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Comparision of physical properties of turmeric rhizomes at fresh, boiled and dried conditions

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Abstract
Boiling and drying are the essential steps followed in processing of turmeric rhizomes. Superheated steam was employed for boiling and subsequent drying of rhizomes in a superheated steam dryer. Overall dimensions namely length, width and thickness of the rhizomes, significantly ($p < 0.05$) increased with boiling whereas significantly decreased with drying process. Bulk density of the fresh, boiled and dried rhizomes were found to be 530.9, 510.1 and 640.8 kg/m^3. Boiling process showed 10% increase in volume of the boiled rhizomes and 30% decrease in volume under drying process when compared to fresh rhizomes. Porosity of the rhizomes increased from 54.11 to 55.18 under boiling and decreased to 47.04 under drying process.

Keywords: Turmeric rhizomes, physical properties, boiling, drying, moisture content

1. Introduction
India is the leading producer, consumer and exporter of turmeric which accounts for approximately 83% of the world turmeric production followed by China, Myanmar and Bangladesh. During 2017-18, India exported 88,728 tonnes of turmeric out of 967860 tonnes of production valued at Rs. 95,165 lakhs. The major countries which import Indian turmeric are UAE, Bangladesh, Malaysia, Iran, UK and USA. These countries prefer Indian turmeric as they have high curcumin content and found to be best in the world in quality.
The demand for turmeric in various applications has increased in recent times. The quality of the end product of turmeric is most important which mainly depends upon the initial quality of turmeric rhizomes after harvest and the postharvest processing methods adopted (Arora *et al.*, 2007) [2]. Processing aids in the marketing of agriculture produce by making them more edible, palatable, attractive and extends the product availability over a long period of time (Jayashree *et al.*, 2015; Pradeep *et al.*, 2016) [13, 20]. Knowledge of engineering properties of the products is important in the feasible design of process equipment and to determine the product behavior during processing. Performance of the processing machineries got improved recently as the design was based through study of various properties (Mohsenin, 1986; Balasubramanian *et al.*, 2012) [17, 5].
Boiling and drying are the essential steps of turmeric processing and causes physical and chemical changes (Blaco *et al.*, 2006) [8]. The knowledge of physical properties such as moisture content, size, shape, bulk density, true density, surface area and volume are very important in order to design process equipment for turmeric whereas the changes in these properties at different stages of processing is not only important in accurate design calculations but also helps to predict the analytical behavior of the boiling and drying processes (Athmaselvi and Varadharaju, 2002) [4]. Many researchers have studied about the engineering properties of turmeric (Jeevarathinam, 2015; Balasubramanian *et al.*, 2012; Barnwal *et al.*, 2014) [12, 5, 7]. Despite an extensive research, no published literature was available on detailed physical properties of turmeric at various stages of turmeric processing using superheated steam. This study was undertaken to determine the physical properties of turmeric rhizomes at fresh, boiled and dried condition.

2. Materials and Methods
Freshly harvested turmeric rhizomes of variety ‘C0 2’ were procured from a local farmer near Kalipalayam, Coimbatore during 2019. The turmeric rhizomes were cleaned to remove the foreign materials and washed with clean water to remove dirt adhering to the rhizomes before the start of the experiment. The turmeric rhizomes were packed in a plastic bag and stored in temperature and humidity controlled chamber set at 6 ^{0}C till the experiments were conducted.

The initial moisture content of the rhizomes was determined using hot air oven at the temperature 130 ^{0}C till the two consecutive readings at 30 min interval was constant and was found as 74% (w.b).

2.1 Physical Properties

The knowledge of physical properties play an important role in the design of the drying equipment and hence these properties were studied for freshly harvested, boiled and dried turmeric rhizomes. The turmeric rhizomes were boiled and dried in a superheated steam dryer developed in Tamil Nadu Agricultural University. The experiment was conducted using superheated steam of temperature 165^{o}C for time 150 min at a pressure gauge of 1.25 bar gauge. In a superheated steam dryer, boiling occurs before actual drying of the product as the superheated steam gets condensed initially when it comes in contact with the product at ambient temperature. The standard methods to determine the physical properties of the samples such as size, shape, bulk density, true density and porosity were adopted and the details are given below;

2.1.1 Size

The axial dimensions; major, intermediate and minor diameters which are also referred as length-l, width-a and thickness-b respectively were measured using a Vernier Calliper. Three batches of sample weighing 1 kg each were randomly selected from the bulk to determine the size of the turmeric rhizomes. These three batches were mixed in a heap and 25 samples were taken randomly to measure the size. The turmeric rhizomes had secondary growth developments and hence dimensions were measured for both primary and secondary fingers of turmeric rhizomes. the tertiary developments in 5% of rhizomes were ignored (Mohsenin, 1986) [17].

By measuring length, width and thickness; geometric mean, arithmetic mean, square mean and equivalent diameter were calculated by the following formulas.

$$Geometric\ mean\ diameter\ (GMD) = \sqrt[3]{lab} \quad (1)$$

$$Arithmatic\ mean\ diameter\ (AMD) = \frac{l+a+b}{3} \quad (2)$$

$$Square\ mean\ diamter(SMD) = \sqrt{la + ab + bl} \quad (3)$$

$$Equivalent\ diamter(EQD) = \frac{AMD+GMD+SMD}{3} \quad (4)$$

2.1.2 Surface Area and Volume

The surface area and volume of turmeric rhizomes were calculated by the relationship given below (Jain and Bal, 1997) [12].

$$S = \frac{\pi B l^2}{2l-B} \quad (5)$$

where, $B = \sqrt{ab}$

$$V = 0.25[\ (\frac{\pi}{6}) l(a+b)^2] \quad (6)$$

2.1.3 Shape

Shape can be expressed in terms of Sphericity and was calculated by the formula given below (Mohsenin, 1986) [17].

$$S = \frac{\sqrt[3]{lab}}{l} \quad (7)$$

where,

S - sphericity, decimal

L, a and b - length, breadth and thickness, mm

2.1.4 Bulk Density

Bulk density is the ratio of mass and volume of the object and the method followed for determination of bulk density is explained below. One bag of turmeric rhizomes which weighs 25 kg was heaped over a horizontal surface from a height of 50 cm slowly and the rhizomes were allowed to fall freely. The slant height 'l' of the pile was measured and average value was noted. The radius of the pile was known by the circumference of the pile formed. The volume of the pile was determined by knowing the values of l and r and hence bulk density was calculated by the formula given below (Jayashree and Vishwanathan, 2011) [14].

$$h = \sqrt{(l^2 - r^2)} \quad (8)$$

$$V_b = \frac{1}{3} \times \pi r^2 h \quad (9)$$

$$\rho_b = \frac{W_b}{V_b} \quad (10)$$

Where,

ρ_b– bulk density of turmeric rhizomes, kg/m^3

W_b– mass of turmeric rhizomes, kg

V_b– volume of the pile, m^3

2.1.5 True Density

The true density of turmeric rhizomes was measured by platform scale method (Mohsenin, 1986)[17]. In this method, the turmeric rhizomes were weighed using a weighing balance of 0.1 accuracy in air and immerse the sample in container which is completely filled with water. The amount of water absorbed by the sample was considered negligible. The mass of displaced water gives the true density of the sample and was calculated using the following formula

$$True\ volume, (m^3) = \frac{Mass\ of\ displaced\ water,(kg)}{Density\ of\ water,(kg\ m^{-3})} \quad (11)$$

By knowing the mass of the turmeric rhizomes in air and the true volume, the true density was calculated as follows,

$$\rho_t = \frac{W_\alpha}{V_t} \quad (12)$$

Where,

ρ_t - true density of turmeric rhizomes, kg/m^3

W_α - mass of turmeric rhizomes in air, kg

V_t - true volume of turmeric rhizomes, m^3

2.1.6 Porosity

The porosity of the turmeric rhizomes was calculated using bulk density and true density with the formula given below (Mohsenin, 1986) [17].

$$\varepsilon = 1 - \left(\frac{\rho_b}{\rho_t}\right) \times 100 \quad (13)$$

Where,

ε – porosity, %

ρ_b – bulk density, kg /m^3

ρ_t– true density, kg /m^3

3. Results and Discussion

3.1 Size

The axial dimension of primary as well as secondary fingers were measured and presented in the table 3.1. The average values of length, width and thickness obtained for fresh, boiled and dried primary turmeric rhizomes are given in the table 3.1. The data revealed that there was 25.90% decrease in length; 36.30% decrease in width and 34.56% decrease in thickness after drying. Increase in moisture content increased the arithmetic mean diameter, geometric mean diameter, square mean diameter and equivalent mean diameter.

From the table it was observed that the dimensions of primary and secondary fingers increased after boiling and decreased after drying. Increase in dimension of the rhizomes after boiling could be attributed due to expansion of rhizomes by penetration of water into the intercellular spaces of the sample. This absorption of water at saturation temperature causes gelatinization of starch and hence swelling of the turmeric rhizomes. A similar trend in results was reported in a study of physical properties of ginger where axial dimensions were increased with increase in moisture content and vice versa (Ajav and Ogunlade, 2014) [1].

The relationship between moisture content (x) and dimensional properties of the rhizomes could be predicted by the following equations. The corresponding R^2 values of the equations are 0.99, 0.98, 0.99, 0.97, 0.99 and 0.93 respectively.

Length, $L = 0.5219\,x + 44.69$ (14)
Width, $W = 0.1859x + 7.561$ (15)
Thickness, $T = 0.169x + 7.5602$ (16)
Arithmetic Mean Diameter, $Da = 0.2924x + 19.840$ (17)
Geometric Mean Diameter, $Dg = 0.2567x + 13.7$ (18)
Square mean diameter, $Ds = 0.47x + 27.268$ (19)
Equivalent diameter, $De = 0.3018x + 21.199$ (20)

Table 1: Physical properties of turmeric at fresh, boiled and dried conditions

Property	Fresh (mm)		Boiled (mm)		Dried (mm)	
	Primary	Secondary	Primary	Secondary	Primary	Secondary
length	81.64±7.95	26.608±6.06	83.28±8.17	27.43±6.08	60.20±3.59	21.77±4.91
width	20.67±2.55	14.45±1.79	21.49±2.56	15.17±1.83	13.126±1.29	10.18±1.42
thickness	19.30±2.68	13.64±1.88	20.05±2.725	14.32±194	12.58±1.60	9.43±1.26
AMD	40.58±3.61	18.16±2.28	41.61±3.75	18.97±2.23	28.63±1.79	13.79±1.84
GMD	31.87±3.24	17.22±1.89	32.93±3.28	17.97±191	21.47±1.79	12.68±1.51
SMD	60.43±5.78	30.54±3.50	62.29±5.88	31.87±3.49	41.34±3.11	22.71±2.77
EMD	44.28±4.16	21.98±2.54	45.65±4.26	22.94±2.52	30.48±2.20	16.39±2.18

3.2 Sphericity

The average values of sphericity for fresh, boiled and dried rhizomes were found to be 0.392 ± 0.0316, 0.396 ± 0.0317 and 0.356 ± 0.024 respectively. The sphericity of the boiled rhizomes had higher values of sphericity whereas the dried rhizomes had lowest sphericity. Increase in the sphericity of the boiled samples may be due to the proportional increase in the sample dimensions such as length, width and thickness due to absorption of moisture and gelatinization of starch after boiling.

Similar results were also reported in a study on effect of moisture content on physical properties of corn grains where sphericity increased from 0.59 to 0.62 when moisture content increased from 12–22% (w.b). The increasing trend in sphericity with gain in moisture content was due to filling of capillaries and voids upon absorption of moisture and subsequent swelling (Seifi and Alimardani, 2010) [21]. The relationship between the sphericity (δ) and moisture content (x) was fitted by the following linear model equation with maximum regression value of 0.825.

Sphericity, $\delta = 0.0196x+0.3424$ (21)

3.3 Surface area and volume

The average values of surface area were 2934.51 ± 546.58, 3122.17 ± 585.94 and 1364 ± 206.19 mm^2 respectively and the average values of volume were found to be 17488.65 ± 5281.91, 19225.03 ± 5730.37 and 5289.64 ± 1315 mm^3 respectively for fresh, boiled and dried turmeric rhizomes. From the results, it was seen that there was 10% increase in volume of rhizomes after boiling and 30% decrease in volume after it was dried. The increase in surface area and volume were due to starch gelatinization and consequent expansion of axial dimension which in turn increased these properties of the sample. The decreased surface area and volume of dried rhizomes were due to reduced axial dimension as the moisture present in it was reduced. The variation in volume and surface area with respect to moisture content was similar to the results reported by (Bamgboye and Adejumo, 2009) [6] for Roselle seeds; (Deshpande *et al.*, 1993) [9] for soybean seeds, (Ozarslan, 2002) [19] for cotton seeds and ginger rhizomes (Ajav and Ogunlade, 2014) [1].

The relationship between surface area (A_s), Volume (V) and moisture content (x) was fitted with linear equation with the R^2 value of 0.8291 and 0.934 respectively.

Surface Area, $As = 878.83x+716.08$ (22)
Volume, $V = 13241 \ln(x) +61091$ (23)

3.4 Bulk density

The bulk density of the turmeric rhizomes at different stages is represented in the fig. 3.1. Bulk density was decreased with increase in moisture content. There was significant difference ($P< 0.05$) between the different stages of turmeric rhizomes. Dried rhizome had highest and the boiled rhizome had lowest bulk density. This behavior of decrease in bulk density might be due to the fact that volume expansion of the sample will occur as a result of increase in moisture content. As the result, the high moisture sample occupies more space than the less moisture product which leads to increased volume and decreased mass of the sample. Similar trend was reported for chickpea seeds by (Konak *et al.*, 2002) [16], African yam bean by (Irtwange and Igbeka, 2002) [10], lablab seeds by (Simonyan *et al.*, 2009) [22] and ginger rhizomes by (Ajav and Ogunlade, 2014) [1].

The relationship between bulk density (ρ_b) and moisture content (x) was fitted linear equation with the R^2 value of 0.997.

$\rho_b = - 2.8462\,x + 726.63$ (24)

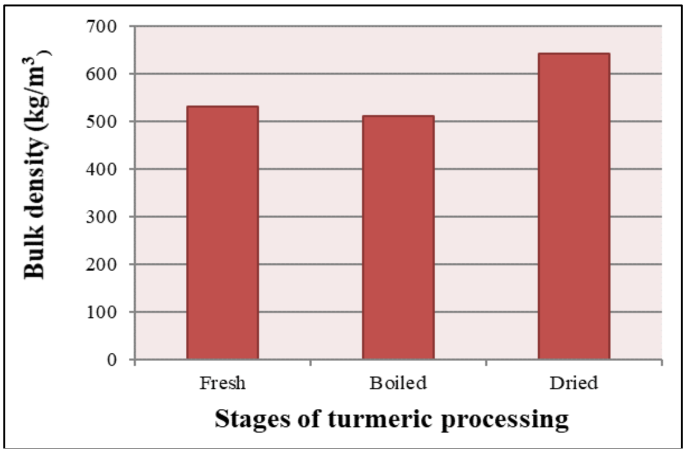

Fig 1: Bulk density of turmeric rhizomes at different stages of turmeric processing

3.5 True density

The true density of the turmeric rhizomes at different stages is represented in the fig. 3.2. There was significant difference ($P< 0.05$) between the different stages of turmeric rhizomes. It was found that true density is inversely proportional to the moisture content of the turmeric rhizomes. This might be due to increase in weight of the rhizomes by the absorbed moisture content after boiling. Similar trend in results were reported by arecanut kernels by (Kaleemullah and Gunasekar, 2002) [15] and round red lentil grains by (Isik, 2007) [11].

The relationship between true density (ρt) and moisture content (x) can be expressed by the following linear equation with the R^2 value of 0.997

$$\rho t = - 1.472 x + 1255 \quad (25)$$

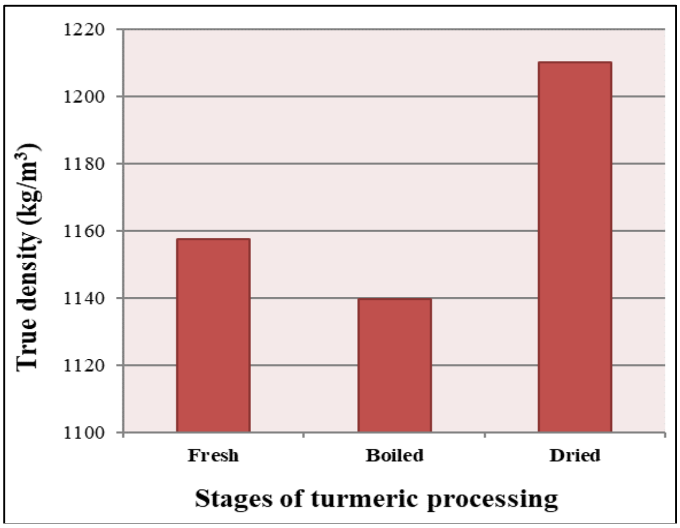

Fig 2: True density of turmeric rhizomes at different stages of turmeric processing

3.6 Porosity

The porosity of fresh, boiled and dried rhizomes were found to be 54.11, 55.18 and 47.04 respectively. The porosity was directly proportional to moisture content and therefore increased with increasing moisture content and it is represented in fig.3.3. Similar trend in results were reported for the Niger seeds (Solomon and Zewdu, 2009) [22] and the three varieties of sorghum (Mwithiga and Sifuna, 2006) [18].

The relationship between Porosity (γ) and moisture content (x) was fitted with linear equation with the R^2 value of 0.996

$$\varepsilon = 0.1793 x + 41.65 \quad (26)$$

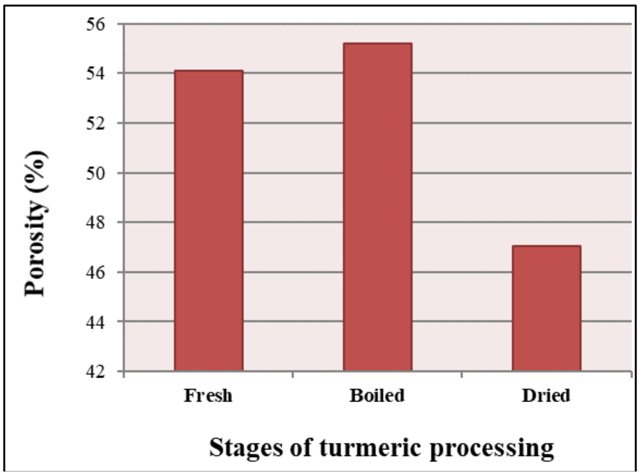

Fig 3: Porosity of turmeric rhizomes at different stages of turmeric processing

4. Conclusion

Physical properties of turmeric rhizomes such as axial dimensions (length, width and thickness), mean diameters, sphericity, volume, surface area, bulk density, true density and porosity at three different stages namely fresh, boiled and dried turmeric rhizomes were determined. The physical properties of the turmeric rhizomes varied linearly with the moisture content. The axial dimensions, equivalent mean diameter, surface area, sphericity, volume, porosity showed an ascending relationship with moisture rise while bulk density and true density had a descending relationship with moisture gain.

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