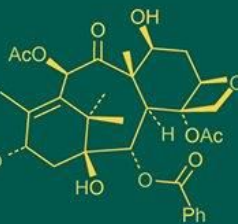
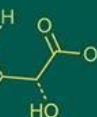
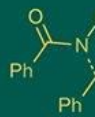


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Effect of steam boiler curing and drying methods on dimensional, physical characteristics of turmeric rhizomes

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Abstract

Steam boiler curing (T₁) and drying methods plays a crucial role in determining the quality of turmeric. An experiment was carried out to study the effect of steam boiler curing and drying methods on dimensional and physical characteristics of turmeric rhizomes. After washing, the fresh rhizomes are cooked using a steam boiler, which helps to soften them and enhance the colour and flavor. Once cooked, the rhizomes are dried by sun (D₁), solar (D₂), cabinet (D₃) and shade (D₄) drying to reduce their moisture content, making them easier to grind. The dried rhizomes are then polished by rotary drum polisher to remove any remaining outer skin and impurities. From the result revealed that dimensional characteristics with respect to length, breadth, thickness greatly reduced in steam boiler curing, with different drying methods as compared to fresh turmeric rhizomes. Also, the weight of rhizomes in both the varieties reduced from 30.6 to 27.9 and 29.6 to 26.13 respectively in Salem and Pragati variety rhizomes treated with (T₁) and dried with cabinet drier and physical characteristics such as 100 rhizomes weight, bulk density and true density were found decreased in steam boiler curing and dried Salem and Pragati turmeric rhizomes as compare to fresh one.

Keywords: Rhizomes, curing, characteristics, boiler, turmeric, variety

Introduction

Turmeric (*Curcuma longa*) is a rhizomatous herbaceous perennial plant belonging to the ginger family *Zingiberaceae*, which is native to tropical South Asia. The turmeric plant needs temperatures between 20 °C and 30 °C and a considerable amount of annual rainfall to thrive. Individual plants grow to a height of 1 m, and have long, oblong leaves. The plants are gathered annually and are reseeded from some of the rhizomes in the following season. The rhizome, from which the turmeric is derived, is tuberous, with a rough and segmented skin. The rhizomes mature beneath the foliage in the ground. The rhizomes are yellowish brown with a dull orange interior. The main rhizome is pointed or tapered at the distal end and measures 2.5–7.0 cm (1–3 inches) in length and 2.5 cm (1 inch) in diameter, with smaller tubers branching off. When the turmeric rhizome is dried, it can be ground to a yellow powder with a bitter, slightly acid, yet sweet, taste (Prasad & Aggarwal, 2011) ^[18].

A number of cultivars are available in the country and are known mostly by the name of locality where they are cultivated. Some of the popular cultivars are Duggirala, Tekkurpet, Sugandham, Amalapuram, Erode local, Salem, Alleppey, Moovattupuzha and Lakdong. The improved varieties of turmeric released from ICAR-Indian Institute of Spices Research, Kozhikode that are Suvarna, Suguna, Sudarsana, IISR Prabha, IISR Pratibha etc (Lijo & Rajeev, 2015) ^[9].

India is the largest producer, consumer and exporter of turmeric in the world. In the year 2022-23, an area of 3.24 lakh ha was under turmeric cultivation in India with a production of 11.61 lakh tonnes (over 75% of global turmeric production). More than 30 varieties of Turmeric are grown in India and it is grown in over 20 states in the country. The largest producing states of Turmeric are Maharashtra, Telangana, Karnataka and Tamil Nadu. India has more than 62% share of world trade in turmeric. During 2022-23, 1.534 lakh tonnes of turmeric and turmeric products valued at 207.45 million USD was exported by more than 380 exporters.

The leading export markets for Indian Turmeric are Bangladesh, UAE, USA and Malaysia. With the focused activities of the Board, it is expected that turmeric exports will reach USD 1 Billion by 2030 (PIB, 2023).

Freshly harvested turmeric rhizomes undergo several postharvest operations, including curing, drying, polishing and milling, before entering the market as a stable commodity. It has been demonstrated that curing and drying methods have a serious effect on physicochemical quality attributes of turmeric powder. Curing after harvesting is an important postharvest processing operation that involves cooking fresh turmeric rhizomes in boiling water. It is an essential operation before drying to avoid the raw odor, destroy the vitality of fresh rhizomes, yield uniformly colored product and reduce the drying time. The method of curing turmeric varies from place to place. There are conventional and improved methods of curing turmeric; however, during the conventional method of boiling turmeric, contents might be leached along with water, which in turn lowers curcumin, oleoresin and essential oil contents (Lokhande *et al.*, 2013; Jayashree *et al.*, 2018)^[10, 6].

Materials and Methods

Raw materials

The raw materials used during the experiment such as fresh turmeric rhizomes of variety 'Salem' and 'IISR-Pragati' procured immediately after harvest from the local villages as Italapur, Sayala, Pedgaon of Parbhani District and Hatta of Vasmat Taluka. Rhizomes kept in the room at ambient room temperature prior to conducting different drying experiments. The raw materials, turmeric rhizomes, were selected, cleaned and washed thoroughly in tap water to remove the adhering soil, hairs and extraneous matter. The undesirable portions were removed manually and then the rhizomes were again washed and cleaned properly.

Chemicals and glassware

Chemicals used in this investigation were of analytical grade and required glassware were used from the laboratory of Department of Food Engineering and Department of Food Chemistry and Nutrition, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani.

Equipments and machineries

The equipments and machineries used in the present investigation include weighing balance, vernier calliper, solar dryer, cabinet dryer etc. The equipments utilized were made available from different department viz., Department of Food Engineering, Department of Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani.

Physical properties of fresh turmeric rhizomes

Understanding of the physical properties of turmeric will help in designing drying equipment, cleaning, grading and processing machines and to determine the product behaviour during processing (Poornima *et al.*, 2019)^[15].

Dimensional properties

A fresh turmeric rhizome was randomly selected from variety 'Salem' and 'Pragati'. Three different dimensional properties (mm) were determined by measuring the length (L), width (W) and thickness (T) of the rhizomes using a vernier digital calliper at an accuracy of 0.01 mm.

Geometric mean diameter

The geometric mean diameter (mm) was determined based on the measured dimensions of turmeric rhizomes samples using equation (Balasubramanian *et al.*, 2012)^[12].

$$\text{Geometric mean diameter (Dg)} = (L \times W \times T)^{1/3}$$

Where, L - length, W- width, T- thickness.

Arithmetic mean diameter

The arithmetic mean diameter (mm) of the sample was obtained using the methods of (Mpotokwane *et al.*, 2008)^[12]. Arithmetic mean diameter was calculated from the dimensional values using following equation

$$\text{Arithmetic mean diameter (Da)} = \frac{(L + W + T)}{3}$$

Where, L - length, W- width, T- thickness.

Sphericity (S)

Sphericity (S) is defined as the ratio of the surface area of a sphere having the same volume as the rhizome to the surface area of the rhizome. The shape of a food material is usually expressed in terms of its sphericity. It is an important property used in fluid flow and heat and mass transfer calculations. Sphericity was determined using the measured geometric dimensions in the formula (Mpotokwane *et al.*, 2008)^[12].

$$\text{Sphericity (S)} = \frac{(L \times W \times T)^{1/3}}{L}$$

Aspect ratio (R)

In order to gather more information about the shape of the rhizome, aspect ratio (R) of the rhizome was determined from the following relationship

$$\text{Aspect ratio (R)} = \frac{W}{L}$$

Surface area (Sa)

The surface area turmeric rhizome were calculated based on the geometric mean diameter (Dg) in the following equation

$$\text{Surface area (Sa)} = \pi (Dg)^2$$

One hundred (100) rhizomes weight

Hundred turmeric rhizomes weight was determined by recording the weight and counting manually the number of the sample. The turmeric rhizomes samples were weighed using digital electronic balance with 0.01 g accuracy.

Bulk density

Bulk density (g/cm³) is described as the ratio of the mass of the sample to its total volume (Vanramkhasti *et al.*, 2008)^[20]. It was determined by filling a 500 mL cylinder with turmeric rhizomes. Bulk density (g/cm³) was calculated as a ratio between the sample weight and the volume of the cylinder using equation.

$$\text{Bulk density (Pb)} = \frac{\text{Sample Weight}}{\text{Volume}}$$

True density

The true density (g/cm^3) was determined by the liquid displacement method using a top loading balance. A total of 100 g of turmeric rhizomes were immersed in graduated beaker containing distilled water. The amount of water displacement was recorded using following equation (Karababa & Coşkuner, 2013) [17].

$$\text{True density (Pt)} = \frac{\text{Sample Weight}}{\text{Initial volume} - \text{Final volume}}$$

Porosity

It was calculated as the percentage of volume of voids for turmeric rhizome. It was calculated by using following equation (Vanramkhashi *et al.*, 2008) [20].

$$\text{Porosity } (\epsilon) = \frac{\text{Pt} - \text{Pb}}{\text{Pt}} \times 100$$

Where ϵ - porosity, pt - true density and pb - bulk density.

Angle of repose

Angle of repose was determined from the height and diameter of the naturally formed heap of food grains and powdered food products (Pradhan *et al.*, 2012) [17].

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

Where

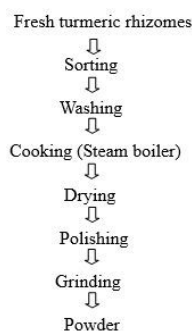
θ - angle of repose in degrees

h - height of the circular plate

D - diameter of the circular plate

Steam boiler curing (T₁) and drying

First, the rhizomes are sorted to remove any damaged or unsuitable pieces. They are then thoroughly washed to eliminate dirt and impurities. After washing, the rhizomes are cooked using a steam boiler, which helps to soften them and enhance the colour and flavor. Once cooked, the rhizomes are dried by sun (D₁), solar (D₂), cabinet (D₃) and shade dryer (D₄) to reduce their moisture content, making them easier to grind. The dried rhizomes are then polished by rotary drum polisher to remove any remaining outer skin and impurities. Finally, the polished rhizomes are ground into a fine powder in impact pulverizer, which is then ready for further analysis.



Flow sheet 1: Processing of turmeric rhizome into powder

Sun drying (D₁)

Farmers mostly prefer sun drying as it is economical to dry the rhizomes in the drying yard. Place the prepared rhizomes/slices in direct sunlight. Choose a location that receives full sunlight throughout the day. Ideally, use a drying rack or a tray with a mesh bottom to promote airflow from all sides. Turmeric rhizomes after boiling were spreaded uniformly (5 cm thick) and exposed to sunlight until the moisture content reached 7%. The time taken for drying depends on the sun intensity and were dried at 30 to 40 °C (Pradeep *et al.*, 2016) [16].

Solar drying (D₂)

The drying was carried out in the developed indirect natural convection solar dryer. The drying was done from 9 AM to 5 PM. Solar drying was done in a solar tunnel dryer and the drier is a concave structure made up of UV stabilized semi-transparent polyethylene sheet (200 micron), with area of 18 m x 3.75 m x 2 m. Rhizomes and slices were spread in trays and the loss in weight was recorded at specific intervals until 7-10% moisture content in about 2-3 days at 30-45 °C. The sample was dried until the moisture level in the sample reduced to a safe storage level of 8% (w.b.) (Singh *et al.*, 2010) [19]. The dried sample was ground to powder.

Cabinet tray drying (D₃)

After completion of curing in T₁, T₂ and T₃ treatment turmeric rhizomes and slices were placed in tray drier for drying. Once the dryer is preheated; the rhizomes were loaded in trays. The optimum drying temperature was 60°C, temperatures higher than this result in a darker coloured product. The drying process regularly monitored to ensure even drying. The dried sample was ground to powder.

Shade drying (D₄)

The turmeric rhizomes and slices are spread out in a single layer on drying trays or mats. These trays are then placed in a well-ventilated area with ample shade. The turmeric is left to dry naturally over a period of several days to weeks, depending on the weather conditions. Shade drying helps preserve the natural color and flavor of turmeric while allowing it to dry slowly and evenly without being exposed to direct sunlight, which can degrade its quality.

Results and Discussion

Firstly, in the research study, determination of dimensional and physical properties of fresh turmeric rhizomes of two promising varieties viz. Salem and Pragati which are commonly and majorly grown in Maharashtra in general and Marathwada in particular. The effect of different processing technologies such as whole rhizome boiling, drying by sun (D₁), solar (D₂), cabinet (D₃), shade drying (D₄) and polishing on physical and morphological properties of fresh turmeric rhizomes were observed for quality of turmeric rhizomes.

Dimensional characteristics of fresh turmeric rhizomes

The physical attributes of turmeric rhizomes facilitate the development of drying apparatus, cleaning, grading and processing machinery, as well as aids in predicting the product performance throughout processing. The properties viz. length, width, thickness, geometric mean diameter (GMD), arithmetic mean diameter (AMD), sphericity, aspect ratio, surface area, 100 rhizomes weight, bulk

density, true density, porosity and angle of repose were calculated. The data on dimensional characteristics of fresh turmeric rhizomes without any processing for Salem compared with Pragati is presented in table 1

The data presented in table 1 revealed that the length, width and thickness of the Salem turmeric rhizomes were 55.2 mm, 35.7 mm and 29.26 mm and 40.1 mm, 29.5 mm and 21.9 mm for Pragati turmeric rhizomes respectively which showed quite high variation. The data obtained during experimentation was significantly different from the results obtained by (Poornima *et al.*, 2019) [15] 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.

Table 1: Dimensional characteristics of fresh turmeric rhizomes

Characteristics	Turmeric variety	
	Salem	Pragati
Length (mm)	55.2±4.95	40.1±2.30
Width (mm)	35.7±3.55	29.5±3.33
Thickness (mm)	29.26±3.74	21.9±1.68
Weight (gm)	30.6±2.62	29.6±2.35
Geometric mean diameter (mm)	37.24±3.88	28.62±2.30
Arithmetic mean diameter (mm)	40.05±4.06	30.53±2.41
Sphericity	0.68±0.02	0.70±0.01
Aspect ratio	0.64±0.01	0.73±0.04
Surface area (mm ²)	4388±917.24	2585±414.59

* Each value is average of three determinations as means±SD

The length, width and thickness of the fresh turmeric rhizomes were used to calculate geometric mean diameter, arithmetic mean diameter, sphericity, aspect ratio and surface area. The average value of weight of single fresh turmeric rhizome, geometric mean diameter, arithmetic mean diameter, surface area, of Salem and Pragati variety were 30.6 gm, 37.24 mm, 40.05 mm, 4388 mm² and 29.6 gm, 28.62 mm, 30.53 mm and 2585 mm² respectively. The geometric mean diameter, arithmetic mean diameter, surface area showed an increasing trend with the increase in length, breadth and thickness of rhizome. It was found that the sphericity and aspect ratio of Salem turmeric rhizomes was 0.68 and 0.64 respectively. All these values were less as compared to Pragati turmeric variety which might be due to difference in width and thickness with varietal difference. The sphericity was found to increase in Pragati turmeric variety with the decrease in moisture content of the rhizomes. The reason was that due to the bend of rhizomes towards the breadth side, the length became shorter, thus increasing sphericity values. The observations for dimensional characteristics are in agreement with the findings of earlier researcher (Khambalkar *et al.*, 2017) [18] reported that the average length of all variety rhizomes was 58.11 mm, breadth 36.71 mm and thickness of 30.17 mm. The average weight of rhizome was found 34.87 gm. The average arithmetic mean diameter, geometric mean diameter, surface area was calculated 41.66 mm, 39.80 mm, 4370.74 mm².

Effect of steam boiler curing (T₁) on dimensional characteristics of turmeric rhizome (Variety: Salem and Pragati)

Using steam boiler curing for turmeric rhizome and subsequent processing into turmeric powder have several effects on the quality of the final product. Steam boiler

curing involves subjecting the turmeric whole rhizome to high-pressure steam, which aids in softening, sterilization, gelatinization of starch in rhizome and also to extract the desired components. Additionally, steam boiler curing can help reduce microbial contamination on the rhizome surface, enhancing the safety of the final product. However, excessive heat exposure during steam curing can potentially degrade heat-sensitive compounds in turmeric, such as volatile oils, oleoresin and curcumin, leading to a loss of colour and nutritional value. Therefore, careful control of steam cooking parameters, including temperature and duration, is essential to preserve the quality of turmeric rhizome and powder.

The determination of dimensional characteristics of dried and polished turmeric by using existing present steam boiling method also an additional effort has been taken to dry the cured turmeric rhizomes by different drying methods viz. sun (D₁), solar (D₂), cabinet (D₃), shade (D₄). Dimensional characteristics are important to design machines and processes for harvesting, handling and storage of these materials and requires understanding for converting these materials into food and feed. For horticultural materials (Rhizomes, vegetables, grapes), dimensions (length, diameter, thickness) are widely used properties to describe them. The physical dimensions of rhizome particularly shape is very important in sorting and grading to determine how many rhizomes can be placed in shipping containers or plastic bags of a given size. Rhizome skin colour is an attribute that determines consumers behaviour and it is accepted as one of the most important external quality parameters.

The data pertaining to dimensional characteristics of Salem and Pragati dried rhizomes under different drying methods is given in table 2. Each variety had been subjected to four different drying methods, labelled as D₁, D₂, D₃ and D₄. Dimensional characteristics measured for each drying method, including length, width, thickness, weight, GMD (geometric mean diameter), AMD (arithmetic mean diameter), sphericity, aspect ratio and surface area.

The arithmetic mean diameter, geometric mean diameter showed an increasing trend in Salem and Pragati variety with the increase in length, breadth and thickness of rhizome. Length, breadth, thickness value of Salem and Pragati variety in D₁ to D₄ drying methods showed an increasing trend ranged from 50.46 - 53.9, 31.5 - 34.5, 25.3 - 28.1 mm and 35.23 - 37.9, 25.4 - 28.33, 18.6 - 20.26 mm respectively.

The arithmetic mean diameter and geometric mean diameter value of Salem and Pragati variety in D₁ to D₄ drying methods were 33.06 - 36.74, 35.75 - 38.83 mm and 24.70 - 26.99, 26.40 - 28.81 mm respectively.

The average value of weight of single dried turmeric rhizomes of Salem and Pragati varieties dried by of D₁, D₂, D₃ and D₄ method were 26.03, 26.63, 27.9, 28.8 and 25.56, 26.08, 26.13, 27.3 gm respectively.

Sphericity and aspect ratio in Pragati variety was more as compare to Salem variety. Whereas the surface area in Salem variety was found more as compare to Pragati variety. Among all the treatments from D₁ to D₄ in both the varieties dimensional characteristics were preserved in D₃ treatment i. e. cabinet tray drying. This may be attributed to greater control of time-temperature relationship in cabinet drying as the mechanical parameters were controlled throughout the process.

D₁ drying involves exposing the fresh rhizome to direct sunlight. This method can lead to rapid moisture removal and may result in shrinkage of the rhizome due to loss of water content. D₂ drying tends to have a similar effect on rhizome length as D₁, but with potentially less shrinkage due to the more controlled drying conditions. D₃ drying often preserves the length of the rhizome better than other methods, as it allows for precise control of drying conditions. D₄ drying typically results in less shrinkage of

the rhizome compared to D₁ drying. The slower drying process helps preserve the natural shape and length of the rhizome to a greater extent.

There was a reduction in dimensions of turmeric rhizome after drying. Surface area reduction in dried rhizome of Salem and Pragati variety was greater in the D₁ drying method followed by D₂, D₃ and D₄. Similar trend was observed by (Balakrishnan *et al.*, 2020) [1].

Table 2: Effect of steam boiler curing (T₁) and drying methods on dimensional characteristics of dried turmeric rhizomes

Variety	Drying Method	Dimensional characteristics								
		Length (mm)	Width (mm)	Thickness (mm)	Weight (gm)	GMD (mm)	AMD (mm)	Sphericity	Aspect ratio	Surface area (mm ²)
Salem	D ₁	50.46±5.27	31.5±3.36	25.3±2.95	26.03±1.95	33.06±3.57	35.75±3.85	0.65±0.005	0.62±0.002	3401±834.7
	D ₂	51.66±4.72	32.03±3.76	25.86±3.05	26.63±2.45	33.7±3.61	36.52±3.81	0.64±0.01	0.61±0.02	3606±775.3
	D ₃	52.43±4.81	33.4±3.78	26.56±4.41	27.9±3.27	34.67±4.08	37.46±4.20	0.65±0.01	0.63±0.02	3811±888.8
	D ₄	53.9±4.12	34.5±2.95	28.1±3.17	28.8±2.38	36.74±3.25	38.83±3.39	0.66±0.009	0.63±0.01	4103±744.5
Pragati	D ₁	35.23±2.40	25.4±2.90	18.6±0.8	25.56±0.83	24.70±1.80	26.40±1.99	0.69±0.01	0.71±0.03	1923±279.0
	D ₂	35.76±2.49	25.93±2.95	18.96±1.05	26.08±1.04	25.16±1.94	26.88±2.11	0.72±0.04	0.72±0.04	1996±304.9
	D ₃	36.13±1.10	26.53±3.17	19.03±1.67	26.13±2.66	25.45±1.81	27.20±1.75	0.70±0.03	0.73±0.08	2041±286.6
	D ₄	37.9±2.40	28.33±3.50	20.26±1.70	27.3±2.06	26.99±2.34	28.81±2.47	0.71±0.01	0.74±0.04	2299±393.9

*Each value is average of three determinations as means±SD

Where D₁ - Sun drying, D₂ - Solar drying, D₃ - Cabinet tray drying and D₄ - Shade drying

T₁ - Steam boiler curing

Physical characteristics of fresh turmeric rhizomes

The data on physical characteristics of fresh turmeric rhizomes without any processing of Salem compared with Pragati is presented in table 3

Table 3: Physical characteristics of fresh turmeric rhizomes

Characteristics	Turmeric variety	
	Salem	Pragati
100 rhizomes weight (gm)	2451±122.7	2376±50.47
Bulk density (kg/m ³)	519±27.87	472±20.42
True density (kg/m ³)	1145±57.50	1010±13.01
Porosity (%)	54.62±0.60	53.98±4.01
Angle of repose (°)	37.3±2.84	38.03±1.95

* Each value is average of three determinations as means± SD

It was revealed from the above table that bulk density, true density and % porosity of Pragati fresh turmeric rhizomes were 472 kg/m³, 1010 kg/m³ and 53.98% respectively whereas Salem reported 519 kg/m³, 1145 kg/m³ and 54.62%, respectively. The values were found to be lower as compared to Salem turmeric variety when compared with Pragati. The similar results values of % porosity such as 54.72% for Prathibha turmeric variety were reported by (Cibi *et al.*, 2021) [3] and similar results values of bulk density 524 kg/m³ for Salem turmeric variety and true density 1137 kg/m³ for Bammi turmeric variety are reported by (Khambalkar *et al.*, 2017) [18].

The angle of repose of Salem turmeric variety was 37.3° which was less as compared to 38.03° angle of repose of Pragati turmeric variety. When the materials are smooth and rounded, the angle of repose is low. For sticky and fine materials, the angle of repose is high. Angle of repose therefore indicates the cohesion amongst the individual units of the materials. (Dhinesh & Anandakumar, 2016) [4] reported the angle of repose of Salem variety 37.52°.

According to (Mohsenin, 1980) [11] bulk density and porosity have an impact on the horizontal and vertical loads in silos during storage and the angle of repose is crucial when designing handling systems and their accessories. These

factors also determine the capacity of the dryer, storage and means of transportation, as well as resistance to air flow during aeration.

The hundred rhizomes weight for Pragati fresh turmeric rhizomes was 2376 gm which was low as compared to Salem turmeric variety i.e., 2451 gm may be due to its small size. The hundred rhizomes weight is a useful tool for the assessment of the potential milling yield. (Gunasekar & Kaleemullah, 2003) [5] reported hundred rhizomes weight for Erode turmeric variety as 1.581 kg rhizome dimensions may vary with varieties.

Effect of steam boiler curing (T₁) and drying methods on physical characteristics of dried turmeric rhizomes

The data provided in table 4 compares the physical characteristics of two varieties of dried turmeric rhizomes Salem and Pragati, subjected to different drying methods as such as D₁, D₂, D₃ and D₄.

In terms of 100 rhizomes weight, Salem variety showed higher values as compared to Pragati variety. The 100 rhizomes weight in both varieties ranged from 562 - 615 gm and 504 - 472 gm in Salem and Pragati variety respectively. Among all the drying methods 100 rhizomes weight was observed highest in shade drying. Each drying method can influence the weight of the Salem and Pragati variety rhizomes differently, D₁ may result in some weight loss due to moisture evaporation, while D₄ might retain more moisture and therefore maintain more weight. D₃ and D₂ can offer controlled environments that may lead to more consistent weight loss compared to natural drying methods. This trend is also reflected in the bulk density and true density values, where Salem variety showed 419 - 457 kg/m³ and 1059 - 1097 kg/m³ whereas Pragati variety showed 372 - 407 kg/m³ and 922 - 957 kg/m³ values for bulk density and true density respectively. The higher density value for both bulk and true density were observed in Salem variety displaying higher values than Pragati, indicating a higher mass per unit volume.

Table 4: Effect of steam boiler curing (T₁) and drying methods on physical characteristics of dried turmeric rhizomes

Variety	Drying Method	Physical characteristics				
		100 rhizomes weight (gm)	Bulk density (kg/m ³)	True density (kg/m ³)	Porosity (%)	Angle of repose (°)
Salem	D ₁	562±13.4	419±27.8	1059±58.5	60.79±0.9	43.33±2.8
	D ₂	582±11.1	440±36.3	1070±57.0	58.86±1.2	41.8±2.5
	D ₃	595±16.1	448±31.7	1075±65.0	58.3±1.0	33.9±2.2
	D ₄	615±6.11	457±32.5	1097±97.7	58.2±1.9	33.8±2.0
Pragati	D ₁	504±5.85	372±19.8	922±21.5	59.6±2.07	44.0±2.1
	D ₂	438±9.60	396±15.0	930±15.0	57.4±1.48	43±1.9
	D ₃	472±20.4	395±23.1	938±3.51	57.8±2.3	35.4±1.8
	D ₄	483±15.5	407±16.1	957±12.5	57.4±1.5	35.2±2.2

*Each value is average of three determinations as means± SD

Furthermore, when observing the angle of repose, both varieties show variations across different drying methods, but there is no consistent trend indicating superiority of one variety over the other. Angle of repose in Salem and Pragati is decreased from 43.33-33.8° and 44-35.2° respectively, as the rhizome moisture content decreases across different drying methods. The reason for this may be that the rhizomes rolled over cone at higher moisture contents due to their good shape at higher moisture contents the rhizome bulged and there were no wrinkles on their surface. At lesser moisture content were wrinkles on moisture rhizomes surface which made a good grip without slippage. Hence the angle of repose was greater at lesser moisture content in D₁ drying method in both varieties. The present results were in good agreement with the (Gunasekar & Kaleemullah 2003) [5] who found that angle of repose decreased from 42.82 - 36.58° as the rhizome moisture content decrease, bulk density, true density and 100 rhizomes weight decrease with decrease of moisture content.

It is revealed from table 4 that in Salem and Pragati varieties porosity was decreased from D₁ to D₄ the percent porosity reported in Salem and Pragati varieties was decreased from 60.79-58.2 and 59.62-57.4 respectively. As moisture evaporates and creates void spaces within the rhizomes the percent porosity values were observed least in D₄ (shade drying) whereas in D₃ method percent porosity was preserved to great extent showed lower porosity as compared to D₁ due to slower moisture removal.

Each drying method had impact on the physical characteristics of dried turmeric rhizomes differently. Sun drying and shade drying are natural methods that may result in more variable outcomes, while cabinet drying and solar drying offer more controlled conditions that could lead to more consistent physical characteristics. These differences in physical characteristics could have implications for various applications, such as storage, transportation and processing of these rhizomes.

Previous studies reported by (Balakrishnan *et al.*, 2020) [11] bulk density of turmeric rhizome was decreased by 3.97% after drying. True density of fresh turmeric rhizome was 1035.61±48.7 kg/m³ and the corresponding value for dry turmeric was 938.8±51.81 kg/m³. After drying the true density of turmeric rhizome was decreased. The porosity of turmeric rhizomes was decreased by 3.92% after drying. Similar results were observed by (Onu & Okafor 2002) [13].

Conclusion

From table 1 and 2 it has been observed that dimensional characteristics with respect to length, breadth, thickness greatly reduced in steam boiler curing (T₁), with different drying methods as compared to fresh turmeric rhizomes.

Also, the weight of rhizomes in both the varieties reduced from 30.6 to 27.9 and 29.6 to 26.13 respectively in Salem and Pragati variety rhizomes treated with (T₁) and dried with cabinet drier. These decrease in dimensional characteristics as well as weight may be due to shrinkage after boiling and reduction of moisture after drying.

From table 3 and 4 it could be seen that physical characteristics such as 100 rhizomes weight, bulk density and true density were found decreased in steam boiler curing (T₁) and dried Salem and Pragati turmeric rhizomes as compare to fresh one. This reduction in 100 rhizomes weight is directly proportional to reduction of moisture after boiling and drying. As in case with bulk density and true density also reduced to a great extent as these are mass dependent properties.

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