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Studies on engineering properties of fresh turmeric (*Curcuma longa* L.) rhizomes

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Abstract
Turmeric (*Curcuma longa* L.) is one of the most important spice crop grown in India which is generally used for cooking as well as medicinal purposes. It is generally used as a condiment in vegetables, meat and fish preparations due to its colour and mild flavor. Turmeric has long been used as a medicine in Ayurveda and Unani systems for medicine in India. The experiment was conducted on physical properties of fresh turmeric rhizomes of "Salem" variety at Dapoli. The average moisture content of fresh turmeric rhizomes was 81.26% (wet basis). The length, width and thickness of the fresh turmeric rhizomes were determined and found to be 67.66 mm, 22.24 mm and 16.78 mm, respectively. The geometric mean and sphericity were 29.11 mm and 0.44. The average mass, volume and surface area of the fresh turmeric rhizomes was found 18.97 g, 14.26 cm^3 and 15.57 cm^2, respectively. The average bulk density, true density and porosity were calculated as 422.87 kg/m^3, 1142.01 kg/m^3 and 62.90%, respectively. The average of angle of repose was 26.68°. The engineering properties of fresh turmeric rhizomes are useful for design of turmeric processing equipments, handling and storage. Also it can be helpful for design of Pulverizer for preparation of turmeric powder.

Keywords: Turmeric, engineering properties, rhizomes *Curcuma longa*

1. Introduction
Turmeric (*Curcuma longa* L.) is one of the most important spice crop grown in India and is generally used for cooking purposes. In addition to its taste and aroma, the turmeric has long been used for medicinal purposes. (Bhat and Hegde, 2018) [3]. Turmeric is an ancient spice crop derived from the rhizomes of *Curcuma longa* which is a member of ginger family (Zingiberaceae). It is also known as 'Golden Spice of India' and it is native to Asia and India. The global production of turmeric is around 11 lakh tonnes per year. In the world, India is one of the largest producer, consumer and exporter of turmeric. India accounts for about 80% of world's turmeric production and 60% of world's exports (Anonymous, 2021) [1]. Turmeric is a non-traditional spice crop in Konkan region of Maharashtra.
Indian turmeric is considered the best in the world due to rich in curcumin content which imparts the distinctive yellow colour. In general, the turmeric rhizomes are used in the form of dried rhizomes or in the powder form. There are different processing methods which were adopted in the different parts of the country are cleaning, washing, boiling, drying, grinding and polishing of rhizome (Dhawle *et al*. 2020) [4]. The important properties used for designing machines are engineering properties, mechanical properties, electrical properties and thermal properties. Engineering property is the most important among these properties which mainly considered in the design of the post-harvest handling and sorting equipment. It gives the proper guidelines to an engineer for designing the machines that will be suitable for handling and processing of agricultural materials (Shirsat *et al*. 2018) [9]. Many researchers have studied about the engineering properties of turmeric rhizomes such as axial dimensions, geometric mean diameter, arithmetic mean diameter, sphericity, bulk density, true density, porosity, angle of repose, volume and surface area (Khambalkar *et al*. 2017; Poornima *et al*. 2019 and Nimbalkar *et al*. 2021) [5, 8, 7]. Therefore, the present study was undertaken to determine some engineering properties of fresh turmeric rhizomes.

2. Material and Method
The fresh turmeric rhizomes of Salem variety were procured from AICRP on spices, Asond Block, Central Experiment station, Dapoli, Maharashtra. The rhizomes were cleaned and washed manually by hands remove adhering soil, hairs and extraneous matter.

The measurements of physical properties were taken in the Laboratory of Department of Agricultural Process Engineering, College of Agricultural Engineering and Technology, Dr. BSKKV, Dapoli. The methods adopted for determination of physical properties are given below.

2.1 Moisture content

The moisture content of fresh turmeric rhizome was determined using hot air oven (0 to 350 °C). The weighed samples were subjected to remove moisture at 105±2 °C for 24 hours. After which it was kept inside a desiccator for cooling to ambient temperature and the change in mass (measured using electronic weighing balance) was noted (AOAC 2000) [2]. The moisture content was expressed as% (wet basis, wb) or (dry basis, db). The moisture content was determined by using following equation:

$$\text{MC (\% wb)} = \frac{w_1 - w_3}{w_2 - w_3} \times 100 \quad (1)$$

Where,
W_1 = Initial mass of the test sample (g)
W_2 = Final mass of the test sample (g)
W_3 = Mass of empty sample box (g)

2.2 Axial dimensions of turmeric rhizome

Fresh turmeric rhizomes were randomly selected for measuring the axial dimensions. Length (l), width (b) and thickness (t) of each rhizome were measured using Vernier caliper (0.01 mm accuracy). A hundred observations were made to get average values of length, width and thickness of the turmeric rhizomes.

2.3 Geometric Mean Diameter (GMD)

The geometric mean diameter (GMD) was determined using measured axial dimensions such as length, width and thickness. The geometric mean diameter was determined using following formula described by Mohsenin (1986) [6].

$$\text{GMD} = \sqrt[3]{(l \times b \times t)} \quad (2)$$

Where,
l = length of the rhizome, mm
b= width of the rhizome, mm
t = thickness of the rhizome, mm

2.4 Sphericity

The sphericity is defined as the ratio of the surface area of the sphere having same volume as the rhizome to the surface area of the rhizome. The shape of the material is usually expressed in terms of its sphericity. The degree of sphericity of the turmeric rhizomes was calculated using following equation described by Mohsenin (1986) [6].

$$\text{Sphericity } (\phi) = \frac{\sqrt[3]{(l \times b \times t)}}{l} \quad (3)$$

2.5 Surface Area

The surface area was determined by tracing the periphery of rhizome on a graph sheet for all the four sides and counting the number of squares within the outline traced (Mohsenin, 1986) [6]. The sum of all the areas gives the surface area of the rhizome.

Mass, volume and surface area were determined for randomly selected 25 rhizomes (Shirsat *et al*. 2018) [9].

2.6 Bulk Density

The bulk density was determined as the ratio between the mass of turmeric rhizome in a container to its volume. Rhizomes were filled in a measuring cylinder of volume 1000 cm^3 and the mass of contents was determined.

$$\text{Bulk Density} = \frac{\text{Mass of the sample,g}}{\text{Volume of the cylinder,cm}^3} \quad (4)$$

2.7 True Density

The true density of fresh turmeric rhizomes was determined by Platform scale method (Mohsenin, 1986) [6]. The known sample of fresh turmeric rhizome was taken and then immersed in a toluene. The toluene displacement method was used for measurement of actual volume of turmeric rhizomes. True density of the turmeric rhizome was determined by taking 15 replications. It is calculated using following expression.

$$\text{True Density} = \frac{\text{Mass of the rhizome (kg)}}{\text{True volume of the rhizome (m}^3\text{)}} \quad (5)$$

2.8 Porosity

Porosity is the percentage of volume of voids in the test sample at given moisture content. It was calculated as ratio of the difference in the true and bulk densities to true plant density and determined by the expression as reported by Sereno *et al*. (2007) as:

$$\text{Porosity\%} = 1 - \frac{\text{Bulk density}}{\text{True density}} \times 100 \quad (6)$$

2.9 Angle of Repose

The angle of repose is the angle made by turmeric rhizomes with the horizontal surface when heaped from a known height. About 15 kg of turmeric rhizomes was heaped over the horizontal surface slowly from a height of 50 cm. the slanted height of the heap was measured and diameter of the heap was calculated from the circumference of heap (Shirsat *et al*. 2018) [9]. The angle of the repose was calculated by the formula:

$$\theta = \tan^{-1}\left(\frac{H}{D/2}\right) \quad (7)$$

Where,
Θ = Angle of repose in °,
H = Height of the heap in cm,
D = Diameter of the heap in cm

3. Results and Discussion

3.1 Moisture content

The initial moisture content of the turmeric rhizomes was determined by oven drying method and the average moisture content was 81.26% (wb). Moisture content of the produce determines the shelf life and the keeping quality of the turmeric. Singh *et al*. (2010) have suggested that the drying of fresh turmeric to a safe limit of moisture content about10% for milling and 6% for storage.

3.2 Axial dimensions

The axial dimensions i.e. length, width and thickness of hundred fresh turmeric rhizomes were measured. The length, width and thickness of the turmeric rhizomes varied in the range of 47.18 to 105.56 mm, 14.68 to 36.30 mm, and 11.54

to 24.46 mm, respectively. The mean values of length, width and thickness were found to be 67.66, 22.24 and 16.78 mm, respectively and the standard deviation was calculated as 13.40, 4.91, and 2.59, respectively. The observations for axial dimensions are in agreement with the findings of earlier researchers. Sinkar *et al*. (2005) [11] reported the length of turmeric rhizomes for different varieties were varied in the range of 58.0 to 92.3 mm. Khambalkar *et al*. (2017) [5] also reported the average values of length, width and thickness of turmeric rhizomes for different varieties were 58.11 mm, 36.71 mm and 30.17 mm, respectively.

The geometric mean diameter ranged from 22.59 to 38.18 mm. The mean value and standard deviation were calculated to be 29.11 mm and 4.17, respectively. The sphericity of the turmeric rhizomes was 0.33 to 0.58 with mean and standard deviation 0.44 and0.06, respectively. Similar trend was reported by Khambalkar *et al*. (2017) [5] for geometric mean diameter and sphericity i.e. 45.4 mm and 0.6, respectively.

3.3 Mass, volume and surface area of the rhizome

The calculated values of mass, volume and surface area of the turmeric rhizomes are the average of 25 rhizomes are shown in the Table 1. The mass, volume and surface area were observed in the ranged from 9.46 to 39.54 g, 6.29 to 31.15 cm^3 and 8.00 to 28.50 cm^2. The mean values of mass, volume and surface area were calculated to be 18.97g, 14.26 cm^3 and 15.57 cm^2 with standard deviation 7.39, 6.30 and 5.69, respectively.

3.4 Bulk density

The bulk density of fresh whole turmeric rhizomes was observed in the range of 418 to 425 kg/m^3. The mean value and standard deviation of bulk density were calculated to be 422.87 kg/m^3 and 2.16.

3.5 True density

The true density of fresh turmeric rhizomes was observed in the range of 1019.15 to 1210.94 kg/m^3. The mean value and standard deviation of true density were calculated to be 1142.01 kg/m^3 and 49.33.

3.6 Porosity

The porosity of the fresh turmeric rhizome varied in the range of 58.99 to 64.99%. The average porosity was calculated as 62.90% with standard deviation 1.60. Similar trend of the observations was recorded by Khambalkar *et al*. (2017) [5] and Nimbalkar *et al*. 2021 [7] for bulk density, true density and porosity were 529.66 kg/m^3, 1018.95 kg/m^3, 46.00% and 343.00 kg/m^3,1352.00 kg/m^3, 74.56%, respectively.

3.7 Angle of repose

The angle of repose of fresh turmeric rhizomes were ranged from 26.07 to 27.09° with standard deviation 0.37. The angle of repose is important in design and construction of the material handling system (Shirsat *et al*. 2018) [9]. Kambalkar *et al*. (2017) reported the average value of angle of repose for Salem variety was 26.20°.

Table 1: Physical properties of fresh turmeric rhizomes (at an average moisture content of 81.26% wb)

Sr. No.	Property	Number of observations	Standard Deviation	Minimum value	Maximum value	Mean value
1	Length (mm)	100	13.40	47.18	105.56	67.66
2	Width (mm)	100	4.91	14.68	36.30	22.24
3	Thickness (mm)	100	2.59	11.54	24.46	16.78
4	Geometric mean diameter (mm)	100	4.17	22.59	38.18	29.11
5	Sphericity	100	0.06	0.33	0.58	0.44
6	Rhizome mass, g	25	7.39	9.46	39.24	18.97
7	Volume, cm^3	25	6.30	6.29	31.15	14.26
8	Surface area, cm^2	25	5.69	8.00	28.50	15.57
9	Bulk density, kg/m^3	15	2.16	418.00	425.00	422.87
10	True density, kg/m^3	15	49.33	1019.15	1210.94	1142.01
11	Porosity, ε (%)	15	1.60	58.99	64.99	62.90
12	Angle of repose, °	15	0.37	26.07	27.09	26.68

4. Conclusion

The present study looked at some selected engineering properties of fresh turmeric rhizomes, such as length (67.66 mm), width (22.24 mm), thickness (16.78 mm), geometric mean diameter (29.11 mm), sphericity (0.44), mass (18.97 g), volume (14.26 cm^3), surface area (15.57 cm^2), bulk density (422.87 kg/m^3), true density (1142.01 kg/m^3), porosity (62.90%) and angle of repose (26.68°). These physical properties of the fresh turmeric rhizomes are very useful in the design and construction of the post-harvest handling and sorting machines as well as processing machines. The knowledge of these engineering properties are also essential in the post-harvest operations like material handling, storage, processing and transportation. These engineering properties are very important to characterize any biological material.

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