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Note

Selected physico-mechanical characteristics of cryogenic and ambient ground turmeric

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A b s t r a c t. In this communication, selected physico-mechanical characteristics of ground turmeric (*cv.* Prabha) were investigated for cryogenic and ambient grinding conditions of turmeric at different moisture contents (4, 6, 8 and 10% w.b.). A cryogenic grinder (Model: 100 UPZ, Hosokawa Alpine, Germany) and a micro pulverizer (hammer mill) were used for cryogenic and ambient grinding, respectively. The ground turmeric was graded in three grades viz. Gr-I, Gr-II and Gr-III with a sieve shaker using BSS Nos. 40, 85 and pan, respectively. Tap densities for cryogenic and ambient ground turmeric decreased from 678.7 (Gr-I) to 546.7 kg m^{-3} (Gr-III) and from 642.3 (Gr-I) to 468.6 kg m^{-3} (Gr-III), respectively, with the moisture increase. The angle of repose for cryogenic and ambient ground turmeric increased linearly from 26.85 (Gr-I) to 34.0° (Gr-III) and from 23.10 (Gr-I) to 28.06° (Gr-III), respectively with the increase in moisture content. The static coefficient of friction was the highest on plywood surface followed by mild steel sheet and galvanized iron sheet. The cryo-ground samples were found better in colour. Thermal conductivity of cryo-ground samples was higher than that of ambient ground samples. These physico-mechanical characteristics of cryogenic and ambient ground turmeric will be helpful for packaging, handling, and storage.

K e y w o r d s: turmeric, physical characteristics, frictional characteristics, cryogenic grinding, ambient grinding

INTRODUCTION

Turmeric (*Curcuma longa* L.), a plant of the family Zingberaceae, is native to India and Southeast Asia. It is valued principally for its yellow-orange colouring compound and 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 ground form and also for the preparation of solvent-extracted oleoresin. It is used to colour liquor, fruit drinks, and cakes. It is used as an antioxidant, digestive, anti-microbial, anti-inflammatory, and anti-carcinogenic agent (Bambirra *et al*., 2002).

Physical characteristics of food materials play a crucial role in design of the equipment for post-harvest operations. Bulk density is useful for designing the material handling and separation equipment. Several researchers have studied and reported the moisture-dependent physical and mechanical properties *eg* dimensions, geometric mean diameter, sphericity, bulk density, true density, porosity, angle of repose, coefficient of friction, rupture force, deformation and energy absorbed (Davies, 2010; Altuntas *et al*., 2005; Yurtlu *et al*., 2010). Coskuner and Karababa (2007) reported the some physical properties of coriander seeds at different moisture contents from 7.10 to 18.94% (d.b.) and they observed that bulk density decreased but true density, angle of repose, coefficient of friction, increased with the increase in moisture content.

Generally, the mechanical process of grinding is used for size reduction or producing ground turmeric. In the ambient grinding process, temperature of the powder raises to as high as 90-95°C resulting in losses of essential oils, aroma, and colour *ie* deterioration of its quality. The concept of the cryogenic grinding technique is widely employed to retain the quality *eg* volatile oil, flavour, and colour of spices (Singh and Goswami, 2000).

The physical characteristics of food powder materials are greatly affected by their moisture content and grinding conditions. Therefore, in the present study, the physico-mechanical characteristics of cryogenic and ambient ground turmeric (*cv*. Prabha) *eg* bulk density, tap density, angle of repose, static coefficient of friction, colour, and thermal

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conductivity have been investigated to study the effect of grinding conditions and different grades of the ground turmeric which will be helpful for handling, packaging, and transport.

MATERIAL AND METHODS

Turmeric rhizomes (*cv*. Prabha), procured from Indian Institute of Spices (IISR), Calicut, India, were cleaned manually and undesired materials namely broken, foreign matter, split and deformed seeds were discarded before the samples were prepared for the experiment.

The initial moisture content of turmeric rhizomes was determined with the hot air oven method at 105°C (AOAC, 1984) and found as 8.09% w.b. The turmeric rhizome was conditioned for different moisture content levels (4, 6, 8, and 10% w.b. moisture content). The rhizomes were dried in a tray dryer at 45°C temperature for 1.5 and 1h to reduce their original weight as per reduced weight calculated by the standard formula and the sample was kept in a dessicator for 1 h before the experiment. The desired quantity of distilled water to be added, or moisture to be evaporated (seed to be dried), was calculated (Barnwal *et al*., 2010; Chakraverty, 1988) and conditioned accordingly. The samples were allowed to equilibrate at room temperature prior to experimentation.

Initially, the size of the turmeric rhizomes were reduced manually and graded using sieves BSS No. 6 and 10. The turmeric sample, retained between BSS No. 6 and 10, was used for cryogenic grinding in a cryogenic grinder (Model: 100 UPZ, Hosokawa Alpine, Germany) for cryogenic conditions (below -50°C) using liquid nitrogen (LN_2) at grinder speed of 10,000 r.p.m. and 1 kg h^{-1} feed rate. The ambient grinding was done in a hammer mill. Thus obtained ground turmeric samples from both conditions were graded into three grades (Gr-I, Gr-II and Gr-III) with a sieve shaker using BSS No. 40, 85 and pan, respectively. The experiments were conducted in triplicates.

Bulk density (Deshpande *et al*., 1993) was determined in triplicates using the standard method (Singh and Goswami, 1996). Tap density was determined in triplicates by filling a measuring cylinder of 10 ml with ground turmeric, tapping until no further decrease in the volume was noticed, and weighing the sample. True density was determined using a gas (nitrogen) pycnometer (Model 2: Hymipyc and make IQI, USA). Before starting the experiment, the pycnometer was calibrated using a calibration kit and a standard volume of the steel ball having 1.0725 cc. After calibration, the weighed ground turmeric samples were placed in a sample chamber for determination of true density. Porosity was computed using the established formula (Singh *et al*., 2004).

To determine the angle of repose (θ), the sample was fed in a tapering hopper having a dimension of 250 × 250 mm from top with a bottom hole of 20 × 20 mm. At 210 mm from the bottom of the hopper, a circular disc of 100 mm diameter was placed on which the ground turmeric fell by sudden release of a horizontal sliding gate at the bottom of the hopper. The angle of repose was calculated from the height and diameter of the naturally formed heap of the ground turmeric samples on a circular plate (Kaleemullah and Gunaseker, 2002; Sahoo and Srivastava, 2002). The static coefficient of friction (μ) of ground turmeric was determined on three structural surfaces: plywood, galvanized iron, and mild steel sheet, using a laboratory set up according to Jha (1999). The experiments were replicated 3 times and the average values were reported.

The colour of the ground turmeric was measured using Hunter Lab labScan XE (Hunter Associates laboratory Inc., Reston, Virginia, USA) in terms of lightness (L*), redness (a*), and yellowness (b*) which varies from 0 to 100. The colourimeter (HunterLab labScan XE) was calibrated using black and white tiles along with the transparent pouch containing sample. The sample in the pouch was then placed at the light port and the colour was measured in four replications in terms of L*, a* and b*and SD of this value was also calculated. The hue angle and chroma value were computed using standard relations (Mridula *et al*., 2010).

Thermal conductivity of ground turmeric samples were measured with a thermal conductivity meter (Model No.: KD2 Pro, M/s Decagon Devices Inc. USA), which was calibrated with glycerin prior to the experiments. A 100 ml beaker was filled with a ground sample and tapped completely to prevent void space. The beaker was covered using aluminium foil and stored overnight in a deep freezer (U 410-86, New Brunswick Scientific, England) at -50°C. The sample from the deep freezer was immediately placed on the plate and a single needle probe (KS-1, 1.3 mm diameter × 60 mm long) was properly inserted in the sample. Readings were recorded at an interval of 5°C temperature from -35 to 25°C under room conditions. For thermal conductivity between 30 to 55°C, the samples were heated slowly using a hot plate.

Data were analyzed as per two factor analysis of variance using LSD of AgRes software statistical package pertaining to three replicates of bulk density, tap density, angle of repose, static coefficient of friction, and four replicates of colour values.

RESULTS AND DISCUSSION

The statistical analysis for bulk and tap densities of ambient and cryogenic ground turmeric (*cv*. Prabha) with moisture content and grades (CGr-I to CGr-III and AGr-I to AGr-III) are given in Table 1. The bulk and tap densities of the ambient and cryo-ground turmeric were found statistically significant for the moisture content and cryogenic and ambient ground grades of turmeric ($p < 0.01$). The bulk density ranged from 402.3 (CGr-III, 10% w.b.) to 610.0 kg m^{-3} (CGr-I, 4% w.b.) for the cryo-ground samples and from 348.3 (AGr-II, 10% w.b.) to 586.7 kg m^{-3} (AGr-I, 4% w.b.)

T a b l e 1. Bulk density, tap density, angle of repose, and static coefficient of friction of different grades of the ground turmeric (*cv.* Prabha)

Moisture content (MC), (% w.b.)	Turmeric ground samples (G)	Bulk density (kg m^{-3})	Tap density (kg m^{-3})	Angle of repose (°)	Static coefficient of friction: Plywood	Mild steel	Galvanized iron
4	CGr-I	610.0a	678.7a	26.85	0.667	0.639	0.546
	CGr-II	448.3ef	603.3d	29.05	0.690	0.670	0.613
	CGr-III	428.7g	579.3fg	34.00	0.727	0.684	0.637
	AGr-I	586.7b	642.3c	23.10	0.803	0.708	0.685
	AGr-II	425.7gh	546.6i	23.94	0.867	0.794	0.713
	AGr-III	380.1k	499.6kl	25.84	0.883	0.806	0.787
6	CGr-I	573.7b	673.3a	27.47	0.728	0.642	0.619
	CGr-II	445.3f	593.0de	29.82	0.735	0.674	0.631
	CGr-III	421.7gh	564.7h	30.96	0.743	0.713	0.658
	AGr-I	561.3c	635.6c	23.51	0.833	0.767	0.745
	AGr-II	414.1hi	523.9j	24.38	0.889	0.808	0.796
	AGr-III	373.1kl	489.7l	26.86	0.917	0.823	0.806
8	CGr-I	487.7d	656.3b	28.66	0.746	0.667	0.629
	CGr-II	420.0gh	587.7ef	30.96	0.802	0.681	0.646
	CGr-III	419.7gh	558.0hi	32.07	0.810	0.758	0.667
	AGr-I	480.0g	583.5ef	24.58	0.850	0.804	0.794
	AGr-II	397.8dj	508.7k	27.59	0.905	0.833	0.812
	AGr-III	363.9l	476.2mn	27.05	0.921	0.844	0.820
10	CGr-I	460.7e	633.3c	29.83	0.802	0.697	0.642
	CGr-II	411.7hij	568.3gh	30.96	0.826	0.730	0.682
	CGr-III	402.3ij	546.7i	33.51	0.857	0.773	0.693
	AGr-I	445.7f	547.5i	25.01	0.873	0.820	0.809
	AGr-II	365.2e	486.7lm	25.22	0.905	0.841	0.823
	AGr-III	348.3m	468.6n	28.06	0.938	0.867	0.833
	F-value						
	MC	277.309**	136.541**	8.017**	25.516**	13.416**	27.083**
	G	714.305**	764.422**	96.969**	53.711**	45.694**	100.380**
	MC × G	30.812**	7.863**	1.252ns	1.273ns	0.484ns	1.135ns
	CD (0.05)						
	MC	5.787	5.303	0.780	0.023	0.024	0.019
	G	7.088	6.494	0.955	0.028	0.030	0.024
	MC × G	14.176	12.989	1.910	0.056	0.059	0.048

MC – moisture content, G – ground samples, CGr – cryo-ground grade, AGr – ambient ground grade, ns – non-significant; **p<0.01, mean values with the same letter are not significantly different.

for the ambient ground samples. The bulk density decreased with the increasing moisture content for both cryogenic and ambient grinding conditions for a moisture range of 4 to 10% w.b. The decreasing trend in bulk density indicates that the increase in volumetric expansion in the sample is higher than weight with the increase in moisture content (Coskuner and Karababa, 2007; Singh and Goswami, 1996). A similar decreasing trend for bulk density was reported by Bagherpour *et al*. (2010), Kibar and Öztürk (2008), and Kiani Deh Kiani *et al*. (2008) for lentil seed, soybean, and red bean grains, respectively. It is clear that tap densities for the ambient and cryogenic ground turmeric decreased from 642.3 (AGr-I, 4% w.b.) to 468.6 kg m^{-3} (AGr-III, 10% w.b.) and from 678.7 (CGr-I, 4% w.b.) to 546.7 kg m^{-3}, (CGr-III, 10% w.b.), respectively with the increase in moisture content (4 to 10% w.b.). The decreasing trend in tap density of ground turmeric with the increase in moisture content may be attributed to the higher increase in volumetric expansion than the weight.

It was observed that the true density of the cryo-ground turmeric was lower than that of ambient ground samples. This may be due to the more crisp, brittle, and finer nature of the cryo-ground turmeric. The true density ranged from 648.3 (CGr-II, 4% w.b.) to 701.2 kg m^{-3} (CGr-I, 10% w.b.) for the cryo-ground samples and from 679.2 (AGr-II, 4% w.b.) to 755.8 kg m^{-3} (AGr-I, 10% w.b.) for the ambient ground samples. The true density increased with the increasing moisture content. The increasing trend of true density may be due to the higher increase in the weight of powder in comparison to its volume expansion with the increasing moisture content (Singh and Goswami, 1996). The porosity of the cryo-ground turmeric was lower than in the ambient ground samples. This may be due to not sticky and clear particles of the cryo-ground turmeric samples. The porosity ranged from 12.04% (CGr-I, 4% w.b.) to 39.94% (CGr-III, 10% w.b.) for the cryo-ground samples and from 18.67 % (AGr-I, 4% w.b.) to 40.68% (AGr-II, 10% w.b.) for the ambient ground samples. The porosity was found to increase with the moisture increase (4 to 10% w.b.).

The statistical analysis of frictional characteristics of the ambient and cryogenic ground turmeric (*cv*. Prabha) with the moisture content and grades (CGr-I to CGr-III and AGr-I to AGr-III) are presented in Table 1. The angle of repose and static coefficient of friction were found significant for the moisture content and cryogenic and ambient ground grades ($p < 0.01$). It was observed that the angle of repose of the cryo-ground turmeric was higher than that of the ambient ground samples. This may be due to the finer nature of the cryo-ground turmeric and hence the surface area. The angle of repose for the cryogenic and ambient ground turmeric (CGr-I and AGr-I) increased between 26.85-29.83 and 23.10-25.01°, respectively with the increase in the moisture content from 4 to 10% w.b. Similar findings of increased angle of repose with an increase in the moisture content have been reported for cumin, fenugreek, and coriander seeds by Singh and Goswami (1996), Altuntas *et al*. (2005) and Coskuner and Karababa (2007), respectively. It was observed that the static coefficient of friction of the cryo-ground turmeric was lower than that of the ambient ground samples. There are several ground product factors affecting the static coefficient of friction *eg* stickiness of ground product, its fineness. The combined effect of these factors is such that the static coefficient of friction of the cryo-ground product was lower. It was observed that that the static coefficient of friction was the highest on the plywood surface followed by mild iron sheet and galvanized iron sheet surfaces, respectively. The static coefficient of friction for the ambient and cryogenic ground turmeric samples increased with the moisture increase (4-10% w.b.) for three structural surfaces namely plywood, mild steel sheet, and galvanized iron sheet. A similar increasing trend of the static coefficient of friction with increasing moisture content were reported for cumin seed, coriander seed, and wheat by Singh and Goswami (1996), Coskuner and Karababa (2007), Kheiralipour *et al*. (2008), and Karimi *et al.* (2009), respectively.

The colour values (L^*, a^*, b^*, h° and C) are shown in Table 2. The values, L^* and a^* were found non-significant, whereas b^*, $h°$, and C were found significant for moisture. The colour values were significant for the cryo-ground and ambient ground turmeric grades ($p <0.01$). The value of L^* for the cryogenically ground turmeric was higher than that for the ambient ground turmeric, which shows that it is lighter in colour than the ambient ground sample. The a^* value was lower for the cryogenically ground turmeric, which suggests that it is less reddish (dark) in colour than the ambient ground sample. Therefore, the cryo-ground samples are better in colour.

Thermal conductivity of the cryogenic and ambient turmeric powder, ground at 4, 6, 8, and 10% w.b. are shown in Fig. 1. It is clear from the figure that thermal conductivity of ground turmeric increases with increasing temperature as expected (Singh and Goswami, 2000). In some experiments (especially samples CGr), an initial decrease in thermal conductivity with a temperature increase in the range of minus temperature was observed. This is so because when the thermal conductivity meter probe was inserted inside the CGr sample due to loose bonding of the sample in the beaker, the temperatures assessed by the probe were not uniform as the probe did not touch the sample completely. Therefore there was an initial fall in temperature. It was also observed that thermal conductivity of the cryo-ground samples was higher than that of the ambient ground samples and hence more attention is needed to keep its quality by avoiding temperature exposure.

T a b l e 2. Colour quality of different grades of cryohenic ground and ambient ground turmeric (*cv*. Prabha)

Moisture content (MC) (% w.b.)	Turmeric ground samples (G)	Colour values				
		*L**	*a**	*b**	h°	*C*
4	CGr-I	54.5	18.2	34.6	62.1gh	39.1
	CGr-II	57.1	19.6	35.5	60.7h	40.7
	CGr-III	58.7	21.5	49.4	66.3cd	53.9
	AGr-I	51.7	22.6	72.5	72.3ab	76.0
	AGr-II	65.3	28.8	88.3	71.7b	93.0
	AGr-III	60.4	29.8	101.5	73.6ab	105.8
6	CGr-I	56.1	19.9	41.3	64.2efg	45.9
	CGr-II	57.4	20.7	41.0	63.0g	46.0
	CGr-III	63.6	20.4	41.8	64.0efg	46.6
	AGr-I	58.5	26.7	85.6	72.6ab	89.6
	AGr-II	58.5	27.5	94.2	73.7ab	98.1
	AGr-III	62.3	30.8	102.0	73.2ab	106.6
8	CGr-I	58.0	19.1	42.6	65.8cdef	46.7
	CGr-II	56.8	20.1	41.1	63.8fg	45.8
	CGr-III	63.3	21.3	46.5	65.3def	51.2
	AGr-I	53.2	24.6	83.2	73.4ab	86.8
	AGr-II	59.1	28.7	88.4	71.9b	93.0
	AGr-III	61.8	30.8	103.0	73.3ab	107.5
10	CGr-I	58.2	19.4	43.6	65.9cde	47.8
	CGr-II	58.5	20.7	47.6	66.4cd	51.9
	CGr-III	62.2	21.5	52.4	67.6c	56.6
	AGr-I	51.9	24.1	84.5	74.0a	87.9
	AGr-II	61.1	29.3	100.3	73.7ab	104.5
	AGr-III	60.6	30.8	101.8	73.1ab	106.4
			F-Value			
	MC	0.413ns	1.457ns	8.540**	10.465**	8.096**
	G	8.211**	118.337**	401.210**	157.726**	406.560**
	MC × G	1.066ns	1.021ns	1.708ns	2.545**	1.682ns
			CD (0.05)			
	MC	2.591	0.988	3.185	0.860	3.151
	G	3.173	1.210	3.902	1.053	3.859
	MC × G	6.347	2.421	7.803	2.107	7.717

Explanations as in Table 1.

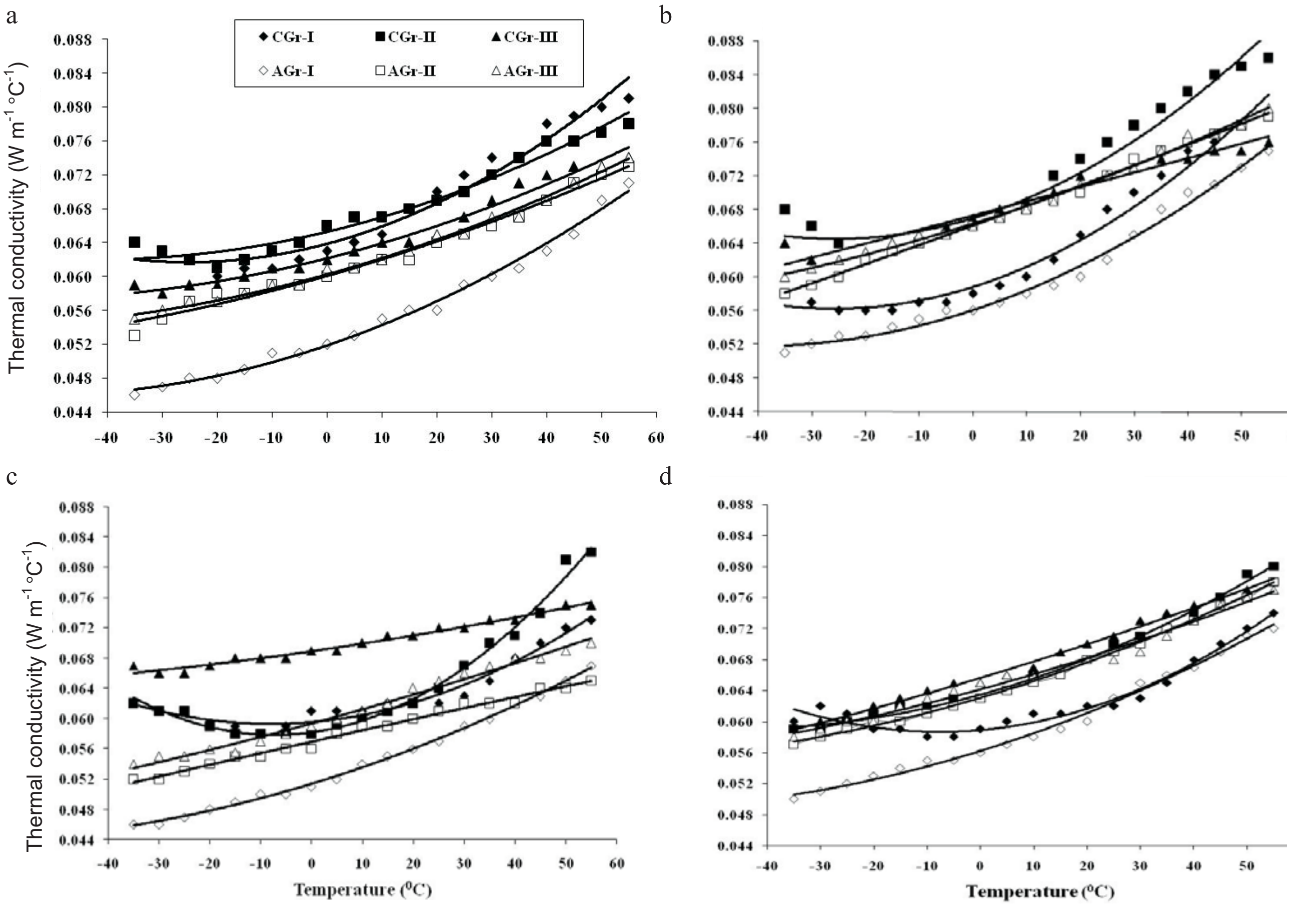

Fig. 1. Variation of thermal conductivity with temperature of cryogenically and ambient ground turmeric: a – 4, b – 6, c – 8, d – 10% w.b.

CONCLUSIONS

1. Bulk and tap densities decreased with the increasing moisture content for both cryogenic and ambient grinding conditions for a moisture range of 4 to 10% w.b.

2. True density of the cryo-ground turmeric was lower than that of the ambient ground samples and it increased with the increasing moisture content.

3. Porosity of the cryo-ground turmeric was lower than that of the ambient ground samples and it increased with the moisture increase (4-10% w.b.).

4. The angle of repose of the cryo-ground turmeric was higher than that of the ambient ground samples.

5. The static coefficient of friction for the ambient and cryogenic ground turmeric samples increased with the moisture increase (4-10% w.b.) for three structural surfaces namely plywood, mild steel sheet, and galvanized iron sheet. It was the highest on plywood surface followed by mild iron sheet and galvanized iron sheet surfaces, respectively.

6. The cryogenically ground turmeric samples were better in colour.

7. Thermal conductivity of the cryo-ground samples was higher than that of the ambient ground samples.

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