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Physical, frictional and thermal properties of turmeric rhizomes

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Abstract
It is important to study the engineering properties to design the dryers. The present investigation aimed to design a rotary dryer, so that some physical and thermal properties of fresh and dried turmeric rhizomes of PTS 10 variety were studied with a moisture content range between 410 to 7% (d.b.). The size of the turmeric decreased as the moisture decreased from 410 to 7% (d.b.). The bulk and true density was decreased with decrease in moisture content. The porosity was increased from 39.14 º ± 1.16 to 46.34° ± 3.5 with decrease in moisture content. The coefficient of friction of turmeric rhizomes was decreased as the moisture content decreased. The thermal conductivity and specific heat was decreased from 0.2532 to 0.13 W m^{-1} K^{-1} and 3.9 to 1.01 kJ $kg^{-1}K^{-1}$, respectively whereas the thermal diffusivity increased from 9.26 x 10^{-8} to 1.9 x 10^{-7} m^2s^{-1} as the moisture content decreases.

Keywords: Turmeric, moisture content, physical, thermal properties, frictional properties

1. Introduction

Turmeric (*Curcuma longa* L.), known as the Indian saffron, is a rhizomatous herbaceous perennial plant belonging to the family Zingiberaceae. India is the largest producer and exporter of turmeric (Shree, 2015) [9]. The knowledge of the physical and thermal properties plays an important role in the design and development of processing equipments of turmeric rhizomes. Thermal properties like specific heat, thermal conductivity and thermal diffusivity are essential for the design of driers and pulverizing equipments. Knowledge of thermal properties of food substances was highly important in the design of heat transfer, dehydrating and sterilizing equipments (Jeevarathinam and Pandiarajan, 2016) [4]. Review of literature revealed that the lack of studies on the physical and thermal properties of turmeric rhizomes. Hence, an attempt was made to study various physical properties of turmeric rhizomes namely size, bulk density, true density, porosity, coefficient of friction and angle of repose and thermal properties such as thermal diffusivity, thermal conductivity and specific heat.

2. Materials and Methods

Turmeric rhizomes of PTS 10 variety were selected for investigation from Thamaraipalayam village, Tamil Nadu, India. The physical and thermal properties were determined for fresh and dried turmeric rhizomes.

2.1 Determination of moisture content

The moisture content was determined by the Dean and Stark distillation method according to the Indian Standard Specification- IS: 1797-1985. The percentage moisture content was calculated by the following formula.

$$\text{Moisture content \% (w. b.)} = \frac{V_w}{M} \times 100 \qquad \ldots (1)$$

Where,
V_w = Volume of water collected, ml
M = Mass of turmeric, g

2.2 Physical properties

2.2.1 Size

The size of the turmeric rhizomes namely the length, width and thickness of the primary, secondary and tertiary fingers were determined with the help of a vernier caliper having a least count of 0.1 mm. Ten samples were randomly selected and the mean values are reported as the size of the turmeric rhizomes.

2.2.2 Bulk and true density

The Bulk density was calculated as the ratio between mass and bulk volume of turmeric. The bulk density was determined by filling a container of known volume and weighing the container. The true density of turmeric was determined by platform scale method (Mohsenin, 1986) [6]. The sample of turmeric was first weighed on an electronic balance of accuracy ±0.01g in air and then immersed in water in a container. The second reading of the scale with turmeric submerged minus the mass of the container with water alone gives the mass of the displaced water, which was used in the following expression to determine the true volume. True density of the fresh turmeric was determined by taking ten replications.

2.2.3 Porosity

The porosity of the fresh turmeric was computed using the formula given below and expressed in per cent (Kaleemullah and Kailappan, 2003) [5].

$$\varepsilon = 1 - \left(\frac{\rho_b}{\rho_t}\right) \times 100 \qquad \ldots (2)$$

Where,
ε is the porosity of turmeric, %
ρ_b is the bulk density of turmeric, kg m^{-3}
ρ_t is the true density of turmeric, kg m^{-3}

2.2.4 Coefficient of friction

The experimental setup used in the friction studies was similar to that reported by Kaleemullah and Kailappan (2003) [5]. The apparatus consisted of a frictionless pulley fitted on a frame, a bottomless cylindrical container (94 mm diameter and 98 mm height), loading pan and test surfaces. The bottomless container placed on the test surface was filled with a known quantity of turmeric and weights were added to the loading pan until the container began to slide. The mass of turmeric and the added weights represent the normal force and frictional force, respectively. The co-efficient of static friction was calculated as the ratio of frictional force (F) to the normal force (N_f) as,

$$\mu = \frac{F}{N_f} \qquad \ldots (3)$$

2.2.5 Angle of repose

The angle of repose was calculated using the methodology provided by Sreenarayanan *et al.* (1988) [12]. The angle of repose is the angle made by turmeric with the horizontal surface when piled from a known height**.** One bag (25 kg) of turmeric was piled over a horizontal surface. The radius of the pile was calculated from the circumference of the pile and the slant height of the pile.

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \qquad \ldots\ldots (4)$$

Whereas θ [°degrees] was the angle of repose, H [mm] was the height of the heap and D [mm] was the diameter of the pile.

2.3 Thermal properties

2.3.1 Thermal conductivity

Thermal conductivity was determined using the line heat source transient heat flow method similar to the method used by Sreenarayanan *et al.* (1988) [12]. The apparatus used to determine was given in fig.1.

Fig 1: Thermal conductivity apparatus (adapted from Jeevarathinam and Pandiarajan, 2016)

2.3.2 Thermal diffusivity

The thermal diffusivity of turmeric rhizomes was determined by Dickerson method (1965) [2]. Determination of thermal diffusivity was done by using the apparatus given in the fig.2.

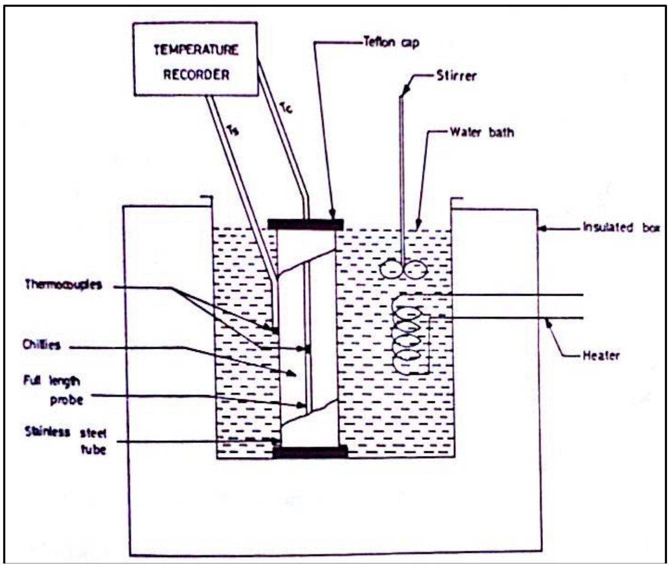

Fig 2: Dickerson apparatus for thermal diffusivity (adapted from Jeevarathinam and Pandiarajan, 2016)

2.3.2 Specific heat

The specific heat of turmeric rhizomes was calculated using the experimental values of thermal conductivity, thermal diffusivity and bulk density (Sreenarayanan *et al.*, 1988) [12]. The apparatus used to determine specific heat is shown in fig.3.

$$C_p = \frac{k}{\alpha \rho_b} \qquad \ldots (5)$$

Where,
C_p = Specific heat of turmeric, J/kg.K
K = Thermal conductivity of turmeric, W/m.K
ρ_b = Bulk density of turmeric, kg/m^3
α = Thermal diffusivity of turmeric, m^2/s

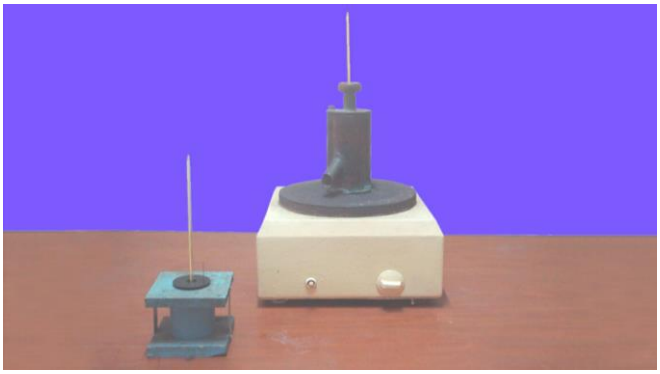

Fig 3: Specific heat apparatus (adapted from Jeevarathinam and Pandiarajan, 2016)

3. Results and Discussion

3.1 Size of the rhizome

The rhizomes of turmeric have branching of varying size and shape. Hence, the whole rhizome was split to primary, secondary and tertiary fingers and the linear dimensions of the split finger are reported separately. The dimensions of the rhizomes were presented in Table 1. There was a reduction in dimensions of turmeric rhizome after drying. The reduction in length for primary, secondary and tertiary fingers was 38.50, 22.14 and 41.36 per cent respectively. The reduction in width for primary secondary and tertiary fingers was 47.25, 49.67 and 49.98 per cent, respectively. The reduction in thickness for primary, secondary and tertiary fingers was 44.3, 38.37 and 42.66 per cent, respectively. The shape of the turmeric rhizomes was considered as the cylinder. The value of cylindricity for fresh turmeric rhizomes were 0.8841 and the corresponding value for dry rhizomes was 0.924. Similar trend was observed by Athmaselvi and Varadharaju, (2002) [1] for turmeric varieties BSR 1.

Table 1: Size of turmeric rhizomes

Dimension	Primary finger (cm)		Secondary finger (cm)		Tertiary finger (cm)	
	Before drying	After drying	Before drying	After drying	Before drying	After drying
Length	9.1 ± 1.81	5.7 ± 1.88	5.22 ± 1.40	4.13 ± 1.40	2.16 ± 1.05	1.36 ± 0.95
Width	3.46 ± 0.90	1.84 ± 0.58	1.64 ± 0.56	0.85 ± 0.44	0.94 ± 0.32	0.46 ± 0.19
Thickness	2.5 ± 0.9	1.44 ± 0.67	1.18 ± 0.28	0.74 ± 0.23	0.66 ± 0.23	0.37 ± 0.11

(values indicate after ± indicates standard deviation)

3.2 Bulk and true density

The changes in bulk density, true density, porosity and angle of repose of turmeric before and after drying are presented in Table 2. The bulk density of fresh turmeric rhizome was 411.85 ± 15.4 kg/ m^3 and the corresponding value for dry turmeric was 395.44 ± 14.9 kg /m^3. The bulk density of turmeric rhizome was decreased by 3.97% after drying. The true density of fresh turmeric rhizome was 1035.61 ± 48.7 kg m^{-3} and the corresponding value for dry turmeric was 938.8 ± 51.81 kg m^{-3}. After drying the true density of turmeric rhizome was decreased. The porosity of fresh turmeric rhizome was 60.15 per cent and the corresponding value for dry turmeric was 57.79 per cent. The porosity of turmeric rhizomes was decreased by 3.92% after drying. Similar results were observed by Onu and Okafor, (2002) [7] for ginger as the moisture content decreased from 81 to 45.6 per cent.

3.3 Angle of repose

The angle of repose for fresh turmeric rhizomes was 39.14 ± 1.16º and increased to 46.34 ± 3.5° for dry turmeric (Table 2). The angle of repose was increased as the moisture content increased. Similar results were reported by Parveen and Kailappan, (2013) [8] that the angle of repose for fresh and dry turmeric rhizomes were 37.59° and 42.84° respectively.

Table 2: True density, bulk density, porosity and angle of repose of fresh and dried turmeric rhizomes

Properties	Before drying	After drying	Decrease in value
True density (kg/m^3)	1035.6 ± 48.71	938.8 ±51.80	9.36 ±1.81
Porosity (%)	60.15 ±2.31	57.79 ±2.27	3.92 ±1.62
Bulk density (kg/m^3)	411.85 ±15.449	395.4 ±14.94	3.97 ±1.33
Angle of repose (degree)	39.143 ±1.1607	46.34 ±3.541	7.20 ±2.38

(Values indicate after ± indicates standard deviation)

3.4 Coefficient of friction

The coefficient of friction of fresh turmeric rhizomes against stainless steel, aluminium, galvanized iron and mild steel surfaces were presented in Table 3. The coefficient of friction of rhizomes against stainless steel, aluminium, galvanized iron and mild steel surfaces were decreased as the moisture content decreased. Athmaselvi and Varadharaju, (2002) [1] reported that the coefficient of friction of finger and mother rhizomes against stainless steel, aluminium, galvanized iron and mild steel surfaces were decreased as the moisture content decreased.

Table 3: Coefficient of friction of turmeric rhizomes

Properties	Before drying	After drying
Stainless steel	0.53± 0.01	0.48 ±0.007
Aluminium	0.66 ±0.02	0.58 ±0.02
Galvanized iron	0.73 ±0.02	0.65 ±0.01
Mild Steel	0.75 ±0.02	0.67 ±0.02

(values indicate after ± indicates standard deviation)

3.5 Thermal Properties

3.5.1 Thermal conductivity

The properties of before and after drying turmeric rhizomes such as thermal conductivity and diffusivity are given in Table 4. The thermal conductivity of fresh turmeric was 0.2532 W m^{-1} K^{-1} and the corresponding value for dry turmeric was 0.13 W m^{-1} K^{-1}. The thermal conductivity of turmeric decreased after drying *i.e.* with decrease in moisture content (Jeevarathinam and Pandiarajan, 2016) [3]. Increase in thermal conductivity of turmeric with the increase in moisture content may be attributed to the fact that the thermal conductivity of water was 0.614 W m^{-1} K^{-1} and increase in water content in turmeric increased the heat required to raise the temperature of the material. A similar trend was reported for rice bran (Sreenarayanan and Chattopadhyay, 1986a) [11], cumin seeds (Singh and Goswami, 2000), borage seed (Yang *et al.*, 2002) [13], and turmeric (Jeevarathinam and Pandiarajan, 2016) [3].

3.5.2 Thermal diffusivity
The thermal diffusivity of fresh turmeric was 0.926 x 10^{-7} m^2 s^{-1} and the corresponding value for dry turmeric was 1.90 x 10^{-7} m^2 s^{-1}. The thermal diffusivity of turmeric rhizomes increased after drying with decrease in moisture content. From 410 to 7% (d.b.). A similar trend was reported for turmeric (Jeevarathinam and Pandiarajan, 2016) [3].

3.5.3 Specific heat
The specific heat of fresh turmeric was 3.9 kJ kg^{-1} K^{-1} and the corresponding value for dry turmeric was 1.01 kJ kg^{-1} K^{-1}. The specific heat of turmeric was found to decrease after drying *i.e.*, with decrease in moisture content (Jeevarathinam and Pandiarajan, 2016) [3]. A linear increase in specific heat with increase in moisture content was reported for turmeric (erode local *var.*) (Jeevarathinam and Pandiarajan, 2016) [3], turmeric (Athmaselvi and Varadharaju, 2002) [1], rice bran (Sreenarayanan and Chattopadhyay, 1986a) [11], cumin seeds (Singh and Goswami, 2000) [10].

Table 4: Thermal properties of fresh and dried turmeric

Sample	Before drying	After drying	Change in value (%)
Thermal conductivity (W m^{-1} K^{-1})	0.2532±0.0018	0.134±0.0075	46.82±3.174
Specific heat (J kg^{-1} K^{-1})	3905.31±35.77	1010±75.24	74.00±2.094
Thermal diffusivity (m^2 s^{-1})	0.926 x 10^{-7}±2.15716E-10	1.90 x 10^{-7}±5.7431E-09	>100±6.587

4. Conclusion
Size, bulk density, true density, porosity, coefficient of friction, thermal conductivity and specific heat were decreased with decrease in moisture content. The shape of turmeric rhizome can be treated as cylinder and the value of cylindricity was 0.8841 and 0.924 for fresh and dry turmeric respectively. The bulk density of rhizome was decreased from 411.85 kg/m^3 to 395.44 kg/m^3 with decrease in moisture content. True density of rhizome was decreased from 1035 kg/m^3 to 938 kg/m^3. The porosity was decreased from 60.158% to 57.794%. The coefficient of friction of turmeric rhizomes was decreased as the moisture content decreased. The thermal conductivity of turmeric decreased from 0.2532 to 0.13 W m^{-1} K^{-1} and specific heat from 3.9 to 1.01 kJ kg^{-1} K^{-1}, whereas the thermal diffusivity increased from 9.26 x 10^{-8} to 1.9x10^{-7} m^2s^{-1} as the moisture content decreases. The thermal diffusivity of turmeric increased after drying with decrease in moisture content.

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