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Thermo-chemical and antioxidant properties of cryogenically ground turmeric powder

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Abstract

In present communication, thermal, chemical and antioxidant properties of turmeric powder, for cryogenically grinding conditions at different moisture contents (4%, 7%, 10%, & 13% w.b.) were investigated. Specific heat, thermal conductivity, thermal diffusivity, glass transition temperature, curcumin content, colour parameters, volatile oil, oleoresin content, total phenols and antioxidant activity in DPPH assay, of cryogenically ground turmeric powder were evaluated. Specific heat increased from 10.45 to 16.26 kJ kg-1K-1 and 10.36 to 14.22 kJ kg-1K-1 in the temperature range of -100°C to +100°C in cryo-ground and control samples of turmeric powder, respectively. The values of thermal conductivity and thermal diffusivity of control and cryo-ground turmeric powder increased from 0.051 to 0.077 W m-1K-1, 0.049 to 0.059 W m-1K-1 and 0.93×10-8 to 1.20 ×10-8 m2s-1, 1.02×10-8 to 1.08 ×10-8 m2s-1, respectively. Cryo-ground turmeric powder retained oleoresin, curcumin, phenol content and antioxidant activity, 87-90%, 76-79%, 93-95%, 84-85%, respectively.

Key words: Cryogenic grinding, curcumin, oleoresin, specific heat, turmeric.

Introduction

Turmeric (*curcuma longa* L.*),* plant of family *zingberaceae*, is native to India and Southeast Asia. India is a leading producer and exporter of turmeric in the world. It is valued principally for its yellow-orange colouring compound. It possesses an appreciable aroma and flavour which necessitates classifying it as a spice. It is directly used as a spice or colouring agent in the powder form and also for the preparation of solvent-extracted oleoresin. It is used to colour liquor, fruit drinks and cakes. It is also one of the principal ingredients of curry powder.

Thermal properties such as thermal conductivity, thermal diffusivity, and specific heat of spices and their powders are necessary for efficient design of processing equipments involving heat transfer. In agricultural materials, temperature and moisture content greatly influence the specific heat, thermal conductivity and thermal diffusivity owing to the relatively high specific heat, thermal conductivity and heat of sorption of water. Generally, the specific heat is expressed as a function of moisture content using linear relations (Mohsenin, 1980). The effect of temperature on specific heat was generally not taken into consideration in early work with agricultural materials (Tang *et al.,* 1991). Several researchers have used the methods described by Mohsenin (1980) to investigate the specific heat of food and agricultural materials. Yang *et al.* (2002) determined the specific heat of borage seed using the differential scanning calorimeter (DSC). Aviara and Haque (2001) used calibrated copper calorimeters placed inside insulated vacuum flasks to measure the specific heat of sheanut kernel. Other workers who used the method of mixtures include Deshpande and Bal (1996), Ogunjimi *et al.* (2002), Oje and Ugbor (1991), Subramanian and Viswanathan (2003) and Taiwo *et al.,* (1996) for specific heat determination.

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The transient heat flow and one dimensional steady state heat flow methods have been used in determining the thermal conductivity of food and agricultural materials. Some researchers used the line heat source thermal conductivity probe to measure the thermal conductivity such as Rahman and Potluri (1991), Fasina and Sokhansanj (1995), Taiwo *et al.* (1996), Singh and Goswani (2000), Yang *et al.,* (2002)**,** Yang *et al.,* (2003) and Subramanian and Viswanathan (2003) for squid meat, alfalfa pellets, ground cowpea, cumin seed, borage seeds, rough rice and millet grains and flours, respectively. The glass transition temperature is the temperature where the material goes from a hard, glass like state to a rubber like state. DSC describes the glass transition as a change in the heat capacity as the solidified oil goes from the glass state to the rubber like viscous state. It is a second order endothermic transition (Goula *et al.,* 2008).

The most active component of turmeric is curcumin (2 to 5% of turmeric). The medicinal properties of curcumin have been known for centuries, although the scientific basis of its actions has been investigated only over the last couple of decades. Curcumin is a potent antioxidant, anti-inflammatory, and anticancer agent and has therapeutic efficacy in numerous diseases. Turmeric is used as antioxidant, digestive, anti-microbial, anti- inflammatory and anti-carcinigenic agent (Bambirra *et al.,* 2002). There is almost no or limited published information available on thermal, chemical and antioxidant properties of turmeric powder ground at different conditions. Therefore, this study was undertaken with the objective to determine some of the major thermal, chemical and anti-oxidant properties of cryogenically and ambient ground turmeric powder.

Materials and methods

Turmeric rhizomes were procured from ICAR-Indian Institute of Spices (IISR), Kozhikode, India. The turmeric rhizomes were cleaned manually to remove undesirable material, broken into smaller pieces and passed through BSS 10 (2.034 mm opening) and 20 sieve number (0.894 mm opening). The broken retained on BSS 20 sieve was used for the present study. The initial moisture content of the broken turmeric was determined using vacuum oven drying method and found as 10.3% wet basis (w.b.). The moisture contents of the broken turmeric were tuned to 4, 7, 10 and 13% w.b. for cryogenic grinding. These samples were dried in vacuum drying oven at 72°C (recording moisture content at every 15 min interval) to achieve 4, 7 and 10% w.b. moisture. The calculated amount of distilled water (Barnwal *et al.,* 2012) was added to achieve 13% w.b. moisture content. The broken turmeric samples, dried to desired moisture content, were stored in sealed, moisture free and water proof flexible polythene bags. The samples of 13% w.b. moisture were kept at 5°C in a refrigerator for one week to allow the moisture to uniformly distribute into broken turmeric samples. The prepared samples were ground in a cryogenic grinder (Model: 100 UPZ, Hosokava Alpine, Germany) below -50°C using liquid nitrogen (LN_2) at grinder speed of 12000 rpm and 1 kg h^{-1} feed rate. Furthermore, one lot of broken turmeric rhizomes were ground at ambient conditions and had been considered as control. The control and cryogenic ground turmeric powder samples were packed in sealed, moisture free and water proof flexible polythene bags for further analysis of thermal, chemical and antioxidant properties.

Thermal properties

Specific heat (C_p, kJ kg^{-1} K^{-1}) of the control (ambient) and cryogenic ground turmeric powder (4, 7, 10 and 13% w.b. moisture) was determined by using the Differential Scanning Calorimeter (Model: DSC 6000 Perkin Elmer, USA) operated by Pyris software. Prior to experiments, DSC was calibrated using indium at scanning rate of 10°C/min. For determination of specific heat, the cryogenic ground turmeric powder samples were kept in an aluminium crucible (capacity 10 μL) in small quantity (5 -5.5mg) . The aluminium crucible was sealed and run in the DSC for the temperature range of -100°C to 300°C. The DSC provided thermogram, in which ordinate shows the heat flow rate (mW mg^{-1}) as a function of time and temperature. Specific heat and glass transition temperature (T_g) were determined from the thermogram according to the procedure given in pyris software. All experiments were performed in triplicate and the mean values were reported.

The bulk thermal conductivity was measured by using portable thermal conductivity meter (Model: KD-2 PRO, Decagon Devices, Inc. USA, and accuracy: 0.001°C). The control and cryogenic ground turmeric powders were filled into 100 ml beaker and completely tapped, then the beakers are covered using aluminium foils and stored over night in deep freezer (Model: U 410-86, New Brunswick Scientific, England) at -50°C for the conditions of below 0°C. For the higher temperature i.e. above 0°C, the powder samples were kept in recirculation type tray dryer (M/s BTPL, Kolkata, India) at 60°C for 4h. The thermal conductivity meter was calibrated with glycerine. After calibration, the powder sample was taken out from the deep freezer and immediately a single needle probe (Model: KS-1, 1.3 mm diameter × 60mm long) of thermal conductivity meter was inserted in the sample and readings were recorded at intervals of 2 minutes.

The average bulk density of control and cryogenic ground turmeric powders ground at different moisture levels, were determined by using a container of known volume. The container was weighed and weight noted down. Then container was filled with turmeric powder and total weight noted down. The subtraction of weight of container from total weight (i.e., turmeric powder and container) provided the mass of sample. Bulk density was calculated using following equation:

$$\rho_b = \frac{mass\ (kg)}{volume\ (m^3)} \qquad (1)$$

The bulk thermal diffusivity of control and cryo-ground turmeric powders was calculated from the values of bulk thermal conductivity, specific heat and bulk density of control and cryo-ground turmeric powder using following equation:

$$\alpha_b = \frac{k_b}{\rho C_p} \qquad (2)$$

where, α_b is the bulk thermal diffusivity in $m^2\ s^{-1}$, C_p is the specific heat in $kJ\ kg^{-1}\ K^{-1}$, k_b is the thermal conductivity in $W\ m^{-1}\ K^{-1}$ and ρ_b is the bulk density in $kg\ m^{-3}$.

Chemical and antioxidant properties

Volatile oil was extracted from the control and cryo-ground turmeric powder sample by hydro distillation using Clevenger apparatus lighter than water type. Oil was quantified as volume by weight percentage.

Turmeric powder with measured amount of absolute alcohol were transferred to double jacketed flasks, which was simultaneously stirred and heated using water bath (M/s Brookfield Inc., USA) at a selected temperature for a predetermined time. Absorbance of sample was taken at 425 nm using UV-spectrophotometer (Model: 1601-Shimadzu Co., Ltd., Japan) and amount of curcumin was calculated from standard curve using following equation:

Curcumin yield (%) = {Curcumin extract (g) / Turmeric used (g)}x 100 (3)

For preparation of standard curve, a stock solution was prepared by dissolving 10 mg of curcumin in absolute alcohol to get concentration of 1 mg/ml. Different concentration were made by diluting the stock solution with absolute alcohol. The absorbance was read at 425 nm and plotted against the concentration (Sogi *et al.,* 2010).

Oleoresin content of turmeric was extracted using Accelerated Solvent Extraction System (Dionex India Ltd.) with hexane as a solvent. The crude extracts in methanol, water and petroleum ether were prepared by soaking the cryogenically ground turmeric powder for overnight, extraction repeated three times and supernatants were pooled for analysis. After collecting the supernatant of all the samples, the extracts were diluted to make a stock solution of known concentration. These diluted extracts were used for determination of the total phenolic as well as antioxidant activities. Total phenol concentration was determined using a Folin-Ciocalteu assay (Amin *et al.,* 2006) with slight modification. An aliquot of 0.1ml extract (5 mg ml^{-1} in respective solvent) was taken in a test tube and made the volume 1ml by adding solvent. Three ml of 10% sodium carbonate was added. Previously

10-fold diluted Folin-Ciocalteu reagent was added to the mixture. The mixture was allowed to stand at room temperature for 90 minutes and then absorbance was measured at 710 nm. Gallic acid was used as the standard phenol. The amount of phenolic content was calculated by using the standard curve of Gallic acid prepared with respective solvent having R^2 value ranged from 0.96-0.99 and was expressed as ppm Gallic Acid Equivalent (GAE)/1000 ppm) crude seed extract.

The antioxidant activity of each extract was evaluated on the basis of its activity in scavenging the stable DPPH (1, 1-Diphenyl-2-picrylhydrazin) radical, using a slight modification of the method (Shimada *et al.,* 1992). Each extract was diluted in methanol, water and petroleum ether to give at least 5 different concentrations. An aliquot (1, 1.5, 2, 2.5 ml) of the extract of each concentration was mixed with 1 ml of 1 M DPPH. The mixture was then homogenized and left to stand for 30 min in the dark. The absorbance was measured at 517 nm against a blank of methanol using a spectrophotometer. DPPH solution plus methanol was used as control and Butyl hydroxyl toluene (BHT) was used as a standard reference synthetic antioxidant with R^2 value ranged from 0.95- 0.99. Results were expressed as a mean standard deviation from three replicate measurements. The percent scavenging effect was calculated using following equation:

$$Scavenging\ effect\ (\%) = \frac{A_{517}\ of\ control - A_{517}\ of\ extract}{A_{517}\ of\ control} \times 100 \quad (4)$$

Colour Attributes

The colour is an important quality attribute to accept or reject the spices because it has direct appealing effect to the consumer. Colour values (i.e L, *a* and b) were determined using Hunter lab colorimeter (Model: D-65 illuminant and 10° observer). L value varies between 0 and 100. A perfectly white body has L=100 and a black body has L = 0. A positive value of '*a*' indicates the redness and negative value greenness. A positive value of 'b' indicates yellowness and negative value of b shows blueness. Yellowness index (YI) was determined as follows (Meghwal and Goswami, 2010):

$$YI = \frac{142.86b}{[} \quad (5)$$

Hue angle (h°) and Chroma (C*) were computed by using the standard formula (Singh *et al.,* 2013).

$$Hue\ angle\ (°) = \tan^{-1}\left(\frac{b}{a}\right) \quad (6)$$

$$Chroma = (a^2 + b^2)^{1/} \quad (7)$$

Statistical analysis

A two way ANOVA was performed / computed using LSD AgReS Software. The relationships existing between thermal properties and temperature of control and cryo-ground turmeric powder were established using MS-Excel 2003 software.

Results and discussion

The specific heat of control and cryo-ground turmeric powder was found to increase with increase in temperature (Fig.1). A higher value of specific heat was observed for cryo-ground sample as compared to control sample. This may be due to the fact that there is better retention of moisture and volatile oil because of inert atmosphere in cryogenic grinding (Singh and Goswami, 1999). Specific heat followed a second order polynomial relationship with temperature irrespective of grinding conditions (Table 1). Nevertheless other research workers (Tang *et al.,* 1991; Wang and Brennan, 1993) observed linear relations of specific heat with temperature for other agricultural materials. Specific heat followed a second order polynomial at all the moistures under cryogenic grinding (Table 1). Hsu *et al.* (1991) also reported non-linear correlation for pistachios. The values of specific heat increased from 10.45 to 16.26 kJ kg^{-1} K^{-1} and 10.36 to 14.22 kJ kg^{-1} K^{-1} in the temperature range of -100°C to 100°C in cryo-ground and control samples of turmeric powder, respectively. The analysis of variance for specific heat showed that grinding conditions and temperature both significantly affected the thermal conductivity at 5% level.

It can be observed from Fig. 2 that the thermal conductivity increased with temperature irrespective of the grinding conditions. However, the thermal conductivity of cryo-ground ground turmeric powder was higher than control sample of turmeric powder. This may be because of inert atmosphere in cryogenic grinding (Singh and Goswami, 1999). The thermal conductivity at given temperature followed second order polynomial relationship regardless of grinding conditions (Table 1). However, it was found that thermal conductivity increased with increase in moisture content at cryogenic grinding. The relationship was observed to be a second order polynomial for all the moisture contents. However, other research workers (Hsu *et al.,* 1991; Aviara and Haque, 2001) reported the existence of a linear relationship of thermal conductivity with moisture content for other agricultural materials. The results are in agreement with the findings of Singh and Goswami (2000) who reported thermal conductivity of cumin seed as a non-linear function of moisture content. The values of thermal conductivity increased from 0.051 to 0.077 W m^{-1} K^{-1} and 0.049 to 0.059 W m^{-1} K^{-1} in cryo-ground and control samples of turmeric powder, respectively in the temperature range of -40°C to 60°C. The analysis of variance for thermal conductivity showed that grinding conditions and temperature significantly affected the thermal conductivity at 5% level.

The thermal diffusivity of control and cryo-ground turmeric powder exhibited second order polynomial relationship with temperature (Table 1). Overall, thermal diffusivity increased from 0.93×10^{-8} to 1.20 $\times10^{-8}$ m^2 s^{-1} and 1.02×10^{-8} to 1.08×10^{-8} m^2 s^{-1} with increase in temperature from -40°C to 60°C for control and cryo-ground turmeric powder, respectively (Fig. 3). However, the relationship between thermal diffusivity (α), moisture content (M) and temperature have been reported in literature in both ascending [e.g. for gram (Dutta *et al.,* 1988)] and descending [e.g. for borage seeds (Yang *et al.,* 200) and for cumin seed (Singh and Goswami, 2000)] trends, as the magnitude of α_b depends on the combined effect of k_b, ρ_b and C_p. Nevertheless, a higher value of thermal diffusivity was found for control sample. This may be due to increased pore volume in control sample due to coarse particle size achieved in ambient grinding. The thermal diffusivity displayed quadratic relationship with moisture (Table 1). Similar trend was reported by Singh and Goswami, (2000) for cumin seeds. The analysis of variance for thermal diffusivity showed that grinding conditions and temperature significantly affected the thermal diffusivity at 5% level. It can be inferred from Fig. 4 that the magnitude of T_g decreased with an increase in moisture content at cryogenic grinding, which may be due to the plasticization effect of water. Similar prototype was detected for osmo-dried apple and pear by Mrad *et al.*, (2013).

The cryo-ground turmeric powder retained approximately 80% volatile oil irrespective of the moisture content i.e 15% higher than control sample i.e turmeric powder ground at ambient conditions (Table 2). Furthermore, the oleoresin and curcumin content showed significant increase over control sample of turmeric powder. The cryo-ground turmeric powder clutched 87-90% and 76-79% of oleoresin and curcumin content, respectively. A higher recovery of curcumin and oleoresin i.e 12-15% and 20-23% was found at cryogenic grinding irrespective of the moisture content than control sample of turmeric powder. The reason of obtaining higher volatile oil, oleoresin and curcumin content in cryogenically ground turmeric is that in normal grinding process of turmeric, due to high temperature, fat may have melted and stick on grinding surfaces. The extremely low temperature, in cryogenic grinding, solidifies oils so that the spices become brittle, crumble easily permitting grinding to a finer and more consistent size with minimum or no loss of oil during grinding process (Saxena *et al.,* 2013). Similar results have been reported by Gopalakrishnan *et al.,* (1991), Singh and Goswami (2000) and Mathew and Sreenarayan (2007) for ambient grinding of cardamom, cumin seed and black pepper, respectively. The volatile oil, oleoresin and curcumin content were significantly affected by moisture content and grinding conditions (Table 2).

It can be observed from Table 3 that the maximum values for phenols and percentage free radical scavenging was found in alcohol extract as compared to water and petroleum ether extract regardless of grinding conditions. Phenolics are quite heat unstable and reactive compounds (Cheynier, 2005) and during ambient grinding there is temperature rise leading to reduction in phenols which can be appreciably reduced in cryogenic grinding. Higher quantities of methanol crude seed extract in cryo-ground turmeric powder may be the effect of temperature on constituents of spices during grinding (Saxena *et al.,* 2013). DPPH scavenging % was invariably more in cryo-ground turmeric powder than control sample irrespective of the moisture content (Table 3). The cryo-ground turmeric retained approximately 93-95% and 84-85% total phenols and antioxidant activity respectively i.e 22% higher than control sample of ambient grinding. The enhanced retention of total phenolic content and antioxidant activity may be due to the fact that in cryogenic grinding the vaporization of liquid nitrogen to the gaseous state creates an inert and dry atmosphere which ultimate reduces the loss of quality parameters of spices (Singh and Goswami, 1999). Higher phenolic content and antioxidant activity was also found in cryo-ground coriander and fenugreek (Saxena *et al.*, 2012).

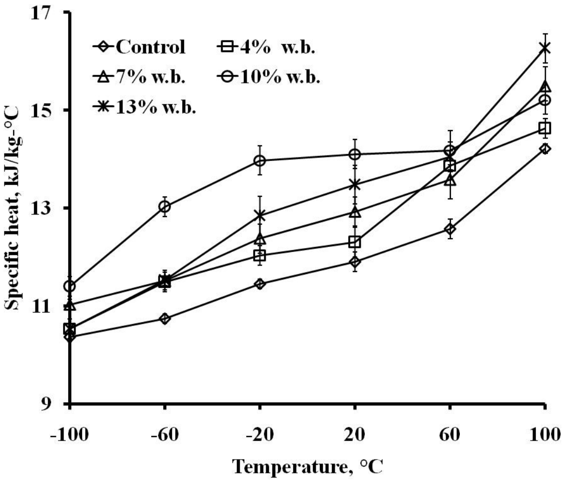

Fig.1. Effect of temperature on specific heat of control and cryo-ground turmeric powder

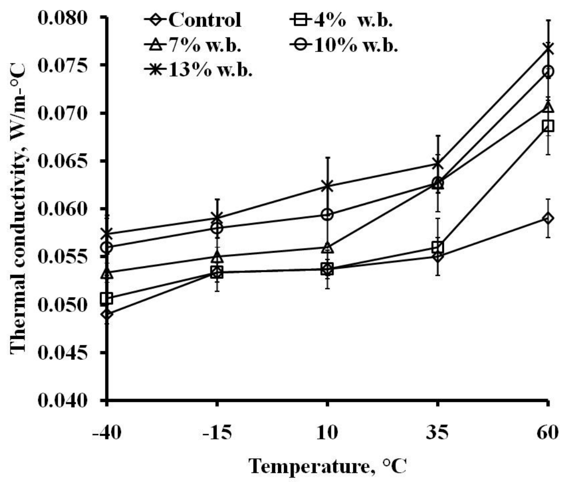

Fig. 2. Effect of temperature on thermal conductivity of control and cryo-ground turmeric powder

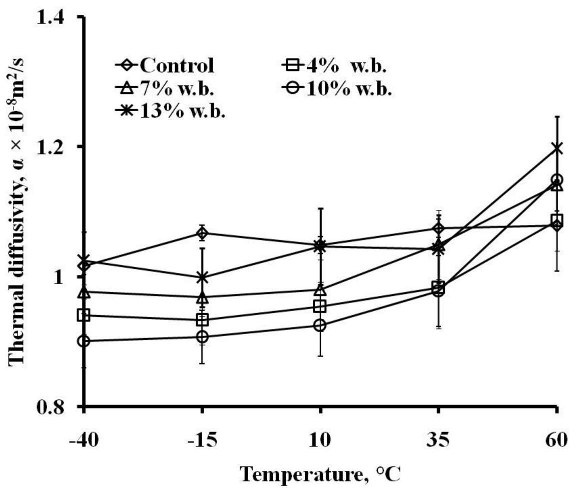

Fig. 3. Effect of temperature on thermal diffusivity of control and cryo-ground turmeric powder

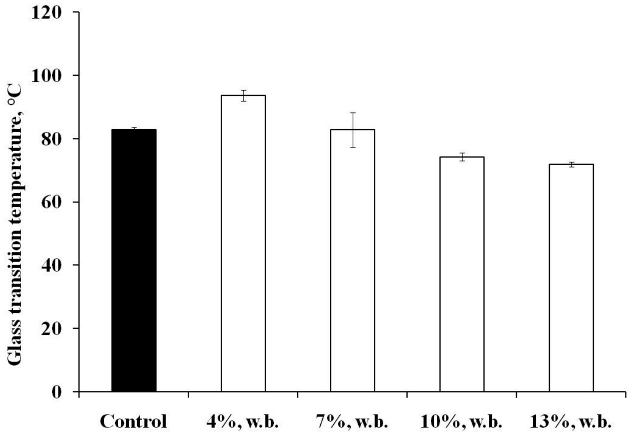

Fig. 4. Effect of grinding conditions and moisture content on glass transition temperature of turmeric powder

Table 1. Second order polynomial regression equations for prediction of thermal properties

Thermal property	Sample	Regression equation	R^2
Specific heat, C_p	Control	$C_p = 7E\text{-}05T^2 + 0.018T + 11.55$	0.980
	4% wb	$C_p = 3E\text{-}05T^2 + 0.019T + 12.31$	0.971
	7% wb	$C_p = -7E\text{-}05T^2 + 0.016T + 13.98$	0.922
	10%wb	$C_p = -7E\text{-}05T^2 + 0.016T + 13.98$	0.922
	13%wb	$C_p = 2E\text{-}05T^2 + 0.027T + 12.96$	0.966
Thermal conductivity, k_b	Control	$k_b = 0.000000T^2+0.000088T + 0.053120$	0.931
	4% wb	$k_b = 0.000003T^2 + 0.000106T + 0.050669$	0.961
	7% wb	$k_b = 0.000003T^2 + 0.000107T + 0.054474$	0.998
	10%wb	$k_b = 0.000004T^2 + 0.000110T + 0.053149$	0.988
	13%wb	$k_b = 0.000004T^2 + 0.000127T + 0.056194$	0.999
Thermal diffusivity, α_b	Control	$\alpha_b = -0.000003T^2 + 0.000551T + 1.042441$	0.704
	4% wb	$\alpha_b = 0.00004T^2 + 0.00103T + 1.08861$	0.968
	7% wb	$\alpha_b = 0.00005T^2 + 0.00076T + 1.07221$	0.968
	10%wb	$\alpha_b = 0.00007T^2 + 0.00132T + 0.83143$	0.976
	13%wb	$\alpha_b = 0.00006T^2 + 0.00075T + 0.93569$	0.987

Table 2. Effect of grinding conditions and moisture content on curcumin content, volatile oil and oleoresin content of cryo-ground turmeric powder

S.No.	Moisture content (% wb)	Curcumin (%)	Oil %	Oleoresin (%)
1	Control	4.17 ± 0.02^a	4.27 ± 0.12^a	10.12 ± 0.63^a
2	4	$4.96\pm0.03b^c$	5.20 ± 0.10^b	13.05 ± 0.03^b
3	7	$5.07\pm0.02b^d$	5.13 ± 0.06^b	13.24 ± 0.04^b
4	10	$5.17\pm0.02b^e$	5.17 ± 0.06^b	13.28 ± 0.02^b
5	13	$4.95\pm0.02b^c$	5.20 ± 0.10^b	13.55 ± 0.04^b
F-Value				
m		68.24*	0.20^{NS}	0.54^{NS}
t		19438.23*	665.33*	515.20*
CD (0.05)				
m		0.01	0.11	0.41
t		0.01	0.08	0.29

Mean values with the same superscript letters within the same column do not differ significantly (p > 0.05)

Table 3. Effect of grinding conditions and moisture content on DPPH Scavenging % and phenol content in alcohol, water and petroleum ether extract of turmeric powder

S.No	Moisture content (% wb)	DPPH (%)			Phenol content (%)		
		Alcohol	Water	Petroleum ether	Alcohol	Water	Petroleum ether
1	Control	63.14±0.48[a]	54.16±0.04[a]	31.14±0.18[a]	1.54±0.06[a]	0.57±0.02[a]	0.24±0.01[a]
2	4	84.17±0.02[bc]	72.10±0.07[bc]	40.13±0.03[bc]	2.03±0.01[be]	0.45±0.02[b]	0.21±0.16[b]
3	7	84.50±0.05[bcd]	72.31±0.08[bd]	40.17±0.02[bc]	2.08±0.01[bc]	0.56±0.03[ab]	0.30±0.01[b]
4	10	84.88±0.06[bd]	72.48±0.04[be]	40.28±0.02[bc]	2.11±0.01[bc]	0.70±0.01[bd]	0.31±0.01[b]
5	13	85.35±0.03[be]	72.57±0.03[bf]	40.58±0.21[bd]	2.24±0.01[bd]	0.83±0.10[be]	0.33±0.02[b]
F-Value							
m		6.30*	57.76*	5.54*	10.43*	157.30*	1.30[NS]
t		45351.25*	18128.6*	44011.61*	1679.78*	90.19*	5.43*
CD (0.05)							
m		0.30	0.04	0.13	0.04	0.01	0.06
t		0.21	0.02	0.09	0.03	0.01	0.04

Mean values with the same superscript letters within the same column do not differ significantly (p > 0.05)

Table 4. Effect of grinding conditions and moisture content on colour parameters of turmeric powder

S. No	Moisture content (%, wb)	L-value	a-value	b-value	*Hue,°*	*Chroma*	*Yellowness index*
1	Control	52.64±0.78 [a]	17.70±0.73	33.35±0.74[a]	62.04±1.51[a]	37.76±0.32[a]	90.51±2.06[a]
2	4	53.86±0.75 [b]	18.52±0.60	36.65±0.61[b]	63.20±0.38[b]	41.07±0.81[b]	97.24±2.72[b]
3	7	54.27±1.04 [b]	18.25±0.21	36.69±0.88[b]	63.55±0.47[b]	40.98±0.84[b]	96.63±4.11[b]
4	10	54.76±1.17 [b]	17.39±0.83	36.29±0.44[b]	64.40±1.09[b]	40.24±0.55[b]	94.68±1.47[b]
5	13	55.09±0.34 [b]	18.06±0.86	36.65±1.22[b]	63.78±0.48[b]	40.86±1.45[b]	95.06±3.64[b]
F-value							
m		0.79[NS]	0.68[NS]	0.23[NS]	0.37[NS]	0.71[NS]	0.66[NS]
t		37.11*	1.50[NS]	266.53*	17.09*	190.56*	51.33*
CD(0.05)							
m		0.92	0.88	0.59	1.24	0.66	2.28
t		0.65	0.62	0.42	0.88	0.47	1.61

Mean values with the same superscript letters within the same column do not differ significantly (p > 0.05)

In control (ambient) samples, lower values of L, *a* and yellowness index were found indicating a dark coloured powder which lost its brightness (Table 4). On the hand, in cryogenic grinding, a light and vivid powder obtained due to preservation of brightness and natural lust of powder despite of the moisture content (Meghwal and Goswami, 2010). The L, b, hue, chroma and yellowness index were found to be varied significantly with the grinding conditions (Table 4).

Conclusions

Thermal, chemical, and antioxidant properties of cryo-ground turmeric powder such as specific heat, thermal conductivity, thermal diffusivity, glass transition temperature, *L, a, b,* yellowness index, hue , chroma, volatile oil, curcumin and oleoresin content, total phenols and antioxidant activity varied significantly with the grinding conditions, whereas colour parameter, *a* value varied non significantly with grinding conditions. The specific heat, thermal conductivity and thermal diffusivity followed second order polynomial relationship with temperature and moisture. The variation of glass transition temperature with moisture may be best represented in quadratic manner. The cryo-ground turmeric powder retained almost 80-95% chemical properties indicating that the cryo-grinding of spices retains the chemical and anti-oxidant properties irrespective of the moisture content.

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