SIZE AND SHAPE CHARACTERISATION OF *TACCA INVOLUCRATA* TUBERS

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ABSTRACT

Physical properties of crops are useful for proper design of processing machines and handling equipment. This study was designed to determine selected size and shape characteristics of tacca tubers using standard procedures. The physical characteristics determined include geometrical attributes, gravimetric properties and shape indicators. Length, width, thickness, Arithmetic Mean Diameter, Geometric Mean Diameter and Equivalent Mean Diameter of tacca tubers ranged from 34.81-114.24, 20.05-94.58, 22.48-87.81, 29.72-97.92, 28.82-97.36 and 29.51-97.38 mm, respectively. Projected areas along the three mutually-perpendicular axes ranged from 6.03-80.35, 5.89-61.48 and 8.40-82.79 cm^2 respectively. Surface area and criterion area ranged from 26.10-297.88 and 6.77-74.87 cm^2 respectively. Mass, volume and density ranged from 14.80-566.40 g, 13.00-460.00 cm^3 and 915.15-2,625.00 kg/m^3 respectively. Shape characteristics namely sphericity, aspect ratio, shape index, eccentricity and elongation ratio ranged from 60.32-99.03%, 0.52-0.99, 1.01-2.47, 0.11-0.85 and 1.01-1.91 respectively. Volume of the assumed ellipsoid shape was closer to the actual volume, indicating that tacca tubers are closer to being ellipsoidal in shape. The study has provided information that could serve as a guide in the design of systems for sorting, processing and handling tacca tubers.

Keywords: Tacca tubers, Physical properties, Geometrical attributes, Gravimetric properties, Shape indicators.

INTRODUCTION

Tacca plant (*Tacca involucrata* Schumach. and Thonn.), commonly referred to as Polynesian arrowroot, belongs to the family, *Taccaceae* (Omojola, 2013). It is a perennial herb which is native to the tropical regions of Africa, Southeast Asia, and Australia (Ahemen and Raji, 2017). Tacca is yet to be domesticated in Nigeria and it is still found in the wild where it grows perennially. The underground tubers resemble potato in appearance and are relatively hard (Ukpabi *et al*., 2009; Omojola, 2013).

Tacca is very useful, with almost all its plant parts being utilized for one purpose or the other. The fibre obtained from the plant stem and leaf stalk is used for making mats and hats (Aziz and Susanto, 2015). Extracts from tubers and leaves are used for treatment of several ailments such as internal bleeding, nausea, chest pain, baby rashes, food poisoning, etc (Nandwani *et al*., 2008; Jiang *et al*., 2014). The flour is made into pudding which serves as a meal or a sauce among the Tiv people in Benue State, Nigeria. Starch from tacca tubers is widely known for its low-fat content and it has found applications in the pharmaceutical industry (Ahemen and Raji, 2017). Increasing global demand for starch necessitates exploiting new, lesser-known and under-exploited starch sources including Tacca tubers by increasing their production and commercialisation (Raji and Ahemen, 2011; Omojola, 2013). There is also need for commensurate effort towards ensuring prompt processing of the tubers after production so as to minimize postharvest losses.

Tacca tubers undergo some level of processing in its conversion into some of its final products such as starch and flour. Some of these processing operations include peeling, grating, washing, milling, sieving, drying and packaging. Most of these operations are carried out manually with its attendant challenges. There is therefore, need for increased efforts towards mechanising these processing operations.

Data on the physical properties of tacca tuber are essential in the design of handling equipment and machines for mechanising these unit operations (Raji and Oyefeso, 2017). Ahemen and Raji (2017) reported that the physical properties of agricultural materials constitute essential engineering data which are useful in the design of processing and handling systems. This has resulted in several studies which have been aimed at determining selected physical properties of various agricultural products. Some of these agricultural products include cassava tuber (Adetan *et al*., 2003), garcinia kola (Igbozulike and Aremu, 2009), fava beans (Lorestani and Ghari, 2012), sweet cherry (Khadivi-Khub and Naderiboldaji, 2013), taro and tannia tubers (Olalusi, 2014), persimmon fruits (Subbarao and Vivek, 2017), sweet and Irish potato tubers (Oyefeso and Raji, 2018), Engler nuts (Ehiem *et al*., 2019), Belleric myrobalan fruit (Pathak *et al*., 2020), Indian

Coffee Plum (Barbhuiya *et al*., 2020) and pepper berries (Azman *et al*., 2021).

Selected engineering properties of tacca tuber have also been investigated by Raji and Ahemen (2011) and Ahemen and Raji (2017) although with less focus on the detailed characterisation of the size and shape of the tubers. This study was therefore, designed to determine the size and shape characteristics on tacca (T*acca involucrata*) tubers which are grown in Nigeria, with the aim of generating data which could serve as a guide in the design of processing and handling equipment for tacca tubers.

MATERIALS AND METHODS

Tacca tubers used in this study were purchased from a pit storage stock harvested from Tse-Ikyor and Tse-Adawa villages, Benue State, Nigeria. This study was conducted using 240 tacca tubers which were cleaned and labelled for proper identification and documentation of the results.

The physical characteristics measured include length (L), width (W) and thickness (T), Arithmetic Mean Diameter (AMD), Geometric Mean Diameter (GMD), Equivalent Mean Diameter (EMD), projected areas (PA_L, PA_W and PA_T) along the three mutually-perpendicular axes, criterion projected area (A_c), surface area (A_s), mass, volume (actual and assumed shapes namely prolate spheroid, oblate spheroid and ellipsoid), density, sphericity, shape index, aspect ratio, elongation ratio, eccentricity of tacca tubers.

Measurement of Geometrical Attributes

The linear dimensions along the three mutually-perpendicular axes (L, W and T) were measured with the aid of a digital calliper (Carrera Precision model CP8812-T 12-Inch Titanium Digital LCD Calliper Micrometer, United States) having an accuracy of 0.01 mm. The three mutually-perpendicular axes were determined by allowing each tuber crop to drop freely under gravity and then rest on its natural axis. At this natural resting position, the linear dimensions along the three mutually-perpendicular axes were easily obtained as length (the longest dimension), width (the linear dimension perpendicular to the length) and thickness (the linear dimension which is perpendicular to both length and width). AMD, GMD and EMD were determined according to Equations 1, 2 and 3 respectively (Igbozulike and Aremu, 2009; Raji and Ahemen, 2011; Vivek *et al*., 2017).

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

$$GMD = \sqrt[3]{L \times W \times T} \tag{2}$$

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

where: AMD is the Arithmetic Mean Diameter (mm); GMD is the Geometric Mean Diameter (mm); EMD is the Equivalent Mean Diameter (mm); L is the length or longest diameter of the tuber (mm); W is the width or linear dimension perpendicular to the length (mm); T is the thickness or diameter which is perpendicular to both length and width (mm).

The projected areas along the three mutually-perpendicular axes: PA_L (along the longitudinal plane), PA_W (along the cross-sectional plane) and PA_T (along the transverse plane), were obtained by image processing (Khanali *et al*., 2007). This involved the acquisition of the images of the tubers using a digital camera and saving them in portable pixel format (ppm format) to obtain the digitized forms of the images. The projected areas were then obtained by reading the digitized images as input into an algorithm developed in Fortran 95 programming language. Criterion projected area and surface area of the tubers were calculated using Equations 4 and 5 respectively (Tabatabaeefar, 2002; Pathak *et al*., 2020).

$$A_C = \frac{PA_L+PA_W+PA_T}{3} \tag{4}$$

$$A_S = \pi \times (GMD)^2 \tag{5}$$

where: A_C is the criterion projected area (cm^2); A_S is the surface area of the tuber (cm^2); PA_L is the projected area along the longitudinal plane; PA_W is the projected area along the cross-sectional plane (cm^2) and PA_T is the projected area along the transverse plane (cm^2).

Measurement of Gravimetric Properties

The individual mass of each of the tacca tubers was measured using an electronic weighing balance (A&D Co. LTD, AND EK-6100i model, Japan) with an accuracy of 0.1 g. Since most agricultural products are irregular in shape and tuber crops do not readily absorb water within a short period, the actual volumes of the tacca tubers were obtained using the water displacement method (Mohsenin, 1986; Khanali *et al.*, 2007). This involved submerging each of the tacca tubers into a known volume of water and the volume of water displaced was measured. Volumes of assumed shapes namely prolate spheroid, oblate spheroid and ellipsoid were obtained using Equations 6, 7 and 8 respectively (Vivek *et al*., 2017; Pathak *et al*., 2020).

$$V_p = 4.19 \times \frac{L}{2} \times \left(\frac{W}{2}\right)^2 \tag{6}$$

$$V_o = 4.19 \times \left(\frac{L}{2}\right)^2 \times \frac{W}{2} \tag{7}$$

$$V_e = 4.19 \times \left(\frac{GMD}{2}\right)^3 \quad (8)$$

where: Vp, Vo, Ve are the volumes of assumed prolate spheroid, oblate spheroid and ellipsoid shapes (cm^3) respectively.

Density of the tubers was determined according to Equation 9 (Ahemen and Raji, 2017).

$$\rho = \frac{M}{V} \quad (9)$$

where: ρ is the density of tacca tuber (kg/m^3); M is the mass of tacca tuber (kg); V is actual volume of tacca tuber (m^3).

Measurement of Shape Characteristics

Shape indicators of tacca tubers namely dimensionless sphericity (φ), shape index (I_s), aspect ratio (R_a), elongation ratio (E_r) and eccentricity (e) were determined according to Equations 10, 11, 12, 13 and 14 respectively (Tabatabaeefar, 2002; Raji and Ahemen, 2011; Ahemen and Raji, 2017; Vivek *et al.*, 2017; Pathak *et al.*, 2020).

$$\varphi = \frac{GMD}{L} \times 100 \quad (10)$$

$$I_s = \frac{2L}{(W+T)} \quad (11)$$

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

$$E_r = \frac{L}{W} \quad (13)$$

$$e = \left[1 - \left(\frac{W}{L}\right)^2\right]^{\left(\frac{1}{2}\right)} \quad (14)$$

Microsoft Excel with Data Analysis Adds-In (2016 version) was used to carry out the analysis of variance (ANOVA) and descriptive statistics for the data obtained in this study.

RESULTS AND DISCUSSION

Results of Size and Shape Characteristics of Tacca Tubers

Summary of the determined size and shape characteristics of tacca tubers is presented in Table 1, showing the mean, standard deviation, minimum, maximum and coefficient of variation for each of the properties.

Table 1. Some physical properties of tacca tubers

Physical parameter	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation
Length (mm)	71.88	14.06	34.81	114.24	19.56
Width (mm)	57.22	10.90	20.05	94.58	19.06
Thickness (mm)	46.71	8.79	22.48	87.81	18.82
AMD	58.60	10.54	29.72	97.92	17.99
GMD	57.57	10.31	28.82	97.36	17.91
EMD	57.84	10.37	29.51	97.38	17.93
Mass (g)	129.30	72.38	14.80	566.40	55.98
Actual volume (cm^3)	111.55	62.45	13.00	460.00	55.98
Prolate spheroid volume (cm^3)	135.82	77.05	7.33	525.16	56.73
Oblate spheroid volume (cm^3)	170.90	96.97	12.72	622.38	56.74
Ellipsoid volume (cm^3)	109.64	60.68	12.53	483.29	55.35
Density (kg/m^3)	1,171.79	149.23	915.15	2,625.00	12.74
PA_L (cm^2)	27.17	14.09	6.03	80.35	51.86
PA_W (cm^2)	21.98	10.70	5.89	61.48	48.68
PA_T (cm^2)	32.93	16.47	8.40	82.79	50.01
Criterion Area (cm^2)	27.36	13.67	6.77	74.87	49.96
Surface Area (cm^2)	107.48	38.54	26.10	297.88	35.86
Sphericity (%)	81.92	4.62	60.32	99.03	5.64
Aspect Ratio	0.80	0.08	0.52	0.99	9.62
Shape index	1.39	0.14	1.01	2.47	10.28
Eccentricity	0.58	0.11	0.11	0.85	19.65
Elongation ratio	1.26	0.13	1.01	1.91	10.30

Geometrical Attributes of Tacca Tubers

The mean values and standard deviation of length, width, thickness, AMD, GMD and EMD of tacca tubers were 71.88±14.06, 57.22±10.90, 46.71±8.79, 58.60±10.54, 57.57±10.31 and 57.84±10.37 mm respectively. This indicates that sorting and grading of tacca tubers can be done on the basis of thickness, being the shortest linear dimension. The primary linear dimensions (L, W and T) of tacca tubers were significantly different ($p \leq 0.05$) while the calculated diameters (AMD, GMD and EMD) were not significantly different ($p \leq 0.05$). These findings can help to ensure proper design of machines for separating and processing tacca tubers. These results are similar to those reported by Ahemen and Raji (2017) for tacca tubers at different moisture content levels although higher than the linear dimensions reported for potato tubers (Tabatabaeefar, 2002). This indicates that tacca tubers are larger than potato tubers.

PA_L, PA_W, PA_T, surface area and criterion area ranged from 6.03-80.35, 5.89-61.48, 8.40-82.79, 26.10-297.88 and 6.77-74.87 cm^2 respectively. The projected areas along the three mutually-perpendicular axes (PA_L, PA_W and PA_T) were significantly different at $p \leq 0.05$. The knowledge of these projected areas is essential in the analysis of rate of heat transfer during heat treatment of the tubers.

Gravimetric Properties of Tacca Tubers

Mass, actual volume and density of the tubers ranged from 14.80-566.40 g, 13.00-460.00 cm^3 and 915.15-2,625.00 kg/m^3 respectively. These values are similar to those reported by Raji and Ahemen (2011) and Ahemen and Raji (2017) for tacca tubers of different moisture contents but higher than those reported by Tabatabaeefar (2002) for potato tubers. The volumes of assumed prolate spheroid, oblate spheroid and ellipsoid shapes were within the ranges 7.33-525.16, 12.72-622.38 and 12.53-483.29 cm^3 respectively. The regression analysis showed that the volume of assumed elllipsoid shape was closer to the actual volume of the tubers with R^2 of 0.96, compared with 0.92 and 0.93 for prolate and oblate spheroid shapes respectively. This was made obvious by the closeness of the volume of the assumed ellipsoidal shape to the actual volume of tacca tubers obtained by water displacement, thereby, indicating that tacca tubers are closer to being ellipsoidal in shape. A similar finding has been reported for Iranian-grown potato tubers (Tabatabaeefar, 2002).

Shape Characteristics of Tacca Tubers

Aspect ratio, shape index, eccentricity and elongation ratio of tacca tubers ranged from 0.52-0.99, 1.01-2.47, 0.11-0.85 and 1.01-1.91 respectively. These shape descriptors indicate the degree of irregularity of tacca tubers and they can be applied in separation, handling and packaging systems. Sphericity of the tubers ranged between 60.32 and 99.03%, clearly indicating that tacca tubers are highly spherical in shape.

Data on the geometrical attributes namely linear dimensions (L, W, T, AMD, GMD and EMD) and tuber areas (PA_L, PA_W and PA_T, surface area and criterion), gravimetric properties (mass, volume and density) and shape indicators (sphericity, aspect ratio, shape index, eccentricity and elongation ratio) of tacca tubers obtained in this study are of significance in the design of machines and equipment for separating, processing and handling tacca tubers.

CONCLUSIONS

Selected size and shape characteristics of tacca tubers were determined in this study. The linear dimensions of tacca tubers ranged between 20.05 and 114.24 mm. Sorting of tacca tubers can be done on the basis of thickness, being the shortest linear dimension. Average projected areas of the tubers along the longitudinal, cross-sectional and transverse directions were 27.17±14.09, 21.98±10.70, and 32.93±16.47 cm^2 respectively and they were significantly different at $p \leq 0.05$. Average mass, volume and density of the tubers were 129.30±72.38 g, 111.55±62.45 cm^3 and 1.17±0.15 kg/m^3 respectively. The shape characteristics showed that tacca tubers are highly spherical and much closer to being ellipsoidal in shape. Data from this study are of significance in the design of systems for sorting, grading, processing, handling and packaging of tacca tubers.

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