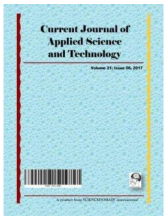

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Effect of Moisture Content on Physical and Mechanical Properties of Turmeric (*Curcuma longa*) Rhizome

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Authors' contributions

This work was carried out in collaboration between all authors. Author PSS designed the study, wrote the protocol, conducted the experiment and wrote the first draft of the manuscript. Author SY managed the literature searches. Author MLJ performed the statistical analysis and managed analyses of the study. Author MND guided and managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

The design of equipment for harvesting, separating, cleaning, handling and storing of any agricultural commodity is influenced by its physical and mechanical properties. The physical properties and mechanical behaviour of turmeric rhizome were determined at different moisture content (6, 8 and 10 % on wet basis) under laboratory conditions. It was observed that physical properties increased linearly with increase in moisture content of rhizome such as length (54.46±8.45 to 55.79±8.61 mm), breadth (12.48±1.61 to 13.21±1.13 mm), thickness (11.32±1.41 to 11.65±1.00 mm), bulk density (555±0.84 to 563±2.54 kg/m^3), true density (1337±2.91

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to 1359±2.00 kg/m^3), porosity (58.47±0.04 to 58.57±0.02 %), the angle of repose (35.87±0.02 to 37.42±0.04º). Mechanical properties coefficient of friction increased linearly (0.240±0.001 to 0.271±0.002) and rupture force decreased from 183.22±5.04 to 83.18±9.87 kg with an increase in moisture content of rhizome. The moisture content showed a significant effect on change in bulk density, true density, the angle of repose, the coefficient of friction and rupture force. However, properties like length, breadth, thickness and porosity are not significantly affected by moisture content.

Keywords: Turmeric rhizome; physical properties; mechanical property; moisture content.

1. INTRODUCTION

India, 'The Land of Spices', is known for cultivation and use of varied types of spices and condiments throughout the world. Spices and condiments are vegetable products or mixtures thereof, free from extraneous matter, used for flavouring, seasoning and imparting aroma in foods. The term applies equally to the product in the whole form or the ground form. It is, therefore, necessary to give due attention to this commodity with particular reference to quality and value addition.

Total production of spices of India in the year 2015 according to Directorate of Arecanut and Spices Development is 5833870 tonnes under the area of cultivation 3145610 ha. Turmeric is one of the most important and ancient spices of India and the traditional item of export. Total production of turmeric is 1092628 tonnes under the area of cultivation of 207570 ha [1]. It can be used as the condiment, dye, drug and cosmetic in addition to its use in religious ceremonies. It is native to tropical South Asia but is now widely cultivated in the tropical and subtropical regions of the world. India is the leading producer and exporter of turmeric in the world.

Spices are ground either for direct use or making value-added products, such as, ground spices, mixes, oleoresins and spice oil extract which have vast industrial applications [2]. However, whole spices are also used in culinary practices to a certain extent. When it comes to turmeric, it is generally used in powdered or paste form. The properties which are useful during design must be known, and these properties must be determined under laboratory conditions [3]. Physical properties of turmeric rhizomes would be useful in the designing of polishers and other processing gadgets [4].

The dimensions, seed mass, bulk density, true density and the projected area of agricultural grains changes with a variety of grain, agronomical conditions that product was grown and moisture content of grain [5]. Physical properties of cumin seed were studied at various moisture content and found that the average length, breadth and thickness, bulk density, true density, porosity, 1000 seed mass, terminal velocity, the angle of repose and static coefficient of friction increased linearly respectively with increasing moisture content [6]. Processing of cumin seed to powder mainly consists of grinding and powder particle size is related to the external forces exerted on each seed between the grinding surfaces [7]. Some studies showed that engineering properties are also important in the design of seed sowing devices [8,9]. Therefore, a study of the relationship between the forces on a single cumin seed is needed for a better understanding of milling. The force required to initiate seed rupture decreased as the moisture content increased. The deformation at seed rupture increased with increasing moisture content. The energy absorbed at seed rupture decreased with the increased moisture content.

2. MATERIALS AND METHODS

2.1 Sample Preparation

Salem variety of turmeric was procured from the local market. The rhizomes chosen were polished and of good quality. The procured sample was bone dried, and the moisture content of the dried sample was determined by using the Dean and Stark method [10]. Initial moisture content observed was 6±0.50 per cent. Then dried turmeric of the weight of 500 gm was taken, and a predetermined quantity of water (equation 1) was added to obtain desired moisture content (6 %, 8 % and 10 %). The sample was packed in sealed moisture resistant flexible pouches and then kept at 5 ºC in a refrigerator for a week to enable the moisture to distribute uniformly throughout the product. Before starting the experiment, the pouches were taken out of the refrigerator and allowed to warm up to the room temperature for 2 hrs. The pouches were opened just before determination of the properties.

The quantity of water added,

$$W = \frac{M\,(m_2 - m_1)}{100 - m_2} \tag{1}$$

Where,

W = Mass of water to be added (g)
M = Initial mass of rhizome (g)
m_1 = Initial moisture content of turmeric rhizome (% wb)
m_2 = Final moisture content of turmeric rhizome (% wb)

2.2 Determination of the Physical and Mechanical Properties Turmeric

Turmeric rhizome was randomly chosen for measuring dimensions. Length, breadth and thickness of each rhizome were measured using Vernier Caliper (Mitutoyo) (least count 0.01 cm). Fifty observations were made to get average values of length, breadth and thickness of the turmeric rhizome.

Bulk density ($\boldsymbol{\rho}_b$), defined as the ratio of the mass of the sample to its container volume, was evaluated by taking the total weight (W) of turmeric rhizome filled in a tin of known mass (M) and volume (V) [11].

$$\rho_b = \frac{W(g) - M\,(g)}{V\,(cm^3)} \tag{2}$$

True density ($\boldsymbol{\rho}_t$) of the turmeric rhizomes was determined by the toluene (C_7H_8) displacement method [12,13]. Weight of single turmeric rhizome and that of beaker plus toluene was taken as W1 and W_2 respectively. Then turmeric rhizome was submerged in the beaker without touching the side of beaker and bottom of the beaker and the weight was taken (W_3). Then the weight of toluene displaced (W_4 = W_3-W_2) was measured.

Volume of toluene displaced (V) =

$$\frac{W4\ (g)}{\text{Specific gravity of toluene}\ (g/cm^3)}$$

$$\rho_t = \frac{W_1}{V} \tag{3}$$

Porosity (P) is a physical property that reflects the number of air spaces in a bulk. True density and bulk density was used to determine the porosity of the turmeric rhizome. The porosity of the turmeric rhizome was computed using the formula given below and expressed in per cent [14].

$$P\,(\%) = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \tag{4}$$

The angle of repose (θ) was determined using a bottomless cylinder (10 cm diameter, 15 cm height) [15]. The cylinder was placed over a smooth surface, and turmeric rhizome was filled in the cylinder was raised slowly permitting the sample to flow down and form a natural slope. The height (H) and diameter (D) of the heap were measured and the angle of repose calculated as follows.

$$\theta = \tan^{-1}\frac{2H}{D} \tag{5}$$

Each rhizome was placed on the mild steel surface of tilting surface and raised gradually by a screw until the rhizome begins to slide. The angle (θ) that the inclined surface makes with the horizontal when sliding begins was measured [14]. The coefficient of static friction (μ) was calculated using the following equation.

$$\mu = \tan\theta \tag{6}$$

Rupture force of turmeric rhizome was measured using a Texture Analyser (TA. HD plus, Stable Micro Systems, Godalming, Surrey, UK) with a P/75 needle probe using 750 kg load cell. The pre-test speed, test speed and post-test speed were set as 1 mm/sec, 0.75 mm/sec and 10 mm/sec, respectively. Auto trigger force was set at 100 g-force. The rupture force was expressed in the unit of a kilogram (kg), measured from the resistance offered by the sample to the penetrating needle probe. The instrument was calibrated before each use.

2.3 Statistical Analysis

The properties were analysed using SAS (Statistical Analysis System) 9.3 software. The completely randomised design was used to investigate the significance of data.

3. RESULTS AND DISCUSSION

The physical properties of turmeric rhizome namely, length, breadth and thickness, bulk density, true density, porosity and coefficient of friction at different moisture content is given in Table 1.

The size parameters namely length, breadth and thickness of rhizome were found to increase linearly (Fig. 1a, 1b and 1c) with an increase in moisture content. However, the increase in size was not significant (at 5 % level of significance) (Table 2). The increase in the dimensions was due to the expansion of rhizomes because of moisture absorption in the porous spaces of turmeric rhizomes. Further, each dimension appeared to be linearly dependent on the moisture content [16,4,17].

Table 1. Physical and mechanical properties of turmeric rhizome at a different moisture content

Sr. no.	Property	Moisture content (%)		
		6	8	10
1	Length (mm)	54.46±8.45^{a}	55.09±7.42^{a}	55.79±8.61^{a}
2	Breadth (mm)	12.48±1.61^{a}	12.85±1.43^{ab}	13.21±1.13^{b}
3	Thickness (mm)	11.32±1.41^{a}	11.47±1.31^{a}	11.65±1.00^{a}
4	Bulk density (kg/m^3)	555±0.84^{a}	558±0.70^{b}	563±2.54^{c}
5	True density (kg/m^3)	1337±2.91^{a}	1345±1.58^{b}	1359±2.00^{c}
6	Porosity (%)	58.47±0.04^{a}	58.51±0.08^{a}	58.57±0.02^{a}
7	Angle of repose (°)	35.87±0.02^{a}	36.55±0.08^{b}	37.42±0.04^{c}
8	Coefficient of friction	0.240±0.001^{a}	0.252±0.002^{b}	0.271±0.002^{c}
9	Rupture force (kg)	183.22±5.04^{a}	116.68±7.35^{b}	83.18±9.87^{c}

**For particular parameter means with the same letter were not significantly different*

Table 2. ANOVA for properties

Properties	Source	DF	SS	MS	F value	Pr > F
Length	Model	2	44.053828	22.026914	0.33	0.7200
	Error	147	9835.042322	66.905050		
	Corrected total	149	9879.096150			
Breadth	Model	2	13.3533493	6.6766747	3.38	0.0368
	Error	147	290.6750880	1.9773816		
	Corrected total	149	304.0284373			
Thickness	Model	2	2.8003840	1.4001920	0.89	0.4138
	Error	147	231.8933820	1.5775060		
	Corrected total	149	234.6937660			
Bulk Density	Model	2	156.1333333	78.0666667	30.42	<.0001
	Error	12	30.8000000	2.5666667		
	Corrected total	14	186.9333333			
True Density	Model	2	1240.000000	620.000000	124.00	<.0001
	Error	12	60.000000	5.000000		
	Corrected total	14	1300.000000			
Porosity	Model	2	0.00000246	0.00000123	0.83	0.4601
	Error	12	0.00001779	0.00000148		
	Corrected total	14	0.00002025			
Angle of Repose	Model	2	6.03633333	3.01816667	928.67	<.0001
	Error	12	0.03900000	0.00325000		
	Corrected total	14	6.07533333			
Coefficient of Friction	Model	2	0.00244333	0.00122167	305.42	<.0001
	Error	12	0.00004800	0.00000400		
	Corrected total	14	0.00249133			
Rupture Force	Model	2	25889.89121	12944.94561	219.29	<.0001
	Error	12	708.36536	59.03045		
	Corrected total	14	26598.25657			

**Probability (pr) value <.0001 implies significant at 5 % level of significance; pr >0.0001 shows non-significant at 5 % level of significance*

There was a linear increase in bulk density for turmeric rhizome with an increase in moisture content (Fig. 1d). This is because of the increase in mass due to the increased moisture content in the sample was higher than the volumetric expansion of the rhizomes bulk. There was a significant change in the bulk density of rhizomes at 5 per cent level of significance (Table 2). A similar result was observed by Subhashini et al. (2015) and Athmaselvi and Varadharaju (2002) for turmeric rhizomes. The bulk density is important for the design of hopper.

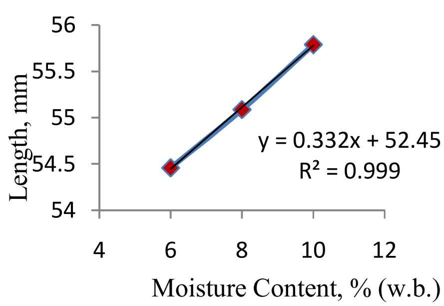
The effect of moisture content on the true density of turmeric rhizome showed a significant increased (at 5 % level of significance) with moisture content (Table 2) (Fig. 1e). Similar results were reported by Athmaselvi and Varadharaju (2002). It was observed that the bulk density was lower than the true density.

There was an increase in porosity with an increase in moisture content (Fig. 1f). However, an increase in porosity was not significant (at 5 % level of significance) (Table 2) which may be due to the rate of increase of true density as compared to that of bulk density was more [17,6].

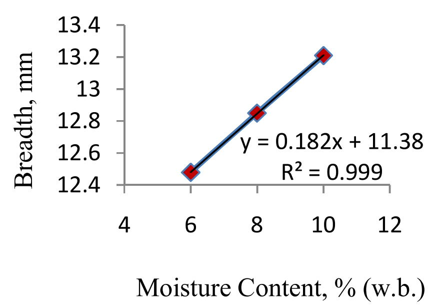
The angle of repose increased linearly (Fig 1g) and significantly (at 5 % level of significance) (Table 2) with an increase in moisture content. Because increasing moisture content increases the cohesive force. Singh and Goswami (1996) and Shubhashini et al. (2015) found a similar result for cumin and turmeric respectively.

It was observed that the coefficient of static friction was significantly (at 5 % level of significance) (Table 2) increased with increase in moisture content (Fig 1h). This may be due to the increased adhesion between the rhizome and the material surfaces at higher moisture values [16].

The effect of moisture content on the rupture force of turmeric rhizome showed a significant decrease with increasing moisture content at 5 per cent level of significance (Table 2) (Fig. 1i). A similar result was reported by Singh and Goswami (1998) for cumin seed. Decrease in rupture force, because of the presence of moisture in the rhizome, it becomes softer, breaks easily.



(a)



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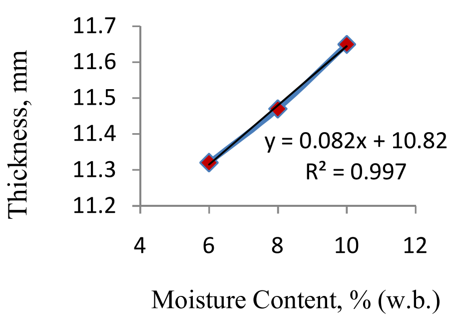

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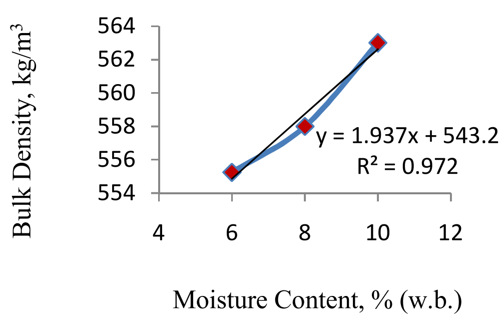

(d)

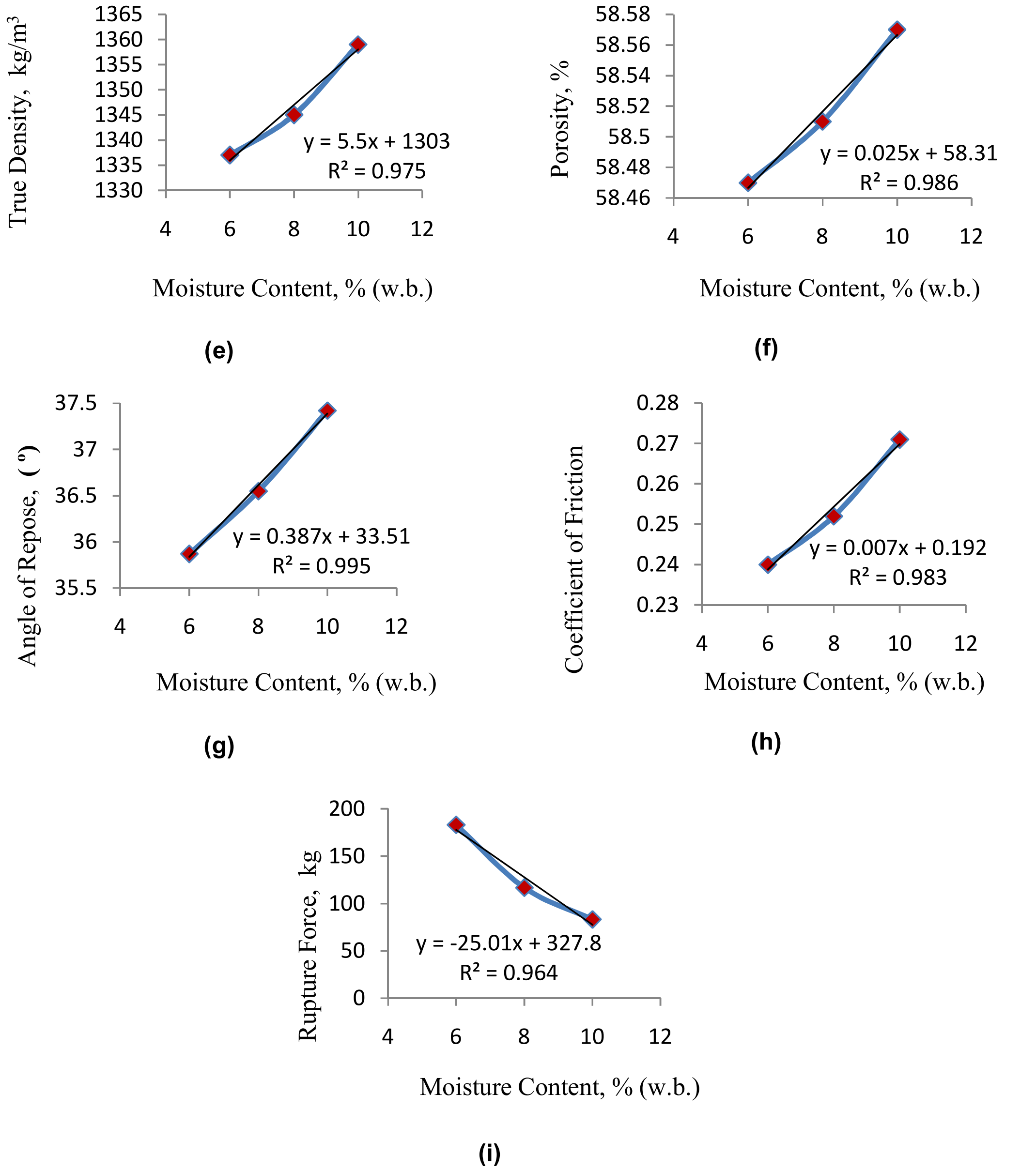

Fig. 1. Effect of moisture content on (a) length (mm), (b) breadth (mm), (c) thickness (mm), (d)bulk density (kg/m^3), (e) true density (kg/m^3), f) porosity (%), (g) angle of repose (º), (h) coefficient of friction, (i) rupture force (kg) of turmeric rhizome

4. CONCLUSIONS

It may be concluded that, with an increase in moisture content of turmeric rhizome, physical properties were increased linearly and the rupture force was decreased. There was a significant change in bulk density, true density, angle of repose, the coefficient of friction and rupture force. Some properties like length, breadth, thickness and porosity are not significantly affected by moisture content.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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