Physical characterisation and development of mass and volume models for tannia (*Xanthosoma sagittifolium*) cormels

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Abstract: Physical properties of agricultural products are important for proper mechanization of their processing and handling operations. Models established based on these physical properties can also take a role in the automation systems and ensure efficient processing. This study determined some physical characteristics of tannia cormel and developed mathematical models for estimating its mass and volume using its geometrical attributes. Linear dimensions were within the range of 20.87-168.30 mm while the projected areas were within the range of 4.63-207.72 cm^2. Average mass, volume and density were within the ranges of 7.40-256.80 g, 7.00-215.00 cm^3 and 947.37-1565.45 kg m^{-3}, respectively. Average sphericity, aspect ratio, shape index, eccentricity and elongation ratio were 0.73, 0.60, 1.84, 0.76 and 1.81, respectively. The results showed that tannia cormels are closer to being prolate spheroid in shape with relatively high sphericity. The mass and volume of tacca cormel can be reliably predicted using its projected areas and volume (for mass modelling only). The most suitable of all the models was obtained for mass model with respect to volume (R^2 = 0.976). Data provided in this study are useful in the development of postharvest handling and processing systems for tannia cormels.

Keywords: Tannia cormel; physical properties; mass/volume modelling; geometrical characteristics; shape indicators.

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1 Introduction

Tannia (*Xanthosoma sagittifolium* (L.) Schott) is a prominent edible aroid which serves as staple food and main source of daily carbohydrate intake for large populations in Africa. Some of its common names include new cocoyam, *tannie*, *yautia*, *chou Caraibe*, *malanga*, *macabo*, *mangarito*, *tanier* etc (Owusu-Darko et al., 2014). Tannia is grown primarily for its edible underground storage organs (corms and cormels) which are used for various purposes such as food products for human consumption and animal feed. Its cormels can be eaten after boiling, roasting or frying. It can also be processed into flakes, chips and flour. Its flour can be easily digested due to its small granules thereby, making it useful for invalids (Owusu-Darko et al., 2014). Prospects of tannia cormels as raw materials for industrial applications such as binding agent in pharmaceutical manufacturing, infant feed formulation, production of pasta, lager beer have been reported (Odeku et al., 2005; Aderolu, 2009; Oyefeso and Raji, 2020). Its leaves are also used as vegetables in different parts of the world (Falade and Okafor, 2014).

Tannia cormel undergoes various processing operations such as cleaning, peeling, cutting, drying etc., in its conversion from raw form to obtain chips, flakes and flour. Many of these unit operations are

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still being done manually with various resultant challenges. Mechanization of these unit operations through effective development of processing machines is therefore, necessary and highly recommended.

Data on the physical characteristics of tannia cormels is essential for proper design of these postharvest handling equipment and processing machines. Among the various physical characteristics of crops, geometrical attributes (axial dimensions and areas), mass and volume are among the important properties in machines for materials separation (Naderiboldaji et al., 2009). Establishing mathematical models among mass, volume, axial dimensions and areas along different orientations could also be beneficial in automation of design and processing operations (Tabatabaeefar, 2002). Although these mathematical models may be quite demanding to develop, they become quick means of predicting the unknown parameters in the relationships once established.

Predictive mathematical models have therefore, been established among some physical characteristics of several agricultural products with varying levels of success achieved. Mass models have been developed for fava beans (Lorestani and Ghari, 2012), varieties of potato tubers (Berberoglu et al., 2014), and fruits such as pomegranate, apricot, mango, lime, persimmon, Sohiong, Belleric myrobalan, coffee plum and pepper berries (Khoshnam et al., 2007; Meisami-asl et al., 2009; Naderiboldaji et al., 2009; Rashidi et al., 2018; Spreer and Müller, 2011; Miraei Ashtiani et al., 2012; Subbarao and Vivek, 2017; Vivek et al., 2017; Pathak et al., 2020; Barbhuiya et al., 2020; Azman et al., 2021). Models for estimating mass and volume have also been developed for citrus fruits (Khanali et al., 2007), some cultivars of potato tubers (Tabatabaeefar, 2002; Oyefeso and Raji, 2018), *Tacca* tubers (Raji and Oyefeso, 2021), and sweet cherry (Khadivi-Khub and Naderiboldaji 2013). Models for predicting surface area of fruits have been developed for bergamot (Jahromi et al., 2007) and apple (Ziaratban et al., 2017).

Agricultural products are often sorted based on axial dimensions and areas of projection although it may be cheaper to develop machines that are capable of sorting by gravimetric properties such as mass or volume of the products. This will necessitate developing models between mass/volume and the geometrical attributes (Jahromi et al., 2007). This study therefore, determined some physical characteristics (geometrical attributes, shape descriptors and gravimetric properties) of tannia cormels and developed predictive mathematical models for mass and volume of the cormels based on the geometrical attributes with a view to providing data that are useful in the development of postharvest handling and processing systems for tannia cormels.

2 Materials and methods

Wholesome Tannia cormels were purchased from Bodija market in Ibadan, South-Western part of Nigeria. The study was conducted on 150 randomly selected cormels which were washed, allowed to drain, and properly labelled for identification.

The physical properties measured include axial dimensions, projected areas, criterion area (A_c), surface area (A_s), mass, volume, density and some shape descriptors of tannia cormels.

2.1 Measurement of geometrical attributes

The axial dimensions were measured with the aid of a digital calliper (Carrera Precision CP8812-T, United States). The axial dimensions were obtained as length, width and thickness according to the method described by Tabatabaeefar (2002) and Ahemen and Raji (2017). Arithmetic mean diameter (*AMD*) was estimated using Equation 1 while geometric mean diameter (*GMD*) and equivalent mean diameter (*EMD*) (mm) were determined according to Equations 2 and 3 respectively (Raji and Ahemen, 2011; Vivek et al., 2017).

$$AMD = \frac{L + W + T}{3} \tag{1}$$

$$GMD = (LWT)^{\frac{1}{3}} \tag{2}$$

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

where:

L is the length (mm); W is the width (mm);

T is the thickness of the cormel (mm).

Image processing method was used to determine the projected areas (Khanali et al., 2007; Oyefeso, 2021). This involved image capturing, digitization and extraction of the area of projection of the cormel relative to the background. Criterion area of the cormel was calculated using Equation 4 while the surface area was calculated using Equation 5 (Pathak et al., 2020; Raji and Oyefeso, 2021).

$$A_c = \frac{PA_L + PA_C + PA_T}{3} \quad (4)$$

$$A_S = \pi \times (GMD)^2 \quad (5)$$

where:

A_C is the criterion projected area (cm^2);

A_S is the surface area of the cormel (cm^2);

PA_L, PA_W and PA_T are the projected areas along the longitudinal, cross-sectional and transverse orientations respectively (cm^2).

2.2 Measurement of gravimetric properties

Mass of tannia cormel was measured using an electronic weighing balance (AND EK-6100i, Japan) while the volume was measured using water displacement method as described by Tabatabaeefar (2002) and Oyefeso (2021). Volumes of assumed shapes namely prolate, oblate and ellipsoid were determined using Equations 6, 7 and 8 respectively (Vivek et al., 2017).

$$V_{pro} = \frac{4\pi}{3} \times \frac{L}{2} \times \left(\frac{w}{2}\right)^2 \quad (6)$$

$$V_{obl} = \frac{4\pi}{3} \times \left(\frac{L}{2}\right)^2 \times \frac{w}{2} \quad (7)$$

$$V_{ellip} = \frac{4\pi}{3} \times \left(\frac{GMD}{2}\right)^3 \quad (8)$$

where:

V_{pro} is the volume of assumed prolate spheroid (cm^3);

V_{obl} is the volume of assumed oblate spheroid (cm^3);

V_{ellip} is the volume of assumed ellipsoid shape (cm^3).

Cormel density (kg m^{-3}) was calculated as the ratio of mass (kg) to the actual volume of the cormel (Raji and Oyefeso, 2021; Oyefeso, 2021).

2.3 Measurement of shape descriptors

Shape indicators namely dimensionless sphericity (φ), shape index (I_s), aspect ratio (R_a), elongation ratio (E_r) and eccentricity (e) of tannia cormel were determined according to Equations 9, 10, 11, 12 and 13 respectively (Raji and Ahemen, 2011; Vivek et al., 2017; Pathak et al., 2020; Oyefeso, 2021).

$$\varphi = \frac{GMD}{L} \times 100 \quad (9)$$

$$I_s = \frac{2L}{(W+T)} \quad (10)$$

$$R_a = \frac{W}{L} \quad (11)$$

$$E_r = \frac{L}{W} \quad (12)$$

$$e = \left[1 - \left(\frac{w}{L} \right)^2 \right]^{\frac{1}{2}} \quad (13)$$

2.4 Data analysis

Microsoft Excel (2016 version) with Data Analysis tool was used for the descriptive statistics, analysis of variance (ANOVA), and determine the suitable mathematical models between the variables of concern. Mass/volume prediction models for tannia cormels were based on the following classifications:

(1) Axial dimensions;

(2) Areas (PA_L, PA_W, PA_T, A_C and A_S);

(3) Mass models based on volume.

3 Results and discussion

Summary of the measured physical characteristics of tannia cormels is presented in Table 1. These physical properties include the geometrical attributes, gravimetric characteristics and shape descriptors for tannia cormels.

3.1 Geometrical attributes of tannia cormels

Average values of length, width and thickness of tannia cormels were 66.89±24.11, 37.03±7.01 and 35.83±6.88 mm respectively. AMD, GMD and EMD of the cormels were within the ranges of 23.23-92.28, 23.13-81.30 and 23.14-81.30 mm respectively. Size sorting of tannia cormels can therefore, be done on the basis of thickness (*T*). The results showed that the values of calculated GMD and EMD were very close for all the cormels considered and this is similar to the report of Pathak et al. (2020). The axial dimensions (*L*, *W* and *T*) of tannia cormels were significantly different ($p \leq 0.05$) while the calculated diameters (AMD, GMD and EMD) showed no significant difference ($p \leq 0.05$). These geometrical attributes are similar to those previously reported for similar tuber crops (Tabatabaeefar, 2002; Balami et al., 2012; Olalusi, 2014; Ahemen and Raji, 2017; Oyefeso, 2021). This showed that tannia cormels are relatively larger than potato tubers.

Projected areas of the cormels namely PA_L, PA_W and PA_T, were within the ranges 5.62-72.68, 4.63-28.67 and 5.67-71.11 cm^2 respectively while the surface area and criterion area were within the ranges 5.31-56.65 and 16.81-207.72 cm^2 respectively. Values of PA_T were smaller than the other projected areas for all cases. PA_L, PA_W and PA_T of tannia cormels were significantly different at $p \leq 0.05$. Data on the projected areas are useful during heat treatments such as drying and cooling of the cormels.

Table 1 Selected physical characteristics of tannia cormels

Physical characteristics	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation
Length (mm)	66.89	24.11	26.12	168.30	36.04
Width (mm)	37.03	7.01	22.50	59.65	18.93
Thickness (mm)	35.83	6.88	20.87	58.13	19.22
AMD (mm)	46.58	11.06	23.23	92.28	23.74
GMD (mm)	44.15	9.35	23.13	81.30	21.18
EMD (mm)	44.17	9.35	23.14	81.30	21.18
PA_L (cm^2)	22.11	14.14	5.62	72.68	63.96
PA_W (cm^2)	12.06	5.73	4.63	28.67	47.49
PA_T (cm^2)	23.08	14.28	5.67	71.11	61.86
Criterion Area (cm^2)	19.08	11.13	5.31	56.65	58.33
Surface Area (cm^2)	64.00	28.18	16.81	207.72	44.03
Mass (g)	53.11	36.43	7.40	256.80	68.60
Actual volume (cm^3)	42.34	30.53	7.00	215.00	72.10
True density (kg m^{-3})	1,271.09	126.7	947.37	1,565.47	9.97
Prolate spheroid volume (cm^3)	53.06	37.37	7.04	277.10	70.43
Oblate spheroid volume (cm^3)	104.48	101.62	8.11	781.74	97.26
Ellipsoid volume (cm^3)	51.40	36.59	6.48	281.41	71.20
Sphericity	0.73	0.11	0.49	1.01	15.63
Aspect Ratio	0.60	0.18	0.25	1.04	29.27
Shape index	1.84	0.58	0.99	4.18	31.30
Eccentricity	0.76	0.17	0.12	0.97	22.92
Elongation	1.81	0.57	1.01	4.01	31.54

3.2 Gravimetric properties of tannia cormels

Average value and standard deviation of mass, actual volume and density of the cormels were 53.11±36.43 g, 42.34±30.53 cm^3, and 1271.09 ± 126.7 kg m^{-3} respectively. Mass and volume of tannia cormels are similar to those reported by Olalusi (2014) for cocoyam although less than those reported for taro (Balami et al., 2012; Olalusi, 2014), potato tubers (Tabatabaeefar, 2002) and tacca tubers (Ahemen and Raji, 2017). Out of 150 tannia cormels used in this study, 26% were within the range 0-30 g, 42% were within the range 30-60 g, 22% were within the range 60-90 g, while the remaining 10% were greater than 90 g. This showed that the masses of tannia cormels predominantly ranged from10 to 90 g. Density of tannia cormels obtained in this study are similar to those of Raji and Ahemen (2011) for tacca at different moisture contents although higher than those reported by Balami et al. (2012), Olalusi (2014) and Tabatabaeefar (2002) for similar tuber crops.

Average volumes of assumed prolate spheroid, oblate spheroid and ellipsoid were 53.06±37.37, 104.48±101.62 and 51.4±36.59 cm^3 respectively. The volumes of assumed shapes were significantly different ($p \leq 0.05$) from the actual volume of tannia cormels. However, regression analysis showed that tannia cormels are closer to being prolate spheroid (R^2 = 0.94) or ellipsoidal in shape (R^2 = 0.93) than oblate spheroid (R^2 = 0.79). This is in agreement with the report of Tabatabaeefar (2002) for Iranian-grown potato tubers.

3.3 Shape indicators of tannia cormels

Average sphericity, shape index, aspect ratio, elongation ratio and eccentricity of tannia cormels were 0.73, 1.84, 0.60, 1.81 and 0.76 respectively. These shape indicators describe the flow characteristics or ability of the cormel to roll on surfaces of machine components. Previous reports for similar crops by Tabatabaeefar (2002), Balami et al. (2012) and Oyefeso (2021) are in agreement with these findings. Knowledge of these shape properties is useful in the development of equipment for postharvest handling and processing the cormels.

3.4 Classification of mass and volume models for tannia cormels

Mass and volume modelling were done with respect to the linear dimensions of the cormels (*L*, *W*, *T*, *AMD*, *GMD* and *EMD*) for the first classification while the second classification was based the projected areas (PA_L, PA_W and PA_T, A_C and A_S). The third classification involved the mass modelling on the basis of volume. Mass models established based on these classifications are presented in Table 2 while the corresponding volume models are as presented in Table 3. The most suitable models of all the different regression models (linear, exponential, logarithmic, power and polynomials) in terms of highest coefficients of determination (R^2) are those reported in this study.

Table 2 Mass prediction models for tannia cormels

No.	Model Type	Model expression	R^2
1	Power	$M = 0.099L^{1.473}$	0.695
2	Power	$M = 0.002T^{2.803}$	0.755
3	Power	$M = 0.002T^{2.785}$	0.724
4	Linear	$M = –106.75 + 0.787L + 1.633T + 1.315W$	0.869
5	Power	$M = 0.003(AMD)^{2.526}$	0.918
6	Quadratic	$M = 0.072(GMD)^2 – 3.192(GMD) + 47.155$	0.955
7	Quadratic	$M = 0.072(EMD)^2 – 3.205(EMD) + 47.449$	0.955
8	Power	$M = 1.371(PA_L)^{1.262}$	0.920
9	Power	$M = 1.268(PA_W)^{1.576}$	0.828
10	Power	$M = 1.173(PA_T)^{1.293}$	0.931
11	Power	$M = –17.50 – 6.701(PA_L) + 1.861(PA_W) + 9.357(PA_T)$	0.777
12	Power	$M = 1.156(A_C)^{1.378}$	0.939
13	Quadratic	$M = –0.001(A_S)^2 + 0.958(A_S) + 17.518$	0.950
14	Linear	$M = 1.179V + 3.183$	0.976

Table 3 Volume prediction models for tannia cormels

No	Model type	Model expression	R^2
1	Power	$V = 0.087L^{1.445}$	0.652
2	Power	$V = 0.001T^{2.861}$	0.765
3	Power	$V = 0.001W^{2.856}$	0.743
4	Linear	$V = –91.03 + 0.617L + 1.159T + 1.3\ 66W$	0.836
5	Power	$V = 0.002(AMD)^{2.526}$	0.893
6	Quadratic	$V = 0.065(GMD)^2 + 3.186(GMD) + 50.273$	0.934
7	Quadratic	$V = 0.065(EMD)^2 + 3.197(EMD) + 50.529$	0.934
8	Power	$V = 0.995(PA_L)^{1.288}$	0.911
9	Power	$V = 0.921(PA_W)^{1.607}$	0.819
10	Power	$V = 0.835(PA_T)^{1.325}$	0.930
11	Linear	$V = –17.58 – 6.649(PA_L) + 1.144(PA_W) + 9.055(PA_T)$	0.782
12	Power	$V = 0.829(A_C)^{1.410}$	0.934
13	Power	$V = 5.779(A_S)^{0.653}$	0.933

3.4.1 First classification models (axial dimensions)

Among the first classification models numbered 1 to 7 in Tables 2 and 3, mass and volume models 6 (*GMD*) and 7 (*EMD*) had the highest R^2. Meanwhile, all the axial dimensions (L, W and T) are needed for the development of models 6 and 7, thereby making the sorting process more cumbersome.

Mass and volume models based on the thickness

(T) had the highest R^2 among the single variable models 1, 2 and 3 in Tables 2 and 3. This indicates that prediction of mass and volume of tannia cormel can be better achieved using its thickness than the other two primary axial dimensions (L and W). Similar findings have been reported by Barbhuiya et al. (2020).

3.4.2 Second classification models (projected areas)

Mass and volume models based on the surface area had relatively higher R^2 values among the models numbered 8 to 13 in Tables 2 and 3. However, sorting on the basis of surface area is more cumbersome since it is obtained from the axial dimensions (L, W and T). Mass and volume models with single independent variable on the basis of PA_L and PA_T gave more reliable results ($R^2 \geq 0.910$) among the models numbered 8 to 10 which were based on single projected area in Tables 2 and 3. These mass and volume models with single variable regressions are preferred because it is easier and faster to compute a single variable compared with multiple ones.

For all the classifications of the mass and volume models, the models that were obtained based on the projected areas gave very consistent and relatively high R^2 values and could therefore, be recommended as the most suitable models to be adopted for the prediction of the mass and volume of tannia cormels. When compared with single or multiple variable models based on linear dimensions, the models with the projected areas as the independent variables had higher R^2 in most cases. This is in agreement with the findings of Tabatabaeefar (2002), Lorestani and Ghari (2012) and Pathak et al. (2020).

3.4.3 Third classification models (volume)

This classification established predictive mass model based on the volume of tannia cormels. The mass model was numbered 14 in Table 2 and it had the highest R^2 (0.976). Figure 1 shows the variation in mass with respect to volume of the cormels. Therefore, the mass of tannia cormels can be accurately predicted using its volume. This is in agreement with the findings of Tabatabaeefar (2002) and Meisami-asl et al. (2009).

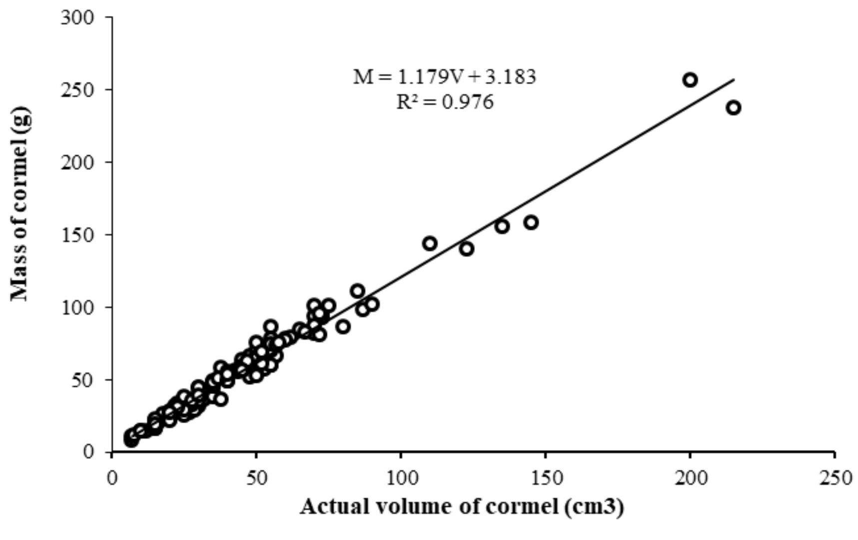

Figure 1 Mass model of tannia cormel based on volume

4 Conclusions

Selected physical characteristics of tannia cormels were determined in this study. Average length, width and thickness of tannia cormels were 66.89, 37.03 and 35.83 mm respectively. Projected areas ranged from 4.63 to 81.30 cm^2. Mass, volume and density of the cormels ranged from 7.40 to 256.8 g, 7.00 to 215.00 cm^3 and 947.37 to 1565.45 kg m^{-3} respectively. Average sphericity, shape index, aspect ratio, elongation ratio and eccentricity were 0.73, 1.84, 0.60, 1.81 and 0.76 respectively. Tannia cormels are closer to being prolate spheroid in shape than oblate spheroid and ellipsoid.

Relatively poor relationships existed between the mass/volume of the cormels and individual axial dimensions (length, width and thickness) with relatively low correlation. Mass and volume models for tannia cormels had consistently high correlation for projected areas along transverse and longitudinal orientations as single independent variables. Mass of tannia cormels can be reliably estimated using its volume. Mass and volume models based on a single variable of projected areas along transverse and longitudinal orientations were the most convenient modelling for tannia cormels since it requires a single image acquisition device and automation of the process can be easily achieved. Data provided in this study are useful in the development of postharvest handling and processing systems for tannia cormels.

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