

## Article

# Dynamics of Drying Turmeric Rhizomes (*Curcuma longa* L.) with Respect to Its Moisture, Color, Texture and Quality

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**Abstract:** Drying involves removing moisture from food. Therefore, to preserve the phenolic and bioactive compounds such as curcumin, dimethoxy curcumin and bisdemethoxy curcumin, etc., an efficient drying method is considered necessary. The primary drying methods are sun drying, hot air oven drying and fluidized bed drying. Traditional drying methods result in the loss of volatile oil (up to 25%) by evaporation and destruction of some light-sensitive oil constituents. Three methods of drying Turmeric with pretreatments boiled/unboiled and whole/sliced (2.5 cm long) were compared on physical and quality parameters. Texture analysis from sundry sliced boiled rhizomes achieved maximum peak force (45.40 kg), which was an indication of maximum uniform drying. Moisture content was strongly and significantly associated with drying time in different drying methods. Out of the three drying methods, in general, the sun drying showed a declining trend of L\*, a\* and b\* values with drying time. Whereas a slower rate of decrease in L\*, a\* and b\* values was predominant in the oven dry method. Interestingly, in the case of the fluidized method, almost static L\*, a\* and b\* values were measured at 3 h of drying onwards after a declining trend of those values. In the case of sun and oven drying, the hue angle reached its peak at the fourth hour of drying, then gradually declined up to final drying. However, for fluidized bed drying, it had a continuous declining trend for other parameters such as chroma and total color change; there was a sharp decreasing trend for all throughout. Turmeric whole boiled dried in the sun produced the maximum curcumin (5.82%) and the sliced boiled ones produced the maximum oleoresin (8.10%), indicating good quality powdered product among all other drying treatments. Considering all the aspects, it is recommended that sun drying should be followed in post-harvest operations, as it produces a quality powder with comparatively more curcumin, despite its longer drying time.

**Keywords:** color; drying methods; moisture; quality; texture; turmeric

## 1. Introduction

Turmeric (*Curcuma longa* L.) is an important spice used for day-to-day cooking throughout the world. It is one kind of herb that has been widely regarded in modern and traditional medicine [1]. Its appearance is dark yellow and has a unique smell. Turmeric belongs to the Zingiberaceae family and is reported to possess numerous medicinal properties,

including antioxidant [2], anti-protozoal [3,4], anti-tumor [5], anti-inflammatory [6] and antivenom activity [5,6]. The main component of Turmeric used in the pharmaceutical industry is curcuminoids, consisting of curcumin, demethoxy curcumin and bisdemethoxy curcumin [7]. Turmeric oleoresin is the organic extract of turmeric comprising mainly of curcuminoids and minor amounts of oils and resins. The curcuminoids represent the predominant coloring pigment of Turmeric. As a natural bioactive component, curcuminoids have become very popular because they possess many health-promoting effects such as improving heart functioning, prevention against Alzheimer's and cancer, and having potent anti-depression and anti-arthritis properties.

Drying is one of the most widely used primary methods of food preservation in Turmeric. The rhizomes are dried to avoid deterioration after harvesting [8]. Therefore, drying is precisely a moisture removal process that can resolve the issues, viz., improving food stability, lowering shipping weights, minimizing chemical and physical changes during storage and reducing microbiological activity due to the decrease in water activity [9]. Sun-drying is the most common method used to preserve agricultural products in tropical and subtropical countries [10]. However, other primary drying methods are hot air oven and fluidized bed drying. A hot air oven is used to sterilize the equipment as well as plant materials. A hot air oven is a type of dry heat sterilization used to dry the samples with high temperature, and fluidized bed drying is a method of fast drying that works on the principle of fluidization of the feed materials. In the fluidization process, hot air is introduced at high pressure through a perforated bed of moist solid particulate. Our research group has already standardized the physicochemical properties of red pepper (*Capsicum annuum* L.) as influenced by different drying methods and temperatures [11]. However, the general perception of drying Turmeric for a better and quality turmeric powder is not clear and the methods have not yet been standardized specifically to a location. Moreover, the possible impact of pretreatments such as slicing, or boiling has not been well understood so far. A few researchers have found that after boiling, the curcumin percentage was increased due to its uniform distribution [12]; however, some did not find any appreciable difference in curcumin content between boiled and unboiled samples [13]. Keeping these in view, the objective of this study was to evaluate the effect of different pretreatments and drying methods on the quality parameters of dried turmeric rhizomes.

## 2. Materials and Methods

These experiments were performed at the Bidhan Chandra Krishi Viswavidyalaya, India (23.5° N latitude, 89.0° E longitude, elevation 9.75 m above MSL) in the laboratory of the Department of Plantation, Spices, Medicinal and Aromatic crops, Faculty of Horticulture and the laboratory of Department of Food Engineering, Faculty of Agricultural Engineering, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, India.

### 2.1. Raw Materials

Twelve kilograms of fresh turmeric rhizomes of local variety 'Suguna' immediately after harvest were purchased from the local market of Mohanpur, Nadia, West Bengal, and 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. The cleaned turmeric rhizomes were sliced to about 2.5 cm in length with a knife. The size of the sliced rhizomes was measured by ruler scale. The initial moisture content of the rhizomes was nearly 93% to 94% (sliced and whole turmeric, respectively), which was determined by moisture analyzer.

### 2.2. Pre-Treatments before Drying

The present study was carried out to observe the effect of different pre-treatments on the drying characteristics at different drying times (1, 2, 3 and 4 h drying and final

drying up to moisture content of 9 to 10%) under different drying methods. One of the common pre-treatments applied for turmeric rhizome is boiling of 2.5 cm sliced turmeric with 1 cm width, and another is boiling of whole Turmeric with normal water for nearly about 45 min to 1 h till the fingers became soft [14]. The sample handled was 4 kg for both boiled and un-boiled samples. Out of that, 2 kg of Turmeric was cut into 2.5 cm length and the remaining 2 kg was treated as a whole finger for both boiled and unboiled samples. The experiments were designed to study the effect of three drying conditions prevailing under sun drying, hot air oven drying and fluidized bed drying methods on drying of Turmeric under control (unboiled) and pre-treated (boiled).

### 2.3. Methods of Drying

#### 2.3.1. Sun Drying

In the sun drying methods, a few drying plates were selected and turmeric slices and whole pieces were spread during April with at least 10 h of sunshine and around 65–70% RH in such a way that a through-flow of air was allowed. The plates were completely cleaned, and the samples were spread uniformly. Rhizomes were turned over after regular intervals of one hour for a constant drying rate. All necessary observations were made from the samples at every one-hour interval, up to the 4th hour, and finally when dried up to desired level (safe moisture content 9 to 10%).

#### 2.3.2. Hot Air Oven Drying

Hot air ovens are electrical devices that use dry heat to sterilize. The oven was kept running for 15 min initially to raise the temperature gradually and to reach the desired level (about 50 °C). Then, the whole and sliced turmeric samples were spread inside the oven over wire meshes for uniform drying with periodic removal of moisture.

#### 2.3.3. Fluidized Bed Drying

Both the boiled and unboiled turmeric samples (1 kg of sample per treatment with batches of 300 g at a time) were kept inside the fluidizing chamber (Constant Displacement System; Kilburn Engineering Ltd., Kalyan, India). The drying temperature was set at the desired level (around 40 °C) by adjusting the thermostat. Airflow rate (4.5 m/s) at the inlet and outlet was measured by means of an anemometer (model: 24-6111, producer: Kanomax, Inc., Osaka, Japan). Temperature and relative humidity of the ambient, as well as the outlet of the dryer, were measured periodically and recorded (Table 1) as follows:

**Table 1.** Time, air flow rate (m/s), drying air temperature (°C) and relative humidity (%) during the experiment.

Sl No.	Time (min)	Air Flow Rate (m/s)	Drying Air Temperature (°C)	Relative Humidity (RH %), Approx.
1	315	4.0	36	35–60
2	315	4.0	36	35–60
3	315	4.5	36	35–60
4	315	4.0	36	35–60

### 2.4. Methods of Analysis

#### 2.4.1. Moisture Content

The moisture content of samples was recorded using a moisture analyzer (Contech Instruments Ltd., Mumbai, India) at a regular interval of time. It was an evaporative type of moisture balance directly displaying moisture content of the sample being tested. Observations were recorded till displayed values became constant. To measure the moisture content, the turmeric was cut into very thin slices by knife keeping the weight of the thin slices to be 2 to 2.5 g afterward, a halogen radiator (model: GLEN HA7017HL; producer: Glen, Noida,

India) was heated and the sample was dried while the integrated balance of the moisture analyzer continually recording the sample weight and, finally the moisture content.

#### 2.4.2. Color Analysis

Color is an important quality parameter for dried turmeric powder. With the use of a colorimeter (MSEZ-4500L, Hunter Lab, Reston, VA, USA),  $L^*$ ,  $a^*$  and  $b^*$  values of dried and fresh turmeric samples were classified based on the readings that are realized at random positions on the surfaces of turmeric samples. The colorimeter was calibrated against standard white plate ( $L^* = 91.78$ ,  $a^* = -0.28$ ,  $b^* = 0.07$ ) before the sample measurement. Other parameters such as total color difference ( $\Delta E$ ), Browning index (BI), Chroma (C) and Hue angle(H) are derived from Hunter color parameter. The Chroma value indicates the degree of saturation of color and is proportional to the strength of color. The Hue angle is another parameter frequently used to characterize the color of food products. An angle of  $0^\circ$  or  $360^\circ$  represents red hue, while  $90^\circ$ ,  $180^\circ$  and  $270^\circ$  represent yellow, green and blue hues, respectively. Throughout the experiment, before every color determination, white-black plates were used for calibration of the colorimeter. First of all, a glass cell that contains a sample was disposed above the light source that is near the nose cone of the colorimeter, and then the initial and final  $L^*$ ,  $a^*$  and  $b^*$  values were saved. Equations (1)–(3) were used to calculate the above parameters [15].

$$C = \sqrt{a^2 + b^2} \quad (1)$$

$$H = \tan^{-1}(b/a) \quad (2)$$

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad (3)$$

where,  $L_0$ ,  $a_0$  and  $b_0$  refer to the Hunter color parameters of fresh turmeric sample.  $L$ ,  $a$ , and  $b$  refer to the Hunter color parameters of the dried turmeric samples.

#### 2.4.3. Texture Analysis

The instrumental Texture Profile Analysis of the hardness of the dried samples was measured using a Texture Analyzer (Make: TATX plus Texture Analyzer, stable Micro systems, Godalming, UK). It was analyzed by measuring peak force (g) (force required to puncture the sample) when the 60 mm diameter cylinder acrylic probe lubricated with silicon was punctured, and the sample was measured with a computer software program attached to the analyzer. Typical settings of the analyzer for measuring the texture of the Turmeric for compression test were pre-test speed (1.0 mm/s), test speed (2.0 mm/s), post-test speed (10.0 mm/s), trigger force (7.0 g), distance (5.0 mm) and Probe (P/75), respectively.

#### 2.4.4. Quality Analysis

##### 1. Curcumin Content

The polyphenolic content of turmeric rhizome, extracted as an orange-yellow crystalline substance, with a green fluorescence is known as curcumin,  $C_{21}H_{20}O_6$  having a melting point of 184 to 185 °C was isolated as early as 1815 [16]. It is insoluble in water but soluble in ethanol and acetone. Curcumin is the product obtained by solvent extraction of ground turmeric rhizome and purification of the extract by crystallization. Curcumin content in rhizome of *Curcuma longa* L. was determined by solvent extraction followed by spectrophotometer method as per formulae (Equation (4)):

$$\% \text{curcumin} = \frac{A_{425} \times \text{Dilution factor} \times 100}{0.42 \times \text{Weight of sample}} \quad (4)$$

where  $A_{425}$  = absorbance of sample at 425 nm; Dilution factor =  $2/10 = 0.2$ .

## 2. Oleoresin Content

Column extraction apparatus was used for extraction of turmeric oleoresin from dried turmeric powder. Ethanol was used as solvent for the extraction of turmeric oleoresin. Then the extracted oleoresin is calculated by using the formulae (Equation (5)) by Blandón Navarro and Ponce Arévalo [17].

$$\text{Oleoresin content (\%)} = \frac{\text{Weight of oleoresin (g)}}{\text{Weight of sample (g)}} \times 100 \quad (5)$$

where: Weight of oleoresin =  $(W_2 - W_1)$  g;  $W_1$  = Weight of beaker with turmeric oleoresin content;  $W_2$  = Weight of empty beaker.

### 2.5. Statistical Analysis

Statistically, analysis of variance is used to analyze the recorded data for different quality parameters during the itinerary of the research. The comparisons of significance were tested, and 5% probabilities of error difference of significant values were computed. Wherever the variance ratio was found significant, Critical Difference (CD) values at a 5% level of significance were computed for comparison among treatments with SPSS software v.20.0.

## 3. Theory

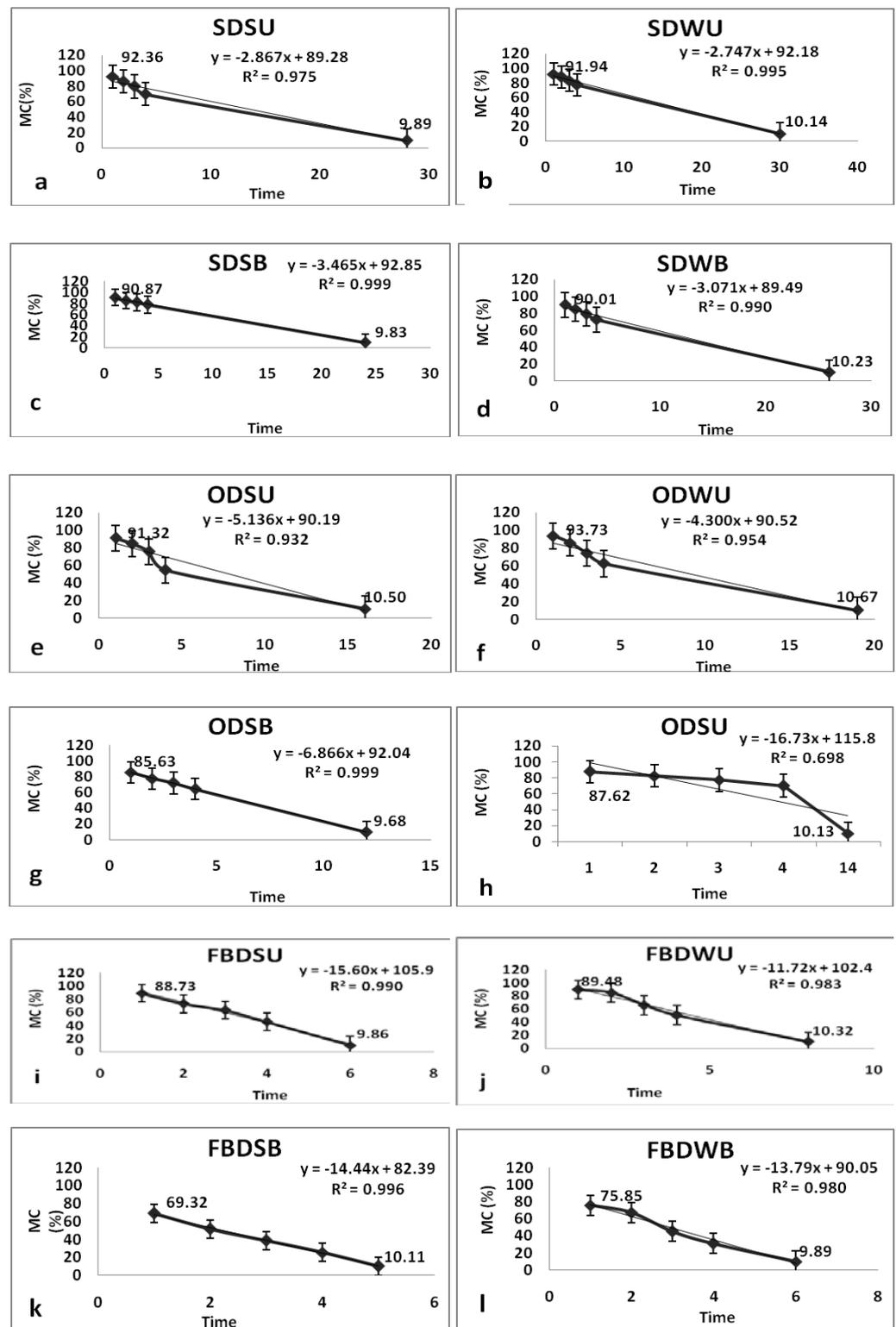
The study evaluates the consequence of different pretreatments (boiling or no boiling, slice or whole) and drying methods (sun drying, hot air oven drying and fluidized bed drying) on moisture, color, texture as well as the quality parameters (curcumin, oleoresin) of dried turmeric rhizomes.

## 4. Results

### 4.1. Moisture Content

The initial moisture content of the fresh turmeric samples was on average 93%. Drying was carried out to reduce the moisture content of samples to nearly about 9 to 10%. There was a decreasing trend in moisture content (from 92.36% to 69.79% in sundry sliced unboiled, from 91.94% to 77.51% in sundry whole unboiled, from 90.87% to 78.20% in sundry sliced boiled and from 90.01% to 72.47% in sundry whole boiled; from 91.32% to 54.91% in oven-dry unboiled slices, from 93.73% to 62.91% in oven-dry unboiled whole, from 85.63% to 64.42% in oven dry boiled slices and from 87.62% to 70.21% in oven dry boiled whole; from 88.73% to 45.59% in fluidized bed dry unboiled slices, from 89.48% to 50.61% in fluidized bed dry boiled whole, from 69.32% to 25.56% in fluidized bed dry boiled slices and from 75.85% to 31.21% in fluidized bed dry boiled whole) during the first four hours.

It is evident from Figure 1 that moisture content was strongly and significantly associated with drying time in different drying methods. The coefficient of determination ( $R^2$ ) values was greater than 0.99 in all drying treatments irrespective of whole and slices as well as boiled and unboiled except in sundry sliced unboiled ( $R^2 = 0.9758$ ), oven-dry slice unboiled ( $R^2 = 0.9323$ ), oven-dry whole unboiled ( $R^2 = 0.9543$ ), fluidized bed dry whole unboiled ( $R^2 = 0.9837$ ) and fluidized bed dry whole boiled ( $R^2 = 0.9808$ ). The corresponding  $R^2$  values in all the treatments were observed with typical curves depicting excellent association with moisture content with time.



**Figure 1.** (a–l): Variation in moisture content of Turmeric with drying time. (SDSB: Sun Dry Slice Boiled, SDWU: Sundry whole unboiled, SDSU: Sundry sliced unboiled, SDWB: Sundry whole boiled, ODSB: Oven dry sliced boiled, ODSU: Oven dry sliced unboiled, ODWB: Oven dry whole boiled, ODWU: Oven dry whole unboiled, FBDSB: Fluidized bed dry sliced boiled, FBDSU: Fluidized bed dry sliced unboiled, FBDWB: Fluidized bed dry whole boiled, FBDWU: Fluidized bed dry whole unboiled).

4.2. Color

The color parameter ( $L^*$ ,  $a^*$  and  $b^*$  values) was presented after the first, second, third, fourth and the final hours of drying for both turmeric whole and slices under boiled and unboiled pre-treatments. In general, a gradual decreasing trend was observed in  $L^*$ ,  $a^*$  and  $b^*$  color values during three drying methods for both boiled and unboiled sliced turmeric.

The color parameters ( $L^*$ ,  $a^*$  and  $b^*$ ) of raw, sun-dried, oven-dried and fluidized bed dried as obtained from the Hunter Lab colorimeter are shown in the graphs (Figure 2). The Chroma value indicates the degree of saturation of color and is proportional to the strength of color. The Hue angle characterized the color of turmeric. Total color change in dried turmeric whole and slices depends on the change in  $L^*$ ,  $a^*$  and  $b^*$  values during drying with the fresh ones [18].

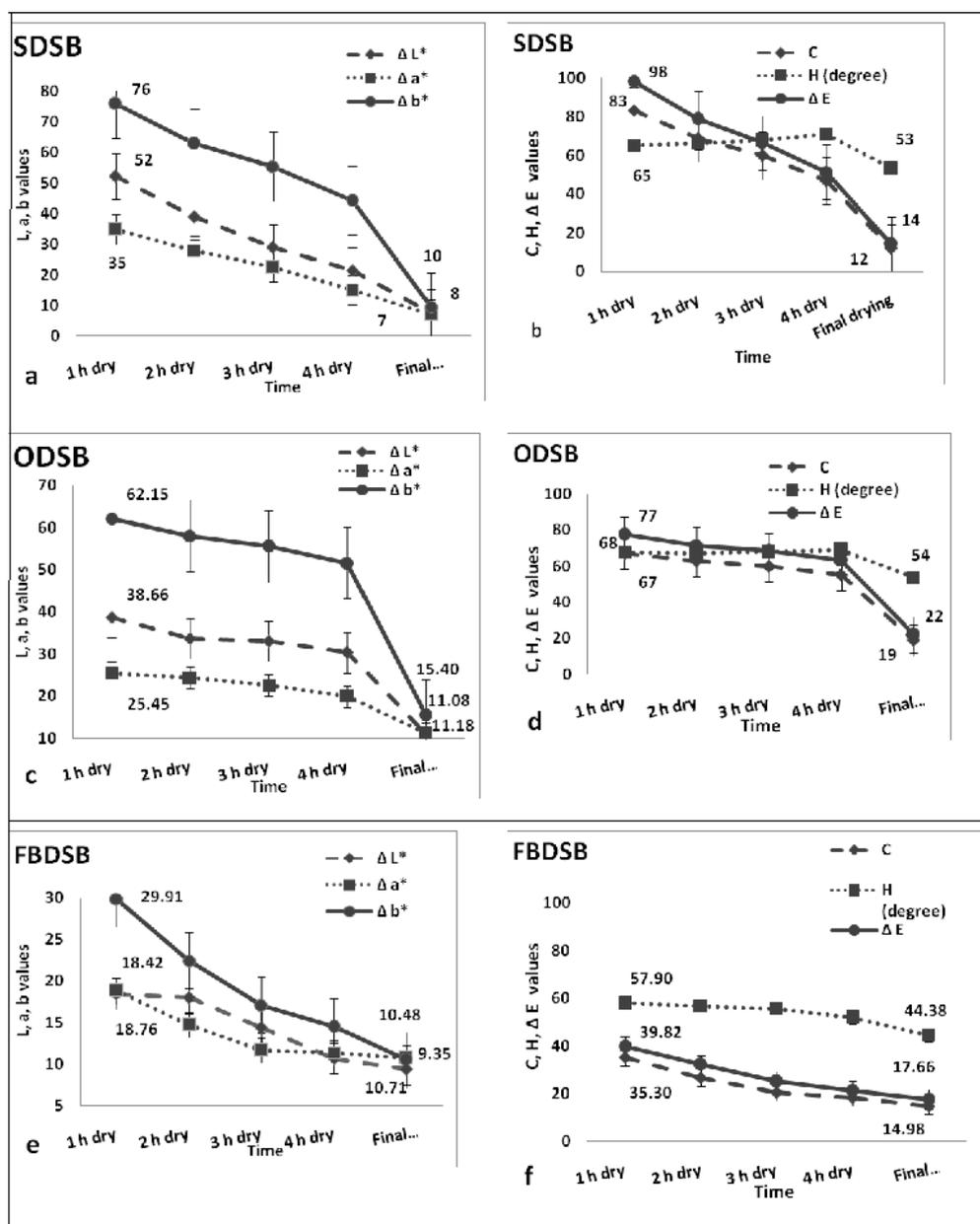


Figure 2. (a–f): Change in color values of turmeric with drying time (a):  $L^*$ ,  $a^*$ ,  $b^*$  values of sun dry sliced boiled; (b): C, H,  $\Delta E$  values of sun dry sliced boiled. (c):  $L^*$ ,  $a^*$ ,  $b^*$  values of oven dry sliced boiled; (d): C, H,  $\Delta E$  values of oven dry sliced boiled. (e):  $L^*$ ,  $a^*$ ,  $b^*$  values of fluidized bed dry sliced boiled; (f): C, H,  $\Delta E$  values of fluidized bed dry sliced boiled.

Out of the three drying methods, in general, the sun drying showed a declining trend of  $L^*$ ,  $a^*$ , and  $b^*$  values with drying time. Whereas a slower rate of decrease in  $L^*$ ,  $a^*$  and  $b^*$  values was predominant in the oven-dry method. Interestingly, in the fluidized method, almost static  $L^*$ ,  $a^*$  and  $b^*$  values were measured at 3 h of drying onwards after a declining trend of those values. A significant effect of the drying methods was observed in the color values of Turmeric. The hot air-drying method culminated in less red color (lower  $a^*$  value) and a darker color (lower  $L^*$  value) as against the combined microwave vacuum drying. However, this drying method yielded a higher yellow color value [8].

In the case of sun and oven drying, the hue angle reached its peak at the fourth hour of drying, then gradually declined until final drying. However, for fluidized bed drying, it had a continuous declining trend for other parameters such as chroma and total color change; there was a sharp decreasing trend throughout. Mahayotheea et al. [19] found that the drying temperature of the hot air drying did not significantly affect the color parameters. They also observed C values of dried ginger to be lower than those of fresh samples, where much lower  $b^*$  and C values were recorded for the sun-dried and solar-dried samples. The dried samples from the solar dryer were still slightly yellower compared to those from sun drying, particularly on the underside of the slice due to increased degradation of curcumin.

#### 4.3. Texture

Turmeric samples were evaluated for textural properties by Texture Analyzer, and the force required to crush or rupture the sample flakes was taken as the index of texture. The initial texture of the fresh turmeric samples was 21.22 kg for sliced Turmeric and 23.87 kg for whole Turmeric, respectively. It was observed that for sun drying, including boiled and unboiled, the average time requirement ranged between 24 and 30 h. For oven drying as well as fluidized bed drying, the time requirement ranged between 12 to 19 h and 5 to 8 h, respectively.

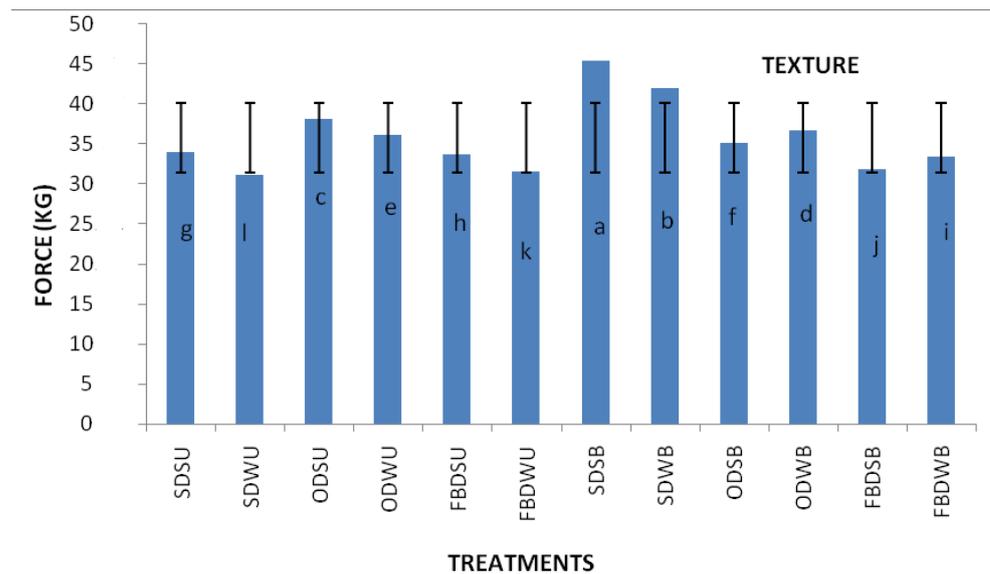
There was a decreasing trend in texture (from 28.5 to 18.8 kg in sundry unboiled slices, from 29.6 to 25.9 kg in sundry unboiled whole, from 25.3 to 17.4 kg in sundry boiled slices and from 27.5 to 17.2 kg in sundry boiled whole; from 45.3 to 14.7 kg in oven-dry unboiled slices, from 42.1 to 23.8 kg in oven-dry unboiled whole, from 23.4 to 12.7 kg in oven-dry boiled slices and from 23.7 to 15 kg in oven-dry boiled whole; from 25 to 11.5 kg in fluidized bed dry unboiled slices, from 30 to 7 kg in fluidized bed dry unboiled whole, from 24.9 to 10.8 kg in fluidized bed dry boiled slices and from 20.5 to 8.3 kg in fluidized bed dry boiled whole) during the first four hours of drying. However, at the final stage of drying (when the moisture content was about 9 to 10%), an increasing trend was also recorded during both pre-treatments, which was represented by the highest peak force indicating more uniform drying among others.

Textural properties of dried Turmeric from all three drying methods were studied in terms of crushing strength. It was observed that Turmeric dried in the fluidized bed dry unboiled whole required the minimum force (29.71 kg) compared to all other drying treatments, indicating controlled and uniform drying in comparison to the other methods where drying was either more severe or non-uniform. It was evident that boiled and unboiled fluidized bed drying produced samples that required the smallest peak force under curves (Figure 3). This comparative study on peak forces among the treatments was complete. It was observed that Turmeric dried in sundry sliced boiled required the maximum peak force (45.40 kg), which was an indication of achieving maximum uniform drying among all.

#### 4.4. Bioactive Compounds of Dried Turmeric

##### 4.4.1. Curcumin Content

It is evident from Table 2 that the curcumin content of dried Turmeric from all three drying methods was studied. It was observed that Turmeric dried in sundry whole boiled produced the maximum curcumin content (5.823%), which is an indication of achieving good quality powdered product among all other drying treatments. Whereas minimum curcumin content resulted from fluidized bed dry whole boiled drying (4.523%).



**Figure 3.** Textural changes in Turmeric with methods of drying. All values are Mean  $\pm$  S D ( $n = 3$ ). The whiskers denote the corresponding SDs. Lowercase letters inside the bars indicate significant differences among the treatments ( $p \leq 0.05$ ). SDSB: Sun Dry Slice Boiled, SDWB: Sun dry whole boiled, SDSU: Sun dry sliced unboiled, SDWU: Sun dry whole unboiled, ODSB: Oven dry sliced boiled, ODSU: Oven dry sliced unboiled, ODWB: Oven dry whole boiled, ODWU: Oven dry whole unboiled, FBDSB: Fluidized bed dry sliced boiled, FBDSU: Fluidized bed dry sliced unboiled, FBDWB: Fluidized bed dry whole boiled, FBDWU: Fluidized bed dry whole unboiled.

**Table 2.** Curcumin and oleoresin content of turmeric obtained with different drying methods.

Treatment	Curcumin Content (%)	Oleoresin Content (%)
SDSU	5.57 <sup>e</sup> $\pm$ 0.079	7.82 <sup>c</sup> $\pm$ 0.115
SDWU	5.60 <sup>d</sup> $\pm$ 0.066	7.70 <sup>d</sup> $\pm$ 0.093
ODSU	5.20 <sup>g</sup> $\pm$ 0.060	7.40 <sup>f</sup> $\pm$ 0.085
ODWU	5.07 <sup>h</sup> $\pm$ 0.119	7.52 <sup>e</sup> $\pm$ 0.179
FBDSU	4.90 <sup>i</sup> $\pm$ 0.012	6.43 <sup>h</sup> $\pm$ 0.015
FBDWU	4.87 <sup>j</sup> $\pm$ 0.058	6.24 <sup>i</sup> $\pm$ 0.072
SDSB	5.72 <sup>b</sup> $\pm$ 0.099	8.10 <sup>a</sup> $\pm$ 0.142
SDWB	5.82 <sup>a</sup> $\pm$ 0.083	7.96 <sup>b</sup> $\pm$ 0.113
ODSB	5.66 <sup>c</sup> $\pm$ 0.143	7.51 <sup>e</sup> $\pm$ 0.187
ODWB	5.36 <sup>f</sup> $\pm$ 0.126	7.28 <sup>g</sup> $\pm$ 0.173
FBDSB	4.78 <sup>k</sup> $\pm$ 0.144	5.89 <sup>j</sup> $\pm$ 0.180
FBDWB	4.52 <sup>l</sup> $\pm$ 0.033	5.50 <sup>k</sup> $\pm$ 0.045
SEm $\pm$	0.07	0.10
CD (0.05)	0.21	0.29

Data are expressed as mean  $\pm$  SD ( $n = 3$ ). Lowercase superscripted letters with respective mean values indicate significant differences among the treatments ( $p \leq 0.05$ ). (SDSU: Sun dry sliced unboiled, SDWU: Sun dry whole unboiled, ODSU: Oven dry sliced unboiled, ODWU: Oven dry whole unboiled, FBDSU: Fluidized bed dry sliced unboiled, FBDWU: Fluidized bed dry whole unboiled, SDSB: Sun Dry Slice Boiled, SDWB: Sun dry whole boiled, ODSB: Oven dry sliced boiled, ODWB: Oven dry whole boiled, FBDSB: Fluidized bed dry sliced boiled, FBDWB: Fluidized bed dry whole boiled).

#### 4.4.2. Oleoresin Content

The Oleoresin content of dried Turmeric from all three drying methods was recorded. It was observed that sundry sliced boiled Turmeric produced the maximum oleoresin (8.10%), achieving a good quality powdered product among all other drying treatments (Table 2). Whereas the minimum oleoresin content resulted from fluidized bed dry whole boiled drying (5.50%). It is evident that boiled and unboiled fluidized bed drying produced samples yielded low oleoresin compared to both sun and oven-dried samples. Jayashree and Zachariah [20] also obtained higher oleoresin content in whole boiled Turmeric compared to sliced turmeric. It is evident from Table 1 that boiled samples of Turmeric produced higher oleoresin content (avg. 7.04%) than unboiled (avg. 7.19%). This result agrees with Nithya et al. [21], who also found that un-boiled samples showed the highest oleoresin content. Padma et al. [22] observed that the oleoresin contents obtained from both boiled and uncoiled turmeric powder samples following all the drying methods were higher than the minimum limit of oleoresins of 7.00%. However, the oleoresins obtained from fluidized bed dry sliced uncoiled, fluidized bed dry whole uncoiled, fluidized bed dry slice boiled and fluidized bed dry whole boiled were 6.43%, 6.24%, 5.89% and 5.50%, respectively, which was lower than the minimum limit of oleoresins of 7.00%.

### 5. Discussion

Drying is an energy-intensive and age-old technique for agricultural products such as turmeric, for preservation as well as further processing, whereby the water activity of turmeric is lowered to a level below which deterioration does not occur for a definite duration [23]. Moreover, escalated prices and a crisis of fossil fuels have increased the emphasis on using alternative renewable energy sources such as sun drying [24]. It is evident from the study that moisture content was strongly and significantly associated with drying time in different drying methods. Bakry et al. [25] also found that the moisture content of tomato decreased with increasing drying period for all drying systems. They also indicated that the shorter drying period (4 h) under the oven drying system was due to the higher temperature (65 °C) and lower relative humidity (10%). The trend of these results agreed with those obtained by Khater et al. [26] and Khater and Bahnasawy [27]. For the color parameter (L, a, and b values) for both turmeric whole and slices under boiled and unboiled pre-treatments, a gradual decreasing trend was observed in L, a, and b color values during three drying methods for both boiled and unboiled sliced turmeric. There was a decreasing trend in texture. It is also indicative that the dried turmeric would require minimum energy during size reduction operations [22]. This might be due to the fact that turmeric rhizomes have less fiber, unlike ginger. However, turmeric dried in the IDS developed by Borah et al. [28] required maximum peak force (8789.006 g) and minimum positive area under the curve (1,0745.264 g/s). As turmeric is generally used in powdered form, the products from sun-drying sliced boiled would be more suitable for grinding. According to Jayashree and Zachariah [20], boiled and unboiled fluidized bed drying produced samples that required low curcumin content compared to both sun and oven drying. So far as the boiling pretreatment was concerned, Charoenchai et al. [13] found no significant difference in curcumin content between boiled and unboiled samples. Higher retention of curcumin was observed in samples boiled after slicing. According to Tonnesen and Carlsen, the presence of alkalis at a higher temperature after boiling could favor the development of ferulic acid and Diferuloylmethane [29]. Part of the Diferuloylmethane was partially formed during alkali degradation and led to condensation reactions resulting in compounds of yellow to yellow-brownish color, affecting the spectrophotometric determination of curcuminoid pigment. Kifelew et al. [30]. The authors reported mean oleoresin yields ranging from 6% to 7.53%. Jayashree et al. [31] reported variations in oleoresin yield from turmeric samples due to differences in the curing treatment. Deterioration of curcumin content at a higher temperature and longer drying time was observed by Saetan et al. [32]. Some studies confirmed the thermal degradation of curcumin at high temperatures in the form of blanching followed by sun drying [33],

indicating the synergetic effect of curing and drying methods on the perceived color of turmeric. Thereby, the findings of this study can help the turmeric growers and primary processors to select an appropriate treatment for meeting the quality requirements of the pharmaceutical and food industries.

## 6. Conclusions

It can be inferred that boiled and unboiled sliced turmeric samples of 2.5 cm in size showed a considerable reduction in drying time. When all the methods of drying are compared together, sun drying required more time to produce the dried sample (moisture content between 9 and 10%) with good amounts of curcumin and oleoresin content. Whereas hot air oven drying required less time than sun drying and resulted in a comparatively good quality product as expressed by enhanced curcumin and oleoresin content. The fluidized bed drying required the shortest time among others and due to the faster drying, the quality of turmeric deteriorated, resulting in reduced curcumin and oleoresin content. Considering all these aspects, it is recommended that the sun drying of turmeric with boiling and slicing as pre-treatments should be followed in post-harvest processing, as it gives an attractive quality powdered product with comparatively more curcumin, despite it taking a longer time to dry. However, further refinement of the study is advocated.

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