International Journal of Applied And Pure Science and Agriculture
e- ISSN: 2394-5532 p- ISSN: 2394-823X
Scientific Journal Impact Factor: 3.762

Influence of blanching and drying methods on the quality characteristics of fresh turmeric (*Curcuma longa* l.) Rhizomes

K. Pradeep[1], R. Ravi[2], JamunaPrakash[3] and M. Madhava Naidu[4]
[1,3]*Department of Food Science & Nutrition, University of Mysore, Karnataka, India*
[2]*Department of Sensory Science, CSIR-CFTRI, Mysore, Karnataka, India*
[4]*Department of Spice and Flavour Science,CSIR-CFTRI, Mysore, Karnataka, India*
CSIR-Central Food Technological Research Institute, Mysore-570020, India
Corresponding author: M. Madhava Naidu

Abstract
Different drying methods were investigated for dehydration of turmeric rhizomes (Curcuma longa L.) for getting good colour and quality. Sun drying normal [SDN, 30-37°C and 30-35% relative humidity (RH)], sun drying coupled with black surface (SDB, 38-60°C and 28-31% RH), hot air (HA, 50±2°C and 58-63% RH), and low humidity air (LHA, 50°C and 28-30% RH) were explored for their drying efficiency of turmeric rhizomes. The quality of unblanched sliced rhizomes dried under HA was superior based onphysico-chemical and CIE colour. SDB was energy efficient due to faster drying. Turmeric oil from blanched and unblanched rhizomes consisted of tumerone, 61.54 and 62.91%; curlone, 27.77 and 25.35%; and cyclohexane, 1.73 and 1.32%, respectively. The HPLC of turmeric oleoresin had curcumin 81.7%, and its analogues de-methoxy curcumin, 12.9% and bis-demethoxy curcumin 5.4%. Among all treatments,hot air dried, unblanched samples were superior followed by SDB drying which was energy efficient. The results of these findings can be exploited by using large quantity of turmeric thus creating or saving huge amount of economy during agricultural practices.

Key words
Sundrying, hot air drier, low humidity drier, blanching, curcumin, volatile oils

I. INTRODUCTION

Turmeric is the “golden spice”, and valuable cash crop, native to Southern tropical Asia. It is rich in phenolic compounds, curcuminoids, and is widely used as a dietary spice and coloring agent in food, herbal, medicine and textile industries (Ravindranet al.,2007). Turmeric rhizomes are cured and dried before use and for storage. Curing is essentially a process of boiling (cooking) of raw rhizomes in water till the bulbs become soft(Blascoet al.,2006). Cooking gives the rhizomes (or bulbs) a uniform colour; the starch gets gelatinized, and the time of drying is considerably reduced. Cooked turmeric rhizomes are spread on prepared yards and dried in the sun for 20-23 days, when it produces a metallic sound when shaken or while breaking. The dried turmeric rhizomes (dry yield 20-25%) are polished either manually or by mechanical aberration of the surface. Mechanical polishing drums are available for small or large batches of rhizomes (Govindarajan,1980). During 2011-2012, India produced 1.167 milliontons of turmeric and exported 185,000 tons valued at11,850million Rupees (Spice Board India, 2013). Major part of the turmeric produced in India is consumed locally. It is used as raw whole, cured-dried (cooking in excess of water and dried under shade) rhizome, ground powder, or an oleoresin. Turmeric powder is stored in bulk in containers such as fibre board drums, multi-wall bags and tin containers in which moisture absorption and light exposure is blocked by suitably lined or coated layers so that flavour and colour are prevented(Sasikumar,2001).

Turmeric has a carbohydrate content of 63-65%, protein, 5-6%, crude fibre, 4.3% and minerals, 2.7%. Curcuminoids in turmeric powder generally comprise of curcumin (70-75%), de methoxy curcumin (18-20%) and bisdemethoxycurcumin (7-10%) (Naidu et al.,2009). The pigment curcumin is industrially produced using turmeric oleoresin as the starting material. There are many reports published indicating the pharmacological properties of turmeric including anti-inflammatory (Nita Chainani-Wu,2003) anti-microbial (Arutselviet al.,2012) antioxidant (Menon and Sudheer2007), anti-mutagenic(Jayaprakashaet al.,2002) and anti-cancer(Bar-Selaet al.,2010) whereas curcumin specifically is used as a nutraceutical (Joe et al.,2004).

Drying or dehydration is a method of food preservation that has been practised all over the world for centuries. Drying involves removing moisture from food; moisture gives rise to bacterial growth causing food spoilage and deterioration (Ute Schweiggertet al.,2007). Various drying methods or sources of drying are employed to dry different food produce and each method has advantages and limitations. Traditionally, indigenously farmerssun dryturmeric rhizomes on mud floors, etc. Sun drying is easy under hot climates in tropical countries, the cost is low and technology is simple. However, the limitations include weather-dependence and requiring long processing time (up to 15 days) and the rhizomes which get infested, are not accepted by the processing industry and exporters.

Kumar et al.,(2000) evaluated the effect of different processing techniques on the recovery of total curcuminoids. However, not much work has been done on mechanical drying of turmeric. In order to investigate the potential of preservation of turmeric by mechanical drying.

Sampathu et al.,(1988) dried turmeric by sun drying and mechanical drying and reported that better colour retention was in mechanically dried uncooked slices compared to conventionally cooked and sun dried turmeric. Krishnamurthy et al.,(1975) and Chandramouli and Murthy (1987) designed a solar cabinet dryer for drying turmeric which took 29 h to reach safe moisture level compared to 64 h taken by traditional sun drying. Haribabu and Anand (1996) developed a tray dryer, which used agriculture waste as heating material that dry cooked rhizomes of turmeric in 58 h to reach safe moisture level compared to 169 h needed by open yard sun drying.

An improved drying is therefore essential to lower the moisture content which takes minimum time without affecting the quality parameters such as colour, flavour, and microbial quality. To achieve this goal present investigation was undertaken to make best use of sunlight to study the effect of different drying techniques including sun drying, sun drying coupled with black surface, hot air drying and low humidity air drying on the quality features of turmeric. Additionally, the effect of blanching and treating rhizomes either in whole or sliced forms for drying was also studied.

II. MATERIALS AND METHODS

Plant Material

Mature fresh turmeric (*Curcuma longa* L.) rhizomes were procured from Mysore local,(Karnataka, India) whichwas harvested eight months after planting. The turmeric samples were cleaned thoroughly in water and surface air dried and stored at 4^{o} C until used for experiments.

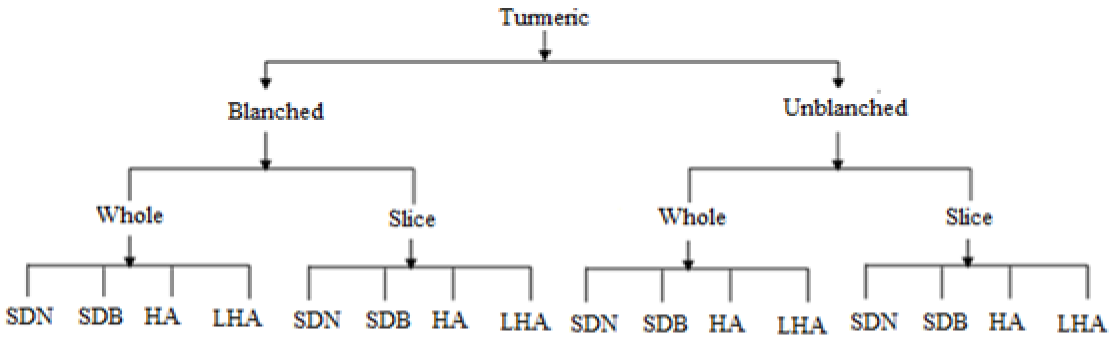
Chemicals

Curcumin from Sigma (St.Louis, MO, USA) and all other chemicals used were of analytical grade obtained from Merck (Darmstadt, Germany).

Turmeric processing

The washed and dried rhizomes were divided into four lots of 2 kg each. The lots were processed on distinct consecutive days. Each lot was divided into four smaller lots (500g), consisting of (a) blanched whole rhizome, (b) blanched slices, (c) unblanched whole rhizome, and (d) unblanched slices. Blanching treatment consisted of cooking of rhizomes in boiling water (material to water ratio 1:2) for 20 min. From this, four lots were sliced longitudinally with 2-3mm thickness and subjected to drying experiments.

A pictorial representation of sample division for different treatments is provided below for clarity.



- SDN - Sun drying normal
- SDB - Sun drying on black surface
- HA – Hot air drier
- LHA- Low humidity drier

In all there were 16 treatments.

Drying methods

About500g of turmeric (1.08 kg/m^2) were used for each treatment and the material was spread on a single layer on the stainless steel trays of the drier. The drying temperature selected for each drying method was based on the product quality as well as time required for drying. The following dryers were used in the study and experiment wasreplicated twice.

Sun drying normal (SDN)

Sun drying normal [SDN, 30-37°C and 35-40% relative humidity (RH)] is a low cost and simple method. It is fully weather-dependent and required long processing time of up to 25 days when the rhizomes are prone to infestation, which may lower the quality.

Sun drying coupled with black surface (SDB)

Sun drying with black surface (SDB 38-50°C and 30-35% RH) sample is spread on a black surface (black coloured polyvinyl chloride sheets, 3' X 4') and exposed to sun. The initial temperature was 35°C, which went upto 45°C later.

Hot air drier (HA)

Through flow air (Velocity 1.3m/sec) dryer (Ms. Armstrong Smith, India) with temperature controller was used. Drying was carried out at 55°±2°C and 58-63% RH and dried to 10% moisture content (Singhet al.,2010).

Low humidity air drier (LHA)

Through flow air (Velocity 1.3 m/sec) dryer (Alpha, India) fitted with a dehumidifier (Bry air, India) having a regenerative desiccant bed for reducing the humidity of inlet air. Air temperature and RH were maintained at 50±2°C and 28-30%, respectively.

Thin layer drying models

Mathematical modelling of the drying process is very useful in design and optimization of dryers. Numerous empirical and semi empirical models have been proposed to describe the drying behaviour of agricultural products Li, et al., (1997). Modelling of a thin layer drying of foods under constant drying conditions has been reported. The three widely employed thin layer models are Exponential Jayas, et al., (1990), Page Li et al., (1997),and Modified Page Patri, (1991) and these were tested for their suitability (Equations 1 to 3).

$$MR = \exp(-kt) \qquad \text{eq. 1}$$

$$MR = \exp(-kt^{n}) \qquad \text{eq. 2}$$

$$MR = k\exp(-t/d^{2})^{n} \qquad \text{eq. 3}$$

MR is moisture ratio = $\frac{W-W_e}{W_0-W_e}$ wherein, W, W_e, and W_0 are moisture content at any given time 't', equilibrium moisture content and initial moisture content, respectively,
t is time in min, 'k' and 'n' are model constants, d is the thickness of sample.

Effective diffusivity

Assuming that the initial moisture distribution is uniform at t=0 and the shrinkage of material does not significantly alter the product shape, the analytical solution of Fick's diffusion equation (Crank, 1975) for slab is given as

$$\frac{W - W_e}{W_o - W_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left\{-(2n+1)^2\pi^2\frac{Dt}{4L^2}\right\} \qquad \text{eq. 4}$$

Wherein 'D' is effective diffusion coefficient, 'L' is the thickness of sample.
The above equation was used for the estimation of effective diffusivity. For long drying time experiments, a limiting form of the above equation can be obtained considering only the first (n=1) term of the series and expressed in a logarithmic form (Equation 5).

$$\ln\left(\frac{W - W_e}{W_o - W_e}\right) = \ln\left(\frac{8}{\pi^2}\right) - Dt\left(\frac{\pi}{2L}\right)^2 \qquad \text{eq.5}$$

For the estimation of moisture ratio, the final moisture content of the sample was considered as the equilibrium moisture content 'W_e'.

The dried rhizomes were ground and sieved by using mesh no. 36 (Endecotts Ltd, London, England). The sieved powder was packaged in polythene bags by removing the excess air before sealing and stored at room temperature (25 ± 1° C). These samples were used for further analysis.

Physico- chemical analysis

Moisture content

Moisture content was estimated by toluene co-distillation method by refluxing about 5g of the sample at the boiling point for a minimum of 2 h. (BIS1988)method no (1797-1985)involves reflux distillation of turmeric with toluene having a higher boiling point (110.6°C) and a lower specific gravity than water. The refluxed water settles and gets collected in the moisture trap while toluene floats in a graduated tube, which is measured by volume.

Curcumin content

Sample was prepared as per the standard method of American Spice Trade Association, (ASTA1988) with the exception of grinding to pass U.S.40 mesh. Curcumin sample of 0.25g (M/S Sigma Chemicals, USA, 95% purity) was weighed and dissolved in acetone and transferred to 100mlvolumetric flask, further dilution as required was carried out with acetone and mixed. Test sample was prepared in similar way. Absorbance was recorded at 420 nm in a UV-VIS 1800 Shimadzu Spectrophotometer, (Kyoto, Japan). Curcumin content was estimated in test sample in relation to the standard.

Colour measurement

Turmeric rhizomes dried by various drying methods were subjected to colour measurement by the method of (Hunt, 1991). The change of colour was measured using a Konica Minolta Spectrophotometer following CIE colour parameters, where 'L*' represents the lightness index (0 indicates black while 100 for white), 'a*' represents red-green, while 'b*' represents yellow-blue colour components. The instrument was calibrated using a standard white (L*= 90.70, a*= -1.08, b*= 0.65) and blank reference tile with illuminant D65 and view angle 10^o. Chroma indicates the purity of the colour or hue as measured along an axis. Hue angle visualizes how an average person sees the colour.

Extraction of volatile oil

The essential oil content of turmeric was determined by the modified Clevenger's distillation method and its aromatic principles were determined by gas chromatography. Known quantity of turmeric was weighed, blended with distilled water (1:2 w/v) and taken in a 2500 ml round bottom flask. Adequate amount of water was added to make up the volume and 2-3 drops of anti-foaming agent or boiling chips were added. A continuous flow of water was maintained and the temperature was set to 100°C. The distillation was carried out for 4-5 h for the isolation of volatile oil. The collected oil was dried by adding anhydrous sodium sulphate to remove excess water (Sayyad and Chaudhari2010).

Volatile oil analysis by gas chromatography

Turmeric oil extracted by Clevenger's distillation method was diluted with acetone (1:20) and subjected to gas chromatographic analysis using a GC-14B (Shimadzu, Kyoto, Japan) coupled with chromatopac data processor and equipped with flame ionization detector. The conditions used for GC-MS analysis were as follows -

Model	:	GC 17A QP 5000 (Shimadzu, Japan)
Column Temperature	:	40^o (2^o/min) to 150^oC (4^oC/min) to 225^o (10′)
Column Type	:	Capillary SPB -1 Supelco
Carrier gas	:	Helium, rate of flow 1.3ml/min
Ion Source	:	Electron Ionization
Mass Analyser (Filter)	:	Quadrupole mass filters
Detector	:	Photomultiplayer

A 1.0 µl sample was injected to obtain the flavor profile. The injection port and the detector temperature were 230^oC and 250^oC, respectively.

Curcumin analysis by HPLC method

The curcuminoids were quantified using high performance liquid chromatography equipped with 2487 dual UV vis absorbance detector set at a sensitivity of 0.01 AUFS, and a wavelength of 425 nm with the data processed by Clarity Lite software (Prague, The Czech Republic) fitted with a reverse phase SS Exsil amino column (4.6 X 250 mm, 5µm) with an isocratic system as per the method outlined by (Naidu etal.,2009).

Oleoresin extraction

Solvent extraction / percolation method was used for the preparation of oleoresin (materials to solvent ratio 1:10). About 25g powdered turmeric embedded in cotton bed were placed in a column, below which a volumetric flask (250 ml) was kept to collect the extract. A 50 ml solvent was first added to the column followed by another 25 ml after every hour until the extraction reached 250 ml. The extract was transferred to a dried pre-weighed round bottom flask and the solvent was evaporated from the oleoresin using a rotary vacuum evaporator (BuchiRotavapor) at 22 bar pressure. The difference in weight is the oleoresin content.

III. RESULTS AND DISCUSSION

Although, the drying temperature was less with HA and LHA, the drying time (350 min) was not significantly high as compared to hot air drying (360 min) at 55°C. The lower humidity of air are responsible for effectively removing moisture from turmeric slices at lower temperature in the case of sun drying with black surface and LHA drying, respectively. Low temperature drying is expected to improve the product quality, and the present study indicated that this could be achieved using LHA and sun drying with black surface methods, without any significant increase in drying time. The drying rate curve plotted for LHA drying indicated predominantly a falling rate period. The average drying rate was slightly higher for LHA drier (0.23 g/h) drying as compared to hot air dryer (0.18 g/h), sun drying with black surface R (0.17 g/h) and sun drying (0.08 g/h), which is responsible for the observed variation in drying time. The drying temperature of 55°C was selected for all further analysis, keeping in view the product quality as well as time required for drying.

Table 1. Effect of drying methods and different pre-treatments on physico- chemical parameters of turmeric

Drying Techniques	Pre-treatments		Yield (%)	Moisture (%)	Curcumin (%) (d. b)	Oleoresin (%) (d. b)
SUN DRYING (NORMAL)	Unblanched	Whole	18.6 ±1.02	10.9 ±0.07	2.5 ±0.17	10.7 ±0.07
		Slice	19.3 ±0.98	10.8 ±0.14	3.4 ±0.19	10.5 ±0.21
	Blanched	Whole	17.0 ±0.89	06.9 ±0.07	3.8 ±0.06	10.1 ±0.14
		Slice	17.7 ±0.99	07.9 ±0.28	4.1 ±0.17	10.2 ±0.14
SUN DRYING (BLACK SURFACE)	Unblanched	Whole	18.8 ±1.04	06.0 ±0.14	2.7 ±0.19	10.7 ±0.07
		Slice	20.2 ±1.02	10.0 ±0.21	3.9 ±0.06	10.4 ±0.07
	Blanched	Whole	17.1 ±0.97	07.9 ±0.14	3.6 ±0.19	10.2 ±0.21
		Slice	18.3 ±1.04	08.0 ±0.21	4.0 ±0.35	10.8 ±0.07
HOT AIR DRYING	Unblanched	Whole	19.3 ±1.01	07.9 ±0.35	3.7 ±0.17	10.8 ±0.07
		Slice	20.6 ±0.88	08.0 ±0.14	4.6 ±0.06	10.8 ±0.07
	Blanched	Whole	17.5 ±0.98	09.0 ±0.21	4.1 ±0.35	10.9 ±0.07
		Slice	18.9 ±1.00	08.0 ±0.35	4.1 ±0.19	10.8 ±0.14
LOW HUMIDITY DRYING	Unblanched	Whole	20.6 ±0.91	10.0 ±0.28	4.0 ±0.17	10.6 ±0.07
		Slice	19.9 ±1.03	07.9 ±0.14	4.2 ±0.06	10.8 ±0.14
	Blanched	Whole	19.9 ±1.00	04.1 ±0.49	3.6 ±0.17	10.4 ±0.07
		Slice	19.7 ±0.88	05.0 ±0.14	3.8 ±0.19	10.3 ±0.14

The results of physico-chemical analysis of turmeric samples as a function of drying techniques and blanching method is presented in Table 1. It can be observed that the moisture content was minimum

(4.16%) in LHA and maximum (10.90%) in SDN method for whole unblanched rhizomes. It is clear that the drying times for whole rhizomes and slices were 19-35 h and 4-10 h, respectively to lower the moisture content from 82% to 9% (weight basis). According to AGMARK specifications turmeric powder can contain up to ~10% moisture as higher moisture content may affect the shelf stability. Jaishree Prasad *et al.*(2006)reported that drying times for hot water treated turmeric slices and thosewithout treated slices were 36 and 42 h, respectively. Whereas in open sun drying it was 266 h for drying of the same product from moisture content of 78% (weight basis) to 9% (weight basis).The oleoresin yield from all differently pre-treated turmeric powders ranged between 10.1 and 10.9%. The variations between treatments were negligible and were not influenced by the drying methods. Similar results were reported by (Jose and Joy2009) who compared the effect of different drying methods on the quality of turmeric rhizome and reported the yield of oleoresin to be in the range of 7.8 to 12.4% in commercial, conventional and solar tunnel dried samples. Shindeetal.,(2011) reported that loss of curcumin and oleoresin in turmeric boiling is more when compared to steam cooking.olour value is contributed by curcumin, de-methoxycurcumin and bis-demethoxycurcumin. The curcumin content range was found to be from 2.5% (SDN) to 4.8% (LHA). Goyal and Korla(1993) examined the curcumin quality in four types of turmeric rhizomes during storage. Curcumin content continued to decline up to 10 months, but thereafter the change was minor. Sampathuet al.,(1988) reported that curcumin is photosensitive; hence, prolonged exposure to direct sunlight affects the quality and quantity. Other factors that influence curcumin content on curing are cooking and sun drying. Hence, traditional blanching followed by sun drying may not be advisable for improving colour quality.

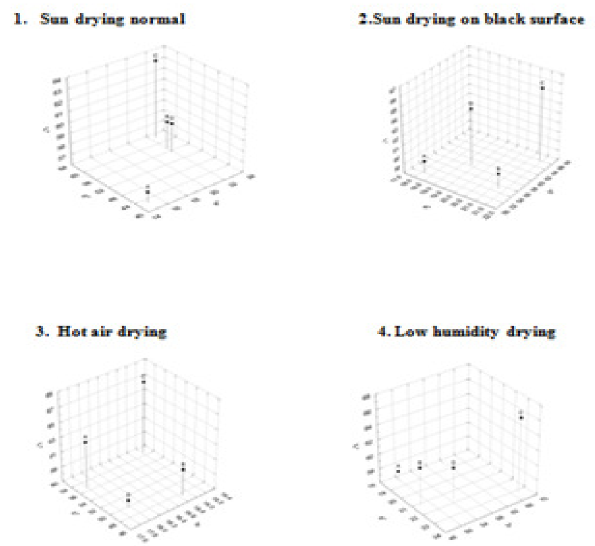
The effect of drying methods on moisture parameters of turmeric is presented in Table 2. As can be seen the initial moisture content of all samples ranged from 80.0 to 82.5%. When the samples were dried in the sun, highest temperatures were recorded at 12.00 noon for SDN (39.6^{o}C) and SDB (46.4^{o}C). For SDN, sliced samples needed a much lesser time to dry than whole rhizomes. This trend was seen for all drying methods which could be attributed to larger surface area facilitating higher evaporation rate. Blanched slices of SDN had also lesser moisture content indicating efficient drying. SDB resulted in faster drying rate for sliced samples whereas for whole rhizomes time was almost same for both sun drying methods. Drying of slices on SDB was faster compared to SDNbecause black surface absorbs and radiates more heat which enhances the drying rate of rhizomes. Mechanical drying was better than sun drying as it needs lesser time. LHA was the most efficient technology with higher rate of evaporation as shown in Fig.2.

Table 2. Effect of drying methods and different pre-treatments of turmeric on moisture parameters

Drying Techniques	Pre-treatments		Initial moisture (%)	Final moisture (%)	Drying Time (Hrs)	Rate of drying (% moisture hr^{-1})
SUN DRYING (NORMAL)	Unblanched	Whole	80.0	10.9	35	02.4
		Slice	80.0	10.8	10	08.6
	Blanched	Whole	82.5	06.9	34	02.6
		Slice	82.5	07.9	10	09.0
SUN DRYING (BLACK SURFACE)	Unblanched	Whole	80.0	06.0	35	02.6
		Slice	80.0	10.0	07	17.5
	Blanched	Whole	82.5	07.9	32	02.8
		Slice	82.5	08.0	06	18.0
	Unblanched	Whole	80.0	07.9	33	02.7

HOT AIR DRYING		Slice	80.0	08.0	06	18.0
	Blanched	Whole	82.5	09.0	22	04.0
		Slice	82.5	08.0	05	18.0
LOW HUMIDITY DRYING	Unblanched	Whole	80.0	10.0	19	04.6
		Slice	80.0	07.9	05	18.0
	Blanched	Whole	82.5	04.1	08	11.8
		Slice	82.5	05.0	04	23.4

FIG.1. CIE COLOUR PARAMETERS OF TURMERIC DRIED UNDER DIFFERENT DRYING TECHNIQUES (1) UNBLANCHED WHOLE (2) BLANCHED WHOLE (3) UNBLANCHED SLICED (4) BLANCHED SLICED



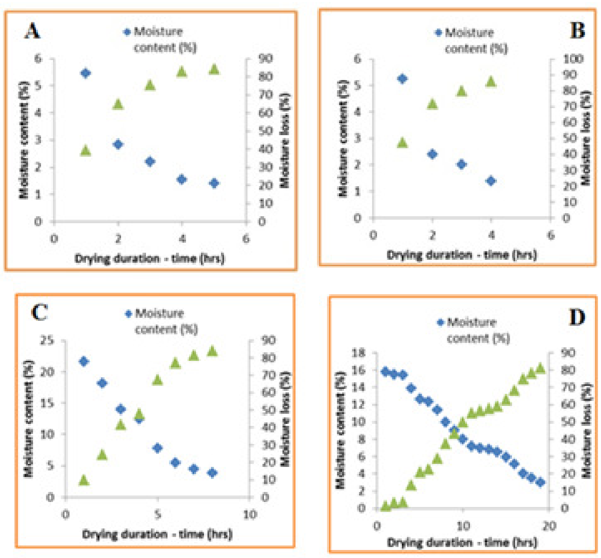


FIG. 2. MOISTURE CONTENT AND MOISTURE LOSS IN TURMERIC DRIED USING LHA DRIER

A. UNBLANCHED WHOLE ; B. BLANCHED WHOLE

C. UNBLANCHED SLICED ; D.BLANCHED SLICED

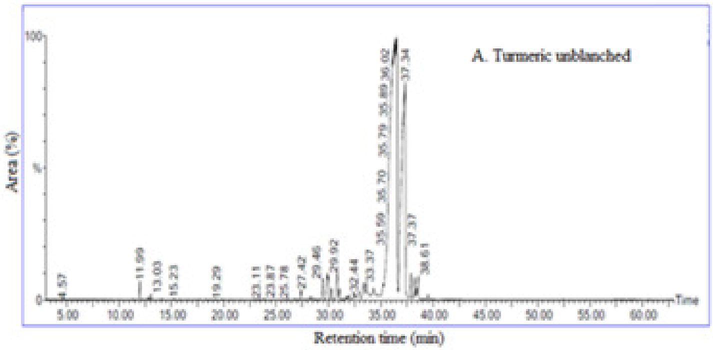
The CIE colour parameters of turmeric samples are presented in Table 3 and Fig. 1. The lightness indicated by L* values varied significantly from 57 to 66.8 indicating the influence of pre-treatments (blanched and unblanched, whole and sliced) and different drying techniques employed. Lowest lightness value was observed in unblanched whole SDN samplewhile highest L value was in sliced unblanched LHA sample. The development of whiteness is attributed to the surface dryness or loss of moisture because of thermal treatment.The redness value indicated by a* values varied from 14 to 22.74 indicating the influence of pre-treatments and drying techniques. Lowest redness value was for unblanched whole SDN sample while highest a* value was for unblanched sliced SDB samples. Yellow colour of curcumin is sensitive to ultra violet rays hence there is loss of yellowness and redness. On correlating with colour and curcumin content, the colour values were lesser in sun dried,when compared with hot air dried slices.The yellowness indicated by b* values varied statistically from 42 to 67.41 indicating the influence of pre-treatments and drying techniques. Lowest yellowness value was observed in unblanched whole SDN while highest b* value was in unblanched sliced SDB samples. In this case there was no loss of colour, hence more yellowness, unblanched sliced mechanically dried samples also showed high yellowness value and also curcumin content due to efficienthot air mechanical drying.

Table 3.CIE colour parameters

Drying technique	Pre-treatments		CIE Colour Parameters		
			L*	a*	b*
SUN DRYING (NORMAL)	Unblanched	Whole	56.98±0.42	14.92±0.90	42.85±6.00
		Slice	63.25±0.43	22.55±0.09	62.49±1.65
	Blanched	Whole	58.59±0.30	21.96±0.17	57.15±0.97
		Slice	58.74±0.06	21.87±0.12	55.51±1.57
SUN DRYING (BLACK SURFACE)	Unblanched	Whole	57.34±1.11	17.94±0.58	49.67±3.28
		Slice	66.12±0.19	22.74±0.20	67.41±1.01
	Blanched	Whole	60.97±2.12	20.58±1.29	48.12±8.04
		Slice	60.37±0.14	21.25±0.22	54.71±1.23
HOT AIR DRYING	Unblanched	Whole	59.21±2.14	18.12±0.34	52.10±2.55
		Slice	65.66±0.35	21.41±0.30	66.05±2.39
	Blanched	Whole	59.57±1.14	21.24±0.65	54.98±4.10
		Slice	63.99±1.39	19.34±0.74	58.37±4.98
LOW HUMIDITY DRYING	Unblanched	Whole	63.17±2.25	17.8±1.15	56.77±5.70
		Slice	66.86±0.97	19.22±0.57	58.61±6.07
	Blanched	Whole	60.54±1.34	18.86±0.64	47.47±3.59
		Slice	57.97±1.74	17.96±0.69	49.85±3.48

GC-MS characterization of turmeric volatiles

The volatile oils were isolated from blanched and unblanched rhizomes by conventional Clevenger's hydro distillation. Yields of volatile oil from unblanched and blanched turmeric rhizomes were 2.3% and 1.97%,respectively. Turmeric volatile oil was characterized using gas chromatography (GC) followed by MS. The major constituents of turmeric oil from unblanched and blanched are shown in Fig.3A and 3B. Unblanched turmeric oil comprised of tumerone (62.91%), Curlone (25.35%), Cyclohexane, 3-(1,5-dimethyl-4-hexenyl)-6-methylene (1.32%), 1,3-Cyclohexadiene, 5-(1,5-dimethyl-4-hexanyl)-2methyl (1.18%), Benzene,1-(1,5-dimethyl-4-hexenyl)-4-methyl(0.92%), τ-Himachalene(0.87%), Bergamotol, Z-α-trans-(0.72%), 1,5-Heptadien-4-one, 3,3,6-trimethyl-(0.71%), 1-Trimethyl-dodeca-2,4,6,10-tetraenal (0.70%), whereas in blanched turmeric oil Tumerone (61.54%), Curlone (27.77%), Cyclohexane, 3-(1,5-dimethyl-4-hexenyl)-6-methylene (1.73%), Cederen-13-ol, 8-(1.68%), 1,3-Cyclohexadiene, 5-(1,5-dimethyl-4-hexanyl)-2methyl (1.52%), Cyclohexane, (2-nitro-2-propenyl)-(0.84%), β-Himachalenoxide (0.75%), α-Phellandrene (0.66%) were present. From the GC-MS results it can be concluded that tumerones and curlones are the two major compounds found in *Curcuma longa,* which confirms the earlier reports of (Govindarajan1980). Jayprakashaet al.,(2002) reported that turmeric oil contained aromatic turmerone (31.32%), turmerone (15.08%) and curlone (9.7%), whereas fraction III had aromatic turmerone (44.5%), curlone (19.22%) and turmerone (10.88%) as major compounds.



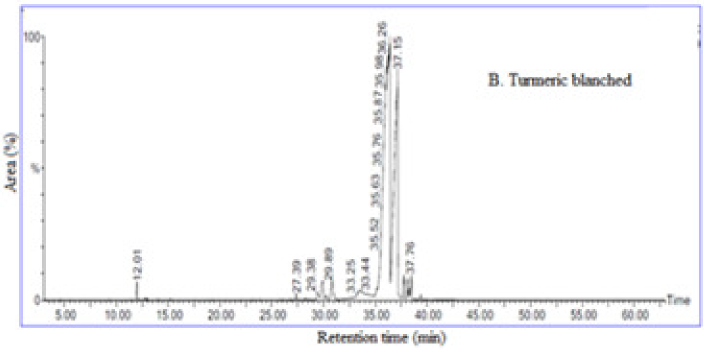


FIG. 3. GC-MS SPECTRA OF A. UNBLANCHED B. BLANCHED TURMERIC VOLATILES

HPLC profile of curcuminoids

The oleoresin obtained from turmeric powder by solvent extraction was decrystallised using iso-propanol to obtain curcumin. Curcumin was diluted with methanol and injected to HPLC. The composition of each curcuminoid (bis-methoxycurcumin, de-methoxycurcumin and curcumin) in oleoresin was quantified using HPLC and the results are shown in Fig.4A.Results revealed that curcumin, and its analogues de-methoxy curcumin (DMC) and bis-demethoxy curcumin (BDMC) are present in 81.7%, 12.9%, and 5.4%, respectivelyas shown in Fig.4B.According to(Jayaprakashaet al.,2005) isolation of pure curcumin from plant material is time consuming and pure curcumin sold in the market is a mixture of curcumin (75–81%), demethoxycurcumin (15–19%) and bis-demethoxycurcumin (2.2–6.6%).

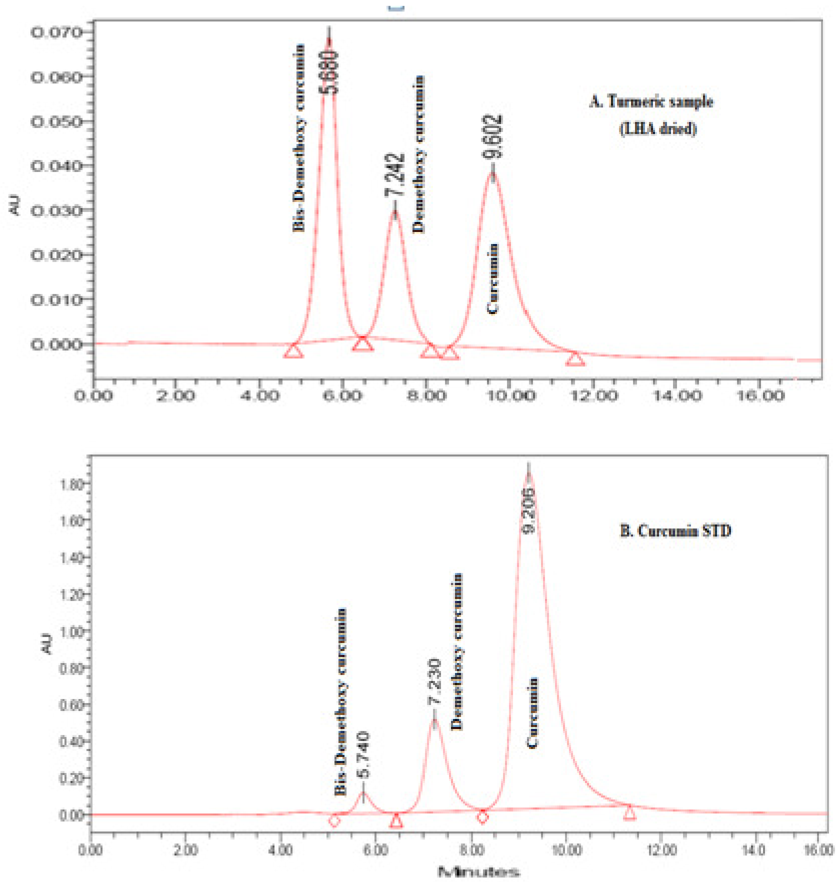


Figure :4

IV. CONCLUSIONS

Present study revealed that, Curcumin content is higher in unblanched turmeric slices dried under mechanical drying followed by black surface coupled with sun drying. Drying in the sun on black surface gave better results than normal sun drying. Hot air dried unblanched sliced turmeric is superior as per CIE colour parameters. The dried product yield of 17.1–20.6% is comparable between different dryers. Unblanched turmeric rhizomes had higher volatile oil content (2.3 ml/100g). GC-MS results of blanched and unblanched turmeric showed tumerones and curlones to be the major compounds. In both Curcumin, and its analogues de-methoxycurcumin (DMC) and bis- demethoxycurcumin (BDMC) are present in the proportion of 81.7%, 12.9%, 5.4%, respectively. Among the various pre-treatments and drying techniques studied, hot air drying of unblanched sliced was found superior based on the physico-chemical analysis but sun drying on black surface was found economical due to its faster drying rate.

V. FUNDING

The authors acknowledge the financial support from the Council of Scientific and Industrial Research (CSIR) , Govt. of India (12 th Five year Plan Project, BSC105)

VI. ACKNOWLEDGMENTS

We thank Prof. Ram Rajasekharan, Director, CSIR-CFTRI, Mysore, India, for his keen interest in this study and the facilities provided. The financial support from CSIR, New Delhi, is gratefully acknowledged.

BIBLIOGRAPHY

[1] ArutselviR, BalasaravananT, Ponmurugan P, Muthu Saranji Nand Suresh P. (2012). Phytochemical screening and comparative study of antimicrobial activity of leaves and rhizomes of turmeric varieties.*Asian Journal of Plant Science and Research*,2(2):212-219.

[2] ASTA.(1988). Method.1.0:Official Method of Analysis, American Spice Trade Association, (3rd Ed.), Englewood Cliffs,NJ, USA.

[3] Bar-Sela G, Epelbaum R and Schaffer M. (2010). Curcumin as an Anti-Cancer Agent.Review of the Gap between Basic and Clinical Applications.*Current Medicinal Chemistry*,17(3): 190-197.

[4] BIS. (1988).Bureau of Indian Standards, Methods of test for spices and condiments, New Delhi.

[5] Blasco M, Garcia-Perez JV and Bon J. (2006). Effect of Blanching and Air Flow Rate on Turmeric Drying.*Food Science and Technology International*,12:315-323.

[6] Chandramouli Gand Murthy SVBS. (1987). Design development and testing of a solar cabinet dryer for drying turmeric: B.Tech Project Report, College of Agricultural Engineering, Bapatla, India, 50.

[7] Crank, J. (1975) *The mathematics of diffusion*. Oxford: Claredon Press.

[8] Govindarajan VS.(1980). Turmeric- Chemistry, Technology and Quality.*Critical Review Food Science Nutrition*,12: 199-301.

[9] Goyal RK and Korla BN. (1993).Changes in the quality of turmeric rhizomes during storage.*Journal of Food Science Technology*, 30: 362–364.

[10] HaribabuS, and Anand A. (1996). Feasibility testing and evaluation of APAU rapid chilli drier for turmeric. Unpublished B.Tech Thesis, College of agricultural Engineering, ANGRAU University, Bapatla, India.

[11] Hunt, RWG. (1991). Measuring Colour, Ellis Horwood, New York, 2, 75-76.

[12] Jaishree Prasad VK, Vijay GN, Tiwari and Sorayan VPS. (2006). Study on performance evaluation of hybrid drier for turmeric (*Curcuma longa* L.) drying at village scale, *Journal of Food Engineering*,75: 497- 502.

[13] Jayaprakasha GK, Jagan Mohan Rao L and Sakariah KK. (2005). Chemistry and biological activities of *C. longa*. *Trends in Food Science & Technology*, 16(12): 533–548.

[14] Jayaprakasha GK, Bhabani S Jena, Pradeep S Negi and Sakariah KK. (2002). Evaluation of Antioxidant Activities and Antimutagenicity of Turmeric Oil: A By-product from Curcumin Production. *ZeitschriftfürNaturforschung C,* 57(9-10): 828–835.

[15] Jayas D.S., Cenkowski, S.,Pabis, S andMuir, W.E. (1990**).** Review of thin layer drying and wetting equations. *Drying Technology*, 9, 551-588.

[16] Joe B, Vijaykumar M and lokeshBR. 2004). Biological properties of curcumin-cellular and molecular mechanisms of action.*Critical reviews in Food Science and Nutrition*,44: 97-111.

[17] Jose KP and Joy CM. (2009). Solar tunnel drying of Turmeric for Quality Improvement.*Journal of Food Processing and Preservation*, 33: 121-135.

[18] Krishnamurthy MN, Padma Bai R, Natarajan CP and Kuppuswamy S. (1975). Colour content of turmeric varieties studies on its processing. *Journal of Food & Science Technology* India, 12(1): 12-14.

[19] Kumar VK, Vadiraj BA, Sivadasam CR and Potty SN. (2000). Post-harvest management of turmeric for higher recovery of curcumin. In: Spice and aromatic plant: Challenges and opportunities in the new century. *Centennial Conference on Spice and Aromatic Plant*, Calicut, Kerala, India, 281- 283.

[20] Li, Y., Cao, C.W. and Liu, D.Y. (1997).Simulation of recirculating circular grain dryer with temperature stage.*Drying Technology*, 15**,** 201–214.

[21] Menon VP and Sudheer AR. (2007). Antioxidant and anti-inflammatory properties of curcumin.*Adv. Exp. Med Biol*. 595: 105-25.

[22] Naidu MM, Shyamala BN,Manjunath JR, Sulochanamma G and Srinivas P. (2009). Simple HPLC method for resolution of curcuminoids with antioxidant potential.*Journal of Food Science*,74: C312-C318.

[23] NitaChainani-WU. (2003).Safety and Anti-Inflammatory Activity of Curcumin: A Component of Tumeric (*Curcuma longa). The Journal of Alternative and Complementary Medicine*,9(1): 161-168.

[24] Patri, M.(1991**).** *Evaluation of selected mathematical models for grain drying. Drying 91,* A.S. Mujumdar I. Filkova, Eds, Elsevier., Amsterdam, 369**.**

[25] Ravindran P, Babu KN and Sivaraman K. (2007).In: Turmeric: The Genus Curcuma. Ed. *CRC Press, Taylor & Francis*, Boca Raton, Florida, 1-369.

[26] Sampathu SR, Krishnamurthy N, Sowbhagya HB and Shankaranarayana ML. (1988). Studies on quality of turmeric (*Curcuma longa* L.) in relation to curing methods.*Journal of Food Science Technology,* 25: 152–155.

[27] Sasikumar B.(2001). Turmeric In: Handbook of Herbs and Spices. K.V. Peter (Ed.), Woodhead Publishing Limited, Cambridge, UK.pp 297-310.

[28] Sayyad FS and Chaudhari RS.(2010). Isolation of Volatile Oil from Some Plants of Zingiberaceae Family and Estimation of their Anti-bacterial Potential.*Journal of Current Pharmaceutical Research*, 4(1): 1-3.
[29] Shinde UG, Kailas J, Kamble, Mahesh G, Harkari and More GR. (2011). Process Optimization in Turmeric Heat Treatment by Design and Fabrication of Blancher.*International Conference on Environmental and Agriculture Engineering IPCBEE* vol.15, IACSIT Press, Singapore.
[30] Singh G, Arora S and Kumar S. (2010). Effect of mechanical drying air conditions on quality of turmeric powder.*Journal of Food Science Technology*, 47(3): 347-350.
[31] Spice Board India. (2013). Statistics.Government of India, Kochi, India.
[32] UteSchweiggert, Reinhold Carle and AndreasSchieber.(2007). Conventional and alternative processes for spice production – A review. *Trends in Food Science & Technology*, 18(5): 260-268.

