



Physical Properties of Finger Turmeric Rhizomes of C.V. “PDKV Waigaon” Under Steam Boiled and Tray Dried Condition

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Abstract

The study was conducted during February, 2024–March, 2024 at the Experimental Learning Unit of the Department of Agricultural Process Engineering, College of Agricultural Engineering and Technology, Akola, Maharashtra, India to study the physical and engineering properties of steam-boiled and tray-dried turmeric rhizomes. The freshly harvested rhizomes of the variety PDKV waigaon were assessed under two conditions: steam boiled and then tray dried. As a moisture content steam boiled turmeric rhizomes decreased from 81.09% to 9.84% the average linear dimensions such as length, breadth and thickness decreased from 66.96, 21.02 and 17.64 mm (steam boiled) to 43.75, 11.47 and 8.14 mm (steam tray dried). Correspondingly, the geometric mean diameter, arithmetic mean diameter and square mean diameter reduced from 29.01, 31.21 and 54.40 mm (steam boiled) to 15.85, 21.12 and 30.70 mm (tray dried). The bulk density decreased from 543.57 kg m⁻³ to 410.24 kg m⁻³, while the true density declined from 1202.02 kg m⁻³ to 1045.27 kg m⁻³. Sphericity and porosity also reduced from 0.44 to 0.37% and 60.68 to 54.85%, respectively. While the angle of repose showed a slight increase from 28.76° to 33.98°. Tray drying resulted in a considerable reduction in axial and geometric dimensions, bulk and true densities, sphericity and porosity, while causing an increase in the angle of repose. These findings provided essential information for improving the design and optimisation of turmeric processing and storage systems.

Keywords: Engineering properties, steam boiled rhizomes, tray dried rhizomes

1. Introduction

Turmeric (*Curcuma longa* L.) is an esteemed ancient spice native to India and holds significant cultural and culinary importance (Govindarajan, 1980; Ravindran et al., 2007; Phuke et al., 2024). Turmeric, ‘the golden spice of life’, is one of the major spice crops in India. India is the major producer, consumer, and exporter of turmeric in the world (Nithya et al., 2020). It belongs to the family *Zingiberaceae* and is predominantly distributed across South and Southeast Asia (Ravindran et al., 2007). This herbaceous perennial plant is highly valued for its underground rhizomes, which serve as a spice, condiment, natural colourant, dye and an important raw material for the cosmetic and pharmaceutical industries (Prasad and Aggarwal, 2011; Peter, 2012). India is the world’s largest producer, consumer and exporter of turmeric, contributing the major share of global production

(Anonymous, 2014). Turmeric owes its medicinal importance mainly to curcuminoids, particularly curcumin, which exhibit antioxidant, anti-inflammatory, antimicrobial and anticancer activities (Prasad and Aggarwal, 2011). Post-harvest processing plays an important role in determining the final yield and quality of turmeric (Balakrishnan, 2007; Anonymous, 2014). Freshly harvested turmeric rhizomes contain about 80–90% moisture and therefore require immediate processing to prevent deterioration (Anonymous, 2014). Processing involves cleaning, washing, curing or boiling, drying, polishing, grinding and packaging (Balakrishnan, 2007; Govindarajan, 1980). Turmeric processing involves cleaning, washing, boiling, drying, polishing, grading and packaging. Curing or boiling of fresh rhizomes promotes the gelatinization of starch, facilitates uniform drying, and increases the drying rate. Curing or boiling promotes starch gelatinization, removes raw odour, improves colour development and facilitates uniform drying of rhizomes



(Govindarajan, 1980; Prasad and Aggarwal, 2011, Nithya et al., 2020). Drying is one of the most critical operations in turmeric processing because it reduces moisture to a safe level for storage and preserves quality (Balakrishnan, 2007; Peter, 2012). Mechanical tray drying provides better control over drying conditions and generally produces superior quality dried turmeric compared with traditional sun drying (Peter, 2012, Kondareddy et al., 2019). The drying behaviour of turmeric depends on processing conditions, pretreatment and slice thickness, which significantly influence drying rate and product quality (Malik and Kumar, 2022). Knowledge of the physical and engineering properties of agricultural materials is essential for designing equipment used in cleaning, grading, drying, conveying and storage (Mohsenin, 1986, Kumar, 2016). Moisture content plays an important role to provide data for designing (Yadav, 2027). The knowledge of physical properties such as moisture content, size, shape, bulk density, true density, surface area and volume is 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). Food products such as turmeric are commonly characterized by their dimensions and density because these properties are widely used in sorting and grading operations (Keramat-Jahromi et al., 2008). Colour is another important quality attribute that strongly influences consumer acceptance and market value (Yu et al., 2017). Many researchers have studied about the engineering properties of turmeric (Balasubramanian et al., 2012). Despite extensive research, no published literature was available on detailed physical properties of turmeric at various stages of turmeric processing using superheated steam. Therefore, it is necessary to study the physical and engineering properties of steam-boiled and tray-dried turmeric rhizomes for efficient post-harvest handling, thermal processing and storage.

2. Materials and Methods

The study entitled “Physical Properties of Turmeric Rhizomes of C.V. “PDKV waigaon” under Boiled and Tray Dried Condition” was conducted during February, 2024–March, 2024 at the Experimental Learning Unit of the Department of Agricultural Process Engineering, College of Agricultural Engineering and Technology, Akola. Freshly harvested turmeric rhizomes of the variety PDKV waigaon were procured from the Department of Vegetable Science. The procured rhizomes were boiled and then dried under tray drying conditions. After drying, the changes in the physical dimensions and properties were assessed. Various physical parameters such as moisture content, length, breadth, thickness, sphericity, geometric mean diameter (GMD), arithmetic mean diameter (AMD), square mean diameter (SMD), true density, bulk density, porosity and angle of repose were determined both before and after drying.

2.1. Moisture content

The moisture content of steam boiled and then tray dried turmeric rhizomes was measured using the standard hot-air oven technique. The samples were weighed accurately and then dried in a hot air oven at $105 \pm 2^\circ\text{C}$ for 24 h to remove all moisture. After drying, the samples were placed in a desiccator to cool to room temperature and their final weight was recorded using an electronic weighing balance, following the (Anonymous, 2000) method. The moisture content was expressed on both a wet basis (wb) and a dry basis (db) and was calculated using the following equation (Devkota, 2025).

$$\text{MC (\% wb)} = (W_1 - W_3) / (W_2 - W_3) \dots\dots\dots 1$$

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. Linear dimensions of turmeric rhizomes

The dimensional properties of steam boiled and then tray dried turmeric rhizomes were assessed along three main axes such as, the longest axis (length), the intermediate axis (width), and the shortest axis (thickness). These dimensions were recorded using a digital vernier calliper with an accuracy of 0.01 mm. Based on these primary measurements, the arithmetic mean diameter (D_a), square mean diameter (D_e) and geometric mean diameter (D_g) were computed using standard formulas and these values were subsequently used to determine the surface area (SA) of the rhizomes. To obtain accurate and representative data, measurements were taken for 100 individual rhizomes and the mean values of length, width and thickness were calculated. (Mohsenin et al., 1970; Murakonda et al., 2022; Pathak et al., 2019).

2.3. Sphericity

The sphericity of steam boiled and tray dried of turmeric 100 finger rhizomes represent how closely their shape approximates a perfect sphere. This property played an essential role in designing handling and processing equipment such as hoppers, conveyors and dehulling systems as it affects the rolling behaviour and flow characteristics of the material. For determining sphericity, the main dimensions of each rhizome such as length, width and thickness were recorded using a digital calliper. The sphericity was then computed using the standard formula given by (Singh and Sahay, 2001).

$$\Phi = (lbt)^{1/3} / l \dots\dots\dots 2$$

2.4. Geometric mean diameter

The geometric mean diameter of 100 steam boiled and tray dried turmeric finger rhizomes was calculated using the measured linear dimensions, namely length (L), width (W) and thickness (T) (Mohsenin, 1970). Based on these primary measurements, the arithmetic mean diameter (AMD), geometric mean diameter (GMD), square mean diameter (SMD) and sphericity were computed following the standard



equations proposed by (Singh and Sahay, 2001; Mohsenin 1970). The corresponding relationships are given below and determined by using below formula,

$$(GMD)=(lbt)^{1/3} \dots\dots\dots 3$$

Arithmetic mean diameter was determined as below,

$$(AMD)=(l+b+t)/3 \dots\dots\dots 4$$

Square mean diameter was also determined by using below formula,

$$(SMD)=(lb+bt+tl)^{1/2} \dots\dots\dots 5$$

2.5. Bulk density (BD)

Bulk density of randomly selected 15 turmeric rhizomes samples in steam boiled, tray dried formed was measured by filling a known volume rectangular box with steam boiled and then tray dried rhizomes and record their mass by using weighing balance. A rectangular box with internal dimensions of 30×20×15 cm³ was used for this purpose. After the box was filled without compacting the material, the total mass of the rhizomes was weighed. Bulk density was then computed using the following expression (Singh and Sahay, 2001, Devkota, 2025).

$$\text{Bulk density}=(\text{Mass of finger rhizome}/\text{Volume of box})\times(\text{kg}/\text{M}^3) \dots\dots\dots 6$$

2.6. True density (TD)

Randomly selected 15 samples of turmeric rhizomes under steam boiled and then tray dried condition were used to determine the actual volume of steam boiled and then tray dried turmeric rhizomes, it was necessary to obtain their true density. Therefore, true density was calculated using a liquid displacement method. The true density of steam boiled, tray dried finger turmeric rhizomes were measured by using toluene (C₆H₅CH₃) solution. It was used as the displacement medium because it possesses several desirable properties: it does not readily penetrate or swell the sample, has low surface tension that allows it to flow easily around the rhizomes, exhibits minimal solvent action on organic constituents such as fats, has a relatively high boiling point and has a lower specific gravity, making it suitable for accurate volume displacement measurements, (Singh and Sahay, 2001).

$$\text{True density}=(\text{Mass of displaced toluene by rhizome}/\text{Density of toluene})\times(\text{kg}/\text{M}^3) \dots\dots\dots 7$$

2.7. Porosity

Porosity refers to the proportion of void space within a sample at a specific moisture content. For turmeric steam boiled, tray dried finger rhizomes, porosity was computed as the percentage of the total volume that was not occupied by solid material. The porosity of the steam boiled, tray dried rhizomes was determined using the calculated bulk density and true density values., (Mohsenin et al., 1986; Singh and Sahay, 2001).

$$\text{Porosity}=(\text{True density}-\text{Bulk density}/\text{True density})\times 100 \dots\dots 8$$

2.8. Angle of repose

The angle of repose was an important indicator of the flowability of a product. For yellow turmeric, this parameter was measured following the procedure described by (Ajav and Ogunlade, 2014). Approximately 15 kg of rhizomes was allowed to fall gradually onto a horizontal surface from a height of 50 cm, forming a natural conical heap. Once stable, the slant height of the heap was recorded and the diameter was determined using the measured circumference. The angle of repose steam boiled, tray dried was then computed using the standard formula, (Singh and Sahay, 2001; Shirsat et al., 2018; Pathak et al., 2019).

$$\Theta=\tan^{-1} (H/(D/2)) \dots\dots\dots 9$$

Where,

Θ=Angle of repose in degree.

H=Height of the heap in cm

D=Diameter of the heap in cm

2.9. Statistical analysis

The physical and engineering properties of steam-boiled, tray dried turmeric rhizomes were analyzed using analysis of variance (ANOVA) and the mean differences were assessed through the least significant difference t-test at the $p=0.05$ probability level. Relationships among the various physical parameters were examined using paired t-tests and ANOVA by employing the Web Agri-Stat statistical software (Megha et al., 2022).

3. Results and Discussion

3.1. Moisture content

The moisture level of turmeric plays a key role in determining its storage stability and quality. Steam-boiled turmeric rhizomes were initially analyzed using the oven-drying method, revealing moisture contents between 81.09% and 86.73% (wb). The rhizomes were then dried up to a moisture range of 9.84–10.57% (wb), after which their engineering properties were assessed. The engineering properties of turmeric rhizomes were measured at 76.18–78.84% by (Shirsat et al., 2018). Similarly engineering properties of turmeric rhizomes were measured at average moisture content up to 81.26% (wb) by (Pooja et al., 2022).

3.2. Linear dimensions of turmeric rhizomes

The linear dimensions such as length, width and thickness of 100 steam boiled, tray dried turmeric rhizomes were measured. After tray drying of fresh turmeric rhizomes, the mean values of length, width and thickness get decreased and it varies from 66.96–43.75 mm, 21.02–11.47 mm, 17.64–8.14 mm respectively. In case of steam boiled turmeric rhizomes values of linear dimensions such as length, width and thickness was varied in the range of 107.32 to 29.82 mm, 29.82–14.37 mm, and 26.09 to 12.76 mm respectively. As a steam boiled turmeric rhizomes get dried the mean value of sphericity was



varies from 0.44 to 0.37.

The linear dimensions of steam-boiled turmeric rhizomes decreased progressively as the moisture content declined as shown in Figure 1. Similar trend regarding the geometric properties also as shown in Figure 2. The geometric mean diameter, arithmetic mean diameter and square mean diameter were found to range between 19.33–38.27 mm, 20.06–50.60 mm and 34.03–72.49 mm, respectively. A paired T-test analysis of the linear dimensions revealed that the differences between steam-boiled and tray dried turmeric rhizomes were statistically significant at the $p=0.05$ probability level. Similar decreasing trends in length, width and thickness of turmeric rhizomes have also been reported by (Khambalkar et al., 2017) and (Pooja et al., 2022; Parveen et al., 2013) further observed a 50.54% reduction in thickness, a 27.38% reduction in length, and an overall volume reduction of 76.80% when the moisture content decreased from 411.25% to 7.81% (db). Decreased in linear dimensions were also observed by (Amin et al., 2004; Kiani et al., 2008).

3.3. Bulk density

The bulk density of boiled, tray dried turmeric rhizomes

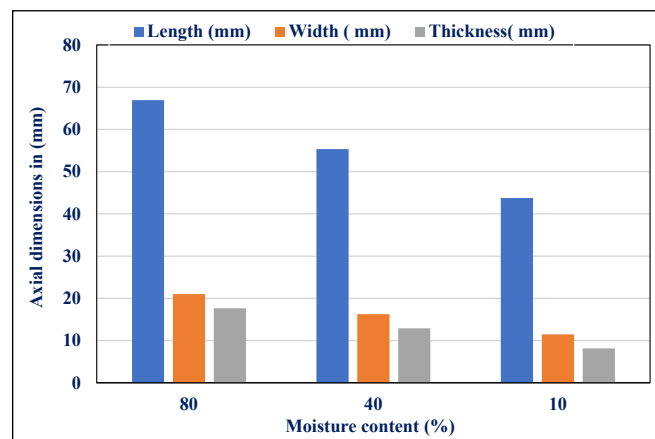


Figure 1: Axial dimensions of turmeric rhizomes of C.V. “PDKV waigaon” under different moisture level

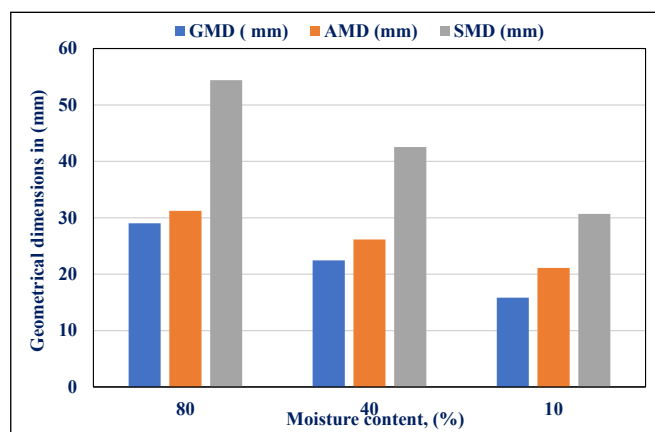


Figure 2: Geometrical dimensions of turmeric rhizomes of C.V. “PDKV waigaon” under different moisture level

was observed to vary between 489.76 kg m⁻³ and 603.07 kg m⁻³, whereas in steam boiled and tray dried rhizomes it ranged from 399.56 kg m⁻³ to 441.62 kg m⁻³. From the results presented in Figure 3 and Tables 1 and 2, it was evident that bulk density increased with higher moisture content. As drying progressed and the moisture content reduced, the average bulk density of steam boiled rhizomes also decreased, with values ranging from 543.57 kg m⁻³ to 410.24 kg m⁻³. The paired T-test indicated that the variation in bulk density was significant at the $p=0.05$ level.

The bulk and true densities of turmeric rhizomes were also found to decline from 606 to 574 kg m⁻³ as the moisture content decreased from 36.83% to 10.12% (db). This decrease may be attributed to a greater reduction in moisture compared to the reduction in volume. Similar observations were reported by (Chandrasekar and Vishwanathan, 1999) for coffee parchments. Studies by (Balkrishnan et al., 2020) also recorded comparable trends in the physical behaviour of fresh and tray dried turmeric rhizomes. In support of this, (Wandkar et al., 2012) reported that bulk density reduced from 749.1 kg m⁻³ to 644.4 kg m⁻³ as the moisture content dropped from 15.80% to 7.37% (db).

3.4. True density

The true density of steam boiled turmeric rhizomes ranged from 1293.42 kg m⁻³ to 1125.12 kg m⁻³, whereas for steam-boiled and tray dried rhizomes it varied between 1138 kg m⁻³ and 986 kg m⁻³. The average true density of turmeric rhizomes during the transition from steam boiling to drying was observed within the range of 1202.02 kg m⁻³ to 1045.27 kg m⁻³. Results from the T-test indicated that the variation in true density during drying was significant at the $p=0.05$ probability level. As illustrated in Figure 3 and Tables 1 and 2, true density showed a direct relationship with moisture content. (Khambalkar et al., 2017) reported a true density of 1018.95 kg m⁻³ for fresh turmeric rhizomes, which is consistent with the trend observed in the present study.

Similar behaviour of true density in turmeric rhizomes has been documented in previous literature. In case of boiled turmeric rhizomes similar trend of observations were reported by (Gunasekar et al., 2003). (Shirsat et al., 2018) reported true density values ranging from 1317.55 kg m⁻³ to 951.10 kg m⁻³, while (Jayashree and Vishwanathan, 2011) observed values between 1099.13 kg m⁻³ and 1011.47 kg m⁻³. (Wandkar et al., 2012) also noted a decline in true density from 1250 kg m⁻³ to 1111.11 kg m⁻³ as moisture content decreased from 15.80% to 7.37% (d.b.). In the present study as well, true density reduced from 1633 kg m⁻³ to 1128 kg m⁻³ corresponding to a drop in moisture content from 369.83% to 10.12% (d.b.). This reduction may be due to a greater mass loss from moisture evaporation relative to the decrease in volume. Comparable findings were also reported by (Chandrasekar and Vishwanathan, 1999) for coffee parchment.

Table 1: Summary of physical properties of steam boiled, tray dried turmeric rhizomes (*Curcuma longa* L.) before drying having moisture content varies from 81.09–86.73% on wet basis

Property	Replications	Mean	SD	Min	Max	CV
Length (mm)	100	66.96	12.933–12.998	29.82	107.32	19.31–19.41
Width (mm)	100	21.02	3.401–3.419	14.37	29.82	16.18–16.26
Thickness (mm)	100	17.64	2.85–2.86	12.73	2609	17.50–17.59
Sphericity (dec)	100	0.44	0.059–0.060	0.33	0.69	13.59–13.65
GMD (mm)	100	29.01	4.114–4.135	19.33	38.27	14.18–14.25
AMD (mm)	100	31.21	5.416–5.44	20.06	50.6	15.38–15.46
SMD (mm)	100	54.4	7.78–7.82	34.03	72.49	14.30–14.37
BD (kg m ⁻³)	15	543.57	36.89–38.18	489.76	603.07	6.78–7.02
TD (kg m ⁻³)	15	1202.02	51.88–53.71	1125	1293.96	4.31–4.46
Porosity (%)	15	60.68	2.25–2.33	55.48	63.24	3.71–3.84
Angle of repose (°)	15	28.76	2.96.3.07	23.74	35.52	10.31–10.67

SD: Standard deviation; Min: Minimum; Max: Maximum; GMD: Geometric mean diameter; AMD: Arithmetic mean diameter; SMD: Square mean diameter; CV: Coefficient of variation

Table 2: Summary of physical properties of steam boiled, tray dried turmeric rhizomes (*Curcuma longa* L.) after drying having moisture content varies from 9.84–10.57% on wet basis

Property	Replications	Mean	SD	Min	Max	CV
Length (mm)	100	43.75	8.35–8.39	23.35	62.29	19.09–19.19
Width (mm)	100	11.47	2.16–2.17	7.4	18.06	18.83–18.93
Thickness (mm)	100	8.14	1.22–1.23	5.15	12.65	16.27–16.32
Sphericity (dec)	100	0.37	0.0524–0.056	0.27	0.54	14.18–14.25
GMD (mm)	100	15.85	2.013–2.025	11.71	22.01	12.70–12.76
AMD (mm)	100	21.12	3.20–3.23	13.37	29.38	15.18–15.26
SMD (mm)	100	30.7	4.09–4.12	21.39	42.86	13.35–13.42
BD (kg m ⁻³)	15	410.24	11.53–11.94	399.56	441.625	2.81–2.91
TD (kg m ⁻³)	15	1045.2713	40.07–41.47	986	1100.38	3.83–3.96
Porosity (%)	15	54.85	6.98–7.22	45.44	69.02	12.72–13.17
Angle of repose (°)	15	33.98	2.66–2.75	27.88	38.44	7.84–8.11

SD: Standard deviation, Min: Minimum, Max: Maximum, GMD: Geometric mean diameter; AMD: Arithmetic mean diameter; SMD: Square mean diameter; CV: Coefficient of variation

3.5. Porosity

The porosity of steam boiled turmeric rhizomes was found to range from 55.48% to 63.24%, whereas in dried rhizomes it varied between 44.44% and 69.02%. As shown in Figure 4 and Tables 1 and 2, porosity increased with an increase in moisture content. The average porosity of steam-boiled rhizomes decreased as the moisture content reduced, with values ranging from 60.68% to 54.85%. Statistical analysis revealed that the porosity of steam-boiled and tray dried rhizomes differed significantly at the $p=0.05$ level of significance.

In case of steam boiled turmeric rhizomes similar type of observation recorded by (Gunasekar et al., 2003). (Shirsat et

al., 2018) reported porosity values of 66.94% to 56.81% for freshly harvested turmeric rhizomes, which supported the trend observed in the present study. (Khambalkar et al., 2018) also documented similar behaviour, with porosity ranging from 63% to 32%. Comparable results were recorded by (Balkrishnan et al., 2020). Additionally, (Wandkar et al., 2012) reported an increase in porosity from 40.07% to 41.9% as the moisture content decreased from 15.80% to 7.37% (d.b.).

3.6. Angle of repose

Average values of steam boiled turmeric rhizome gets varied from 28.76°–33.98° as moisture content decreased from 81.09% to 9.04%. The angle of repose of steam-boiled turmeric



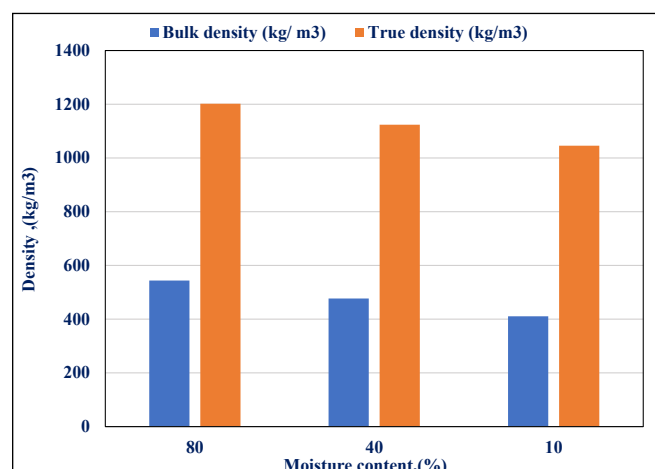


Figure 3: Bulk density and true density of turmeric rhizomes of C.V. "PDKV waigaon" under different moisture level

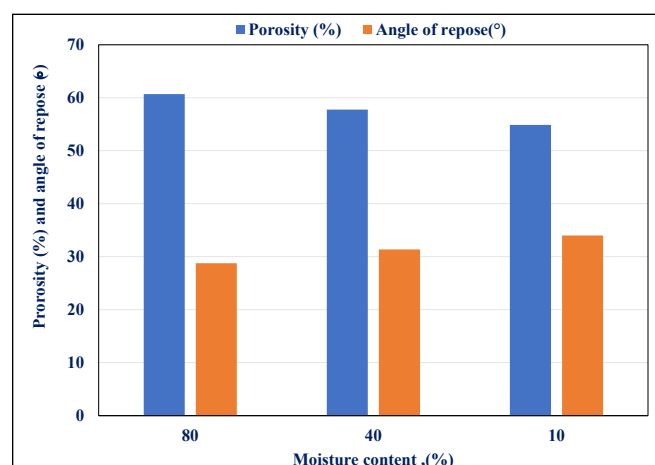


Figure 4: Porosity and angle of repose of turmeric rhizomes of C.V. "PDKV waigaon" under different moisture level

rhizomes increased with rising moisture content and ranged from 23.74° to 35.52°. For tray dried turmeric rhizomes, the angle of repose varied between 27.88° and 38.44°. As the steam-boiled rhizomes underwent drying, the average angle of repose increased from 28.76° to 33.98°.

(Kambalkar et al., 2017) reported an average angle of repose of 26.20° for the Salem turmeric variety. Similarly, (Shirsat et al., 2018) recorded angle of repose values between 22.61° and 28.76°. Jayashree and Vishwanathan (2011) observed that the angle of repose of finger rhizomes increased from 34.9° to 40.2° as the freshly harvested rhizomes dried. Comparable trends were also reported by (Balkrishnan et al., 2020).

4. Conclusion

The physical properties of steam-boiled turmeric rhizomes were considerably affected by moisture reduction during tray drying. Moisture content decreased from 81.09–86.73% to 9.84–10.57%, resulting in noticeable shrinkage and reduction in length, width and thickness. Bulk density, true density,

porosity and sphericity also showed a decreasing trend, whereas angle of repose increased slightly. These changes provided useful information for improving drying efficiency and designing suitable equipment for the processing, handling and storage of turmeric rhizomes.

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