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Physical and mechanical properties of *Curcuma caesia* (Black turmeric)

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Abstract
The physical properties of black turmeric are required for the development of post-harvest equipment and well as to standardize thermal processing of turmeric i.e., boiling, drying, etc. Thus, physical properties or geometric properties namely, the axial dimensions, shape, surface area, sphericity, bulk density, true density and porosity; frictional properties namely, coefficient of friction and angle of repose were determined along with textural properties like cutting strength. The average length, width and thickness of rhizomes were 52.68 mm, 38.85 mm and 31.98mm, respectively. The average value of surface area, sphericity of the rhizomes, bulk density, true density and porosity were 5143.99mm^2, 0.48, 693.67 kg/m^3, 996.68 kg/m^3 and 30.40%, respectively. The angle of repose obtained was 44.05° while the co-efficient of frictions for the black turmeric on steel, plywood, mild steel and glass surfaces were found as 0.5241, 0.6145, 0.6336 and 0.7015, respectively. The average cutting strength of the rhizome was 12.78 kgF.

Keywords: Author guide, article, camera-ready format, paper specifications, paper submission

1. Introduction

Botanically known *Curcuma caesia* or *Curcuma caesia* Roxb is the black turmeric or black zedoary, which belongs to Zingiberaceae family. It is a rare medicinal tropical herb and has an anti-inflammatory and antioxidant properties. Ayurveda mentioned the application of it in treatment of asthma, arthritis, epilepsy, etc. The black turmeric rhizomes are popular for smooth muscle relaxant, antifungal activity and antioxidant activity, anti-asthmatic activity, locomotor depressant, analgesic activity, anxiolytic and CNS depressant activity, anticonvulsant and muscle relaxant effects, anti-ulcer activity, anti-bacterial activity and many other miscellaneous activities (Venugopal *et al.*, 2017) [1].

Its rhizome contains higher concentration of curcumin as compared to other types of Curcuma species. It contains: amino acids, terpenes, alkaloids, tannins, carbohydrates, flavones, steroids and flavonoids, reducing sugars, anthraquinones, proteins, cardiac glycosides and glycosides (Donipati & Sreeramulu, 2015) [2]. The rhizome of the plant is aromatic, contains essential oil and it is used for a variety of purposes (Venugopal *et al.*, 2017) [1]. The black turmeric rhizomes powder is used as a face pack in Northeast Indian states.

Traditionally, the yellow turmeric is harvested, cleaned, sorted, boiled and dried to produce turmeric powder. The study showed that the boiling and drying are the essential steps of turmeric processing affecting quality of turmeric (Blasco *et al.*, 2006) [3]. The thermal treatment in water or steam upto 40 °C had significant effect on the physical and mechanical properties (Poornima *et al.*, 2019) [4]. Those properties are not only important in accurate design calculations but also to predict process of the boiling and drying (Athmaselvi and Varadharaju, 2002) [5]. The studies are available on engineering properties of yellow turmeric (Balasubramanian *et al.*, 2012; Barnwal *et al.*, 2014) [6, 7]. However, no published literature was available on physical properties of black turmeric. Thus the study was undertaken to determine the physical properties of black turmeric rhizomes.

2. Materials and Methods

The black turmeric rhizomes for the experiment were procured from farmers' field in Meghalaya. The procured rhizomes were cleaned before the experiment was conducted. The mother rhizomes and fingers were separated as primary and secondary developments. The primary and secondary fingers of turmeric rhizomes were taken into consideration while the tertiary developments in 5% of the rhizomes were ignored (Mohsenin, 1970) [8].

The physical and frictional properties of the black turmeric rhizomes were measured and calculated by using the standard methods and the methods used by previous researchers.
The initial moisture content of samples was determined by using the standard vacuum oven method at 70±1ºC for 24h as described in AOAC Method 926.12 (AOAC, 1995) [9]. The average value of moisture content was expressed as per cent on wet basis. It was obtained using ten replications.

2.1 Principle dimensions
The randomly selected rhyzomes were used for measuring physical dimensions such as length (l), width (b), and thickness (t). A vernier caliper having least count of 0.01 mm was used for the measurement. Understanding of the physical properties of black turmeric will help in designing drying equipment, cleaning, grading and processing machines, and to determine the product behavior during processing (Poornima *et al*., 2019) [4].
Principle dimensions were used to calculate aspect ratio, geometric mean diameter (D_a), arithmetic mean diameter (D_g) and following equations were used for the determination as per Said and Pradhan (2013) [10] and Poornima *et al*. (2019) [4].

$$D_a = \frac{(l+b+t)}{3} \qquad \dots (1)$$

$$D_g = (lbt)^{1/3} \qquad \dots (2)$$

The shape of the rhizomes can be expressed in terms of sphericity (Ø) and was determined using following equation (Pradhan *et al*., 2013) [11].

$$\emptyset = \frac{(lab)^{1/3}}{l} \qquad \dots (3)$$

The surface area (S, mm^2) of fruit sample was calculated from the following expression (Pradhan *et al*., 2013) [11].

$$S = \pi D_g^2 \qquad \dots (4)$$

The aspect ratio, R_a was calculated as:

$$R_a = \frac{b}{l} \times 100 \qquad \dots (5)$$

Bulk density and true density were determined as per method given by Mohsenin (1970) [8]. The porosity (%) is the parameter indicating the amount of pores in the bulk materials. It was calculated from the bulk and true density using the relationship given as follows (Mohsenin, 1970) [8].

$$\text{Porosity (\%)} = \frac{(\text{True density - Bulk density})}{\text{True density}} \times 100 \qquad \dots (6)$$

2.2 Frictional properties
Angle of repose is the indicator of product's ability to flow. The angle of repose for black turmeric was determined using formula given below (Ajav & Ogunlade, 2014) [12].

$$\text{Angle of repose } (\theta) = \tan^{-1}\left(\frac{2H}{D}\right) \qquad \dots (7)$$

Where, H is the height of the cone form by the turmeric rhizomes and D is the diameter of the horizontal plate.
The coefficient of friction for black turmeric rhizomes were determined on four different surfaces namely stainless steel, plywood, mild steel and glass (Said and Pradhan, 2013) [10]. After measuring the tilt angle from the graduated scale, the coefficient of friction was calculated by using equation given below.

$$\text{Coefficient of friction } (\mu) = \tan\alpha \qquad \dots (8)$$

Where, α is the tilt angle between the inclined plate and the horizontal plane.
The cutting test was used to evaluate the force and energy required to cut the piece of turmeric rhizome in two halves. A special type of shear rig with a stainless steel cutter (HDP / BSW; Blade) at bottom was installed in the load cell. Cutting force was exerted by the cutter at speed of 2 mm/sec cut the piece in two halves. The pre-speed of the test was set at 3 mm/sec and post was 10 mm/sec. To prevent the cutter from touching the steel plate, the downward movement was stopped when the cutter was 20mm from the plate (Bianchi *et al*., 2016) [13].

3. Results and Discussion
The physical properties of black turmeric rhizomes were determined using standard methods described in the materials and methods section. The data obtained for properties like Length (l), Width (b), Thickness (t), Arithmetic mean diameter (Da), Geometric mean diameter (Dg), Aspect ratio, surface area, sphericity, unit mass, bulk density, true density, Porosity, Co-efficient of friction on steel, plywood, mild steel and glass, angle of repose, and cutting force were determined and reported in Table 1. These properties were measured at an average moisture content of 58.77 (%) which was varied from 54.32 to 63.67%.

3.1 Geometric Properties
The average value of length (l), width (b) and thickness (t) obtained were 52.68 (±0.86), 38.85 (±0.75) and 31.98 (±0.55) mm, respectively. The frequency distribution curves (Figure 1) for the dimensions at moisture content of 58.77% (w.b.) showed a trend towards a normal distribution. Furthermore, length of the rhizome was varied between 35.39 to 79.78 mm with standard deviation of 8.63 which showed quit high variation. Similar trend was observed for width and thickness where range of width was 20.06 to 63.53 mm and that of thickness was 17.44 to 43.84 mm. The data obtained during experimentation was significantly different from the results obtained by Poornima *et al*. (2019) [4] for fresh yellow turmeric where length, width and thickness i.e., 81.64, 20.67 and 19.30 mm. Thus, it was again proved that the rhizome dimensions may vary with varieties, climate, cultivation practice, etc.
The average value of arithmetic mean diameter (D_a) and geometric mean diameter (D_g) were 41.17 and 40.06 mm, respectively. The results were at par with the Yewle *et al*. (2019) [14]. Shelake *et al*. (2018) [15] and Dhineshkumar & Anandakumar (2016) [16] observed a linear trend for length, width and thickness of rhizomes with increase in moisture content. The relationship between dimensions i.e., length, width and thickness was determined. The results showed that the l/t ratio exhibited the highest while l/Dg and L/b ratio presented closed values. The following general expression can be used to describe the relationship among the average dimensions of black turmeric rhizomes:

$$l = 1.39b = 1.69t = 1.32D_g = 70.29\emptyset = 2039.45M \text{ and } t = 0.80D_g$$

Where, M= unit weight

Table 1: Geometric, frictional and mechanical properties of black turmeric rhizomes

Property	N	Mean (±SE)	Minimum	Maximum	Standard Deviation
Length (L) of rhizome	100	52.68 (±0.86)	35.39	79.78	8.63
Width (W) of rhizome	100	38.85 (±0.75)	20.06	63.53	7.53
Thickness (T) of rhizome	100	31.98 (±0.55)	17.44	43.84	5.49
Da	100	41.17 (±0.57)	28.24	55.77	5.75
Dg	100	40.06 (±0.57)	27.82	53.38	5.66
Aspect ratio	100	0.74 (±0.01)	0.34	1.00	0.13
Surface area	100	5143.99 (±142.44)	2432.61	8956.54	1424.36
Sphericity	100	0.48 (±0.01)	0.48	0.97	0.09
Unit mass	100	0.14 (±0.00)	0.012	0.070	0.009
BD	10	693.67 (±5.65)	683.42	702.90	9.78
TD	10	996.68 (±1.66)	995.02	1000.00	2.87
Porosity	10	30.40 (±0.67)	29.36	31.66	1.16
Coefficient of friction					
Steel	10	0.5241 (±0.03)	0.4557	0.5658	0.0495
Plywood	10	0.6145 (±0.04)	0.5543	0.7002	0.0762
MS	10	0.6336 (±0.03)	0.6009	0.6873	0.0468
Glass	10	0.7015 (±0.04)	0.6371	0.7673	0.0651
Angle of repose		44.05 (±1.24)	40.18	46.85	2.77
Cutting force		12.78 (±1.17)	11.06	15.01	2.03

Table 2: Relationship of geometric properties

Property	N	Average	Standard Error	Minimum	Maximum	Degree of freedom	Standard Deviation
L/W	100	1.39	0.03	1.00	2.91	99	0.08
L/T	100	1.69	0.04	1.10	3.66	99	0.18
L/M	100	2039.45	84.87	583.00	5625.00	99	720370.12
L/Dg	100	1.32	0.02	1.03	2.06	99	0.03
L/Ø	100	70.29	1.832	42.07	132.76	99	335.75
T/Dg	100	0.80	0.01	0.48	0.95	99	0.01

The study showed that there was positive correlation amongst the width, thickness, geometric mean diameter, unit mass with length and the shape of the biological commodities are determined in terms of its sphericity and aspect ratio. It was seen from the Table 1 that the sphericity and aspect ratio of the black turmeric rhizomes was found to be 0.48 and 74.00, respectively. Considering the high aspect ratio (which relates the width to length) and modest sphericity, it may be deduced that rhizomes would roll slowly on flat surfaces. This tendency to either roll or slide is very important in the design of hoppers and peeling equipment for the rhizomes. Furthermore, the shape indices indicated that the rhizome may be treated as a cylindrical for an analytical prediction of its drying behavior. The surface area of each rhizome was found to be 5143.987mm^2.

The bulk density and true density of the black turmeric rhizomes were ranging from 683.42 to 702.90 kg/m^3 and 995.02 to 1000.00 kg/m^3, respectively. The average values of both densities were 693.67 (±5.65) and 996.68 (±1.66) kg/m^3. The bulk and true densities showed significant variation as they were directly proportional to dimensions. Design of storage vessels, hopper capacities, design of transport systems, etc. are based on database related to densities. The porosity of the batch of rhizome was determined using standard formula and was found to be in the range of 29.36 to 31.66% with average of 30.40 (±0.67) %. Similar results were observed for bulk density, true density and porosity of yellow turmeric (Poornima *et al*., 2019) [4] and ginger (Ajav and Ogunlade, 2014) [12].

3.2 Frictional Properties

The co-efficient of friction of the black turmeric rhizomes was calculated on stainless steel, plywood, mild steel and glass surfaces. It was observed that the glass surface produced highest coefficient of friction (0.7015±0.04) while the stainless steel produced lowest coefficient of friction (0.5241 ±0.03). The least coefficient of friction may be owing to the smoother and more polished surface of the stainless sheet than the other materials used. However, the rhizomes did not roll or slide easily on the surface of the glass, but was adhere to the surface more often than any other surface due to its adhesive properties. The data on the coefficient of friction will be important for selection of material for storage bins, hoppers, pneumatic conveying system, screw conveyors, forage harvesters, threshers, etc. The average angle of repose of the black turmeric rhizomes was 44.046^o compared to 48^o for ginger rhizomes (Ajav & Ogunlade, 2014) [13]. The results showed that the rhizome can easily slide or roll on the surface.

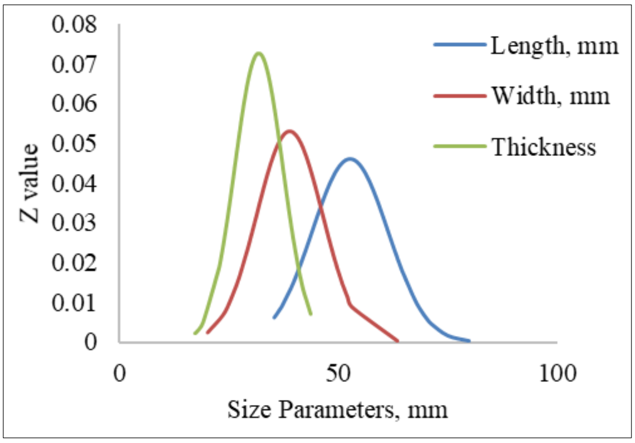

Fig 1: The normal distribution graph of size parameters

3.2 Textural Properties
The textural property like cutting strength were measured using texture analyzer. The cutting strength has significant role in selection of cutting edge. The average maximum positive cutting strength of the turmeric was 12.78kgF from the range of 11.057 to 15.01kgF.

4. Conclusion
Geometric, frictional and textural properties of turmeric rhizomes such as length, width, and thickness, arithmetic and geometric mean diameter, densities, porosity, coefficient of friction, angle of repose and cutting strength were measured. The results showed that the black turmeric and yellow turmeric were having similar physical and mechanical properties. The frequency distribution curve for axial dimensions was showing normal distribution of the data obtained. The knowledge of the properties would provide useful database for its post-harvest processing including boiling and other heat treatments.

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