g)	100	92.67	58.10 – 119.30	14.00
Volume (cm^3)	100	86.96	51.98 – 114.98	13.95

Table 1: Mass-Geometrical Models for African Bush Mango

Model No.	Classification	Independent Variable	Model Equation	R²
1	Dimension	L (mm)	M = 3.089L – 103.1	0.623
2		W (mm)	$M = 0.01W^{2.275}$	0.788
3		T (mm)	$M = -0.233T^2 + 26.09T - 632.6$	0.672
4		L, W, T (mm)	M = –142.98 + 1.120L + 2.12W + 1.014T	0.849
5		AMD (mm)	$M = 0.002AMD^{2.661}$	0.842
6		GMD (mm)	$M = 0.002GMD^{2.640}$	0.842
7	Projected Area	PA_L (mm^2)	$M = 0.003PA_L^{1.306}$	0.818
8		PA_W (mm^2)	$M = 0.013 PA_W^{1.137}$	0.788
9		PA_T (mm^2)	$M = 0.011 PA_T^{1.178}$	0.798
10		PA_L, PA_W and PA_T	$M = 0.0261 PA_L - 0.00143 PA_W + 0.0251PA_W - 27.0198$	0.851
11		CPA (mm^2)	$M = 0.004CPA^{1.278}$	0.847

Table 3: Volume-Geometrical Models for African Bush Mango

Model No.	Classification	Independent Variable	Relation	R^2
1.	First	L (mm)	$V = 3.097L – 109.3$	0.631
2.		W (mm)	$V = 0.005W^{2.403}$	0.778
3.		T (mm)	$V = –0.23T^2 + 26.05T – 636.6$	0.666
4.		L, W, T (mm)	$V = –147.801 + 1.197L + 2.023W + 1.005T$	0.844
5.		AMD (mm)	$V = 0.001AMD^{2.892}$	0.842
6.		GMD (mm)	$V = 0.001GMD^{2.805}$	0.841
7.	Second	PA_L (mm^2)	$V = 0.003{PA_L}^{1.387}$	0.817
8.		PA_W (mm^2)	$V = 0.007\ {PA_W}^{1.201}$	0.778
9.		PA_T (mm^2)	$V = 0.006\ {PA_T}^{1.248}$	0.792
10.		$PA_L,\ PA_W,\ PA_T$	$V= -32.235 + 0.0279\ PA_L - 0.00332\ PA_W - 0.0243\ PA_T$	0.845
11.		CPA (mm^2)	$V = 0.002CPA^{1.354}$	0.847

projected areas perpendicular to the length, width and thickness were found to be 2691.48, 2292.50 and 2101.29 mm^2 while the Criterion Projected Area (CPA) was 2361.77 mm^2. The mean values obtained for the mass and volume of bush mango fruits were 92.67 g and 86.96 mm^3 respectively. The values obtained were less than the ones obtained by Rafiee *et al*. (2007) for bergamot fruits and Spreer and Müller (2011) for a mango fruit variety. However, Aremu and Fadele (2011) reported similar values of geometric properties for doum palm fruit; indicating that the shape and size of both doum palm fruit and bush mango fruit are similar.

Models for Mass-Geometric Properties

A total of 11 prediction models were developed using linear and non-linear regression to estimate the mass of African bush mango fruits. The mathematical relationship between the mass of the bush mango fruit and dimensions such as length, width, thickness as well as AMD and GMD were established as shown in Table 2. The linear model relating the mass with length, width and thickness has the highest coefficient of determination (R^2) of 0.849, while least was obtained for linear model relating mass to length with a R^2 value of 0.623. Moreover, the mathematical models obtained showed that the mass of bush mango fruit could be predicted through the application of the selected geometric properties (Feizellah and Satar, 2012).

Furthermore, the mathematical relationship between the mass of the bush mango fruit and projected areas in all the dimensional axis viz. length, width and thickness as well as Criterion Projected Areas (CPA) were established as shown in Table 2. The linear model relating the mass with projected areas in all the dimensional axis has the highest coefficient of determination (R^2) of 0.851 while least was obtained for linear model relating mass to projected area along the width axis. Moreover, the mathematical models obtained showed that the mass of bush mango fruit could be predicted through the projected areas in all the dimensional axis.

Models for Volume-Geometric Properties

A total of 11 prediction models were developed using linear and non-linear regression to estimate the volume of African bush mango fruits. The mathematical relationship between the volume of the bush mango fruit and dimensions such as length, width, thickness as well as AMD and GMD were established as shown in Table 2. The linear model relating the volume with length, width and thickness has the highest coefficient of determination (R^2) of 0.844 while least was obtained for linear model relating volume to length with a R^2 value of 0.631. Moreover, the mathematical models obtained showed that the volume of bush mango fruit could be predicted through the application of the selected geometric properties (Feizellah and Satar, 2013).

In addition, mathematical models were developed to predict the volume of bush mango fruit through the projected areas along the three-dimensional axes viz. length, width and thickness were established as well as Criterion Projected Areas (CPA) as shown in Table 3. The linear model relating the volume with projected areas in all the dimensional axis has the highest coefficient of determination (R^2) of 0.845

while least was obtained for linear model relating volume to projected area along the width axis. Moreover, the mathematical models obtained showed that the mass of bush mango fruit could be predicted through the projected areas in all the dimensional axis. Moreover, the mathematical relationship between mass and volume was also established as shown in Equation 7. This model gave R^2 of 0.988 which indicates that the variation in the independent variable such as volume accounts for 98.80% of the total variability in the mass of bush mango fruits.

$$M = 0.998V + 5.857 \qquad (R^2 = 0.988) \qquad (7)$$

Conclusion

Some physical properties of African bush mango were measured and presented in the study. Mathematical models were developed using some of these properties for the estimation of mass and volume of the fruit. The mathematical relationship between the mass and volume was found to have a coefficient of determination of 0.988. Mass and volume modeling based on one projected area can be identified as the best models from an economic standpoint because it involves the use of a single image-capturing device and the whole measurement could, therefore, be automated. The developed models could be useful in the automation of sorting and packaging of African bush mango fruit.

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