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Physical and functional properties of low temperature ground turmeric (*Curcuma longa*) powder

P S Sapariya[1*], N U Joshi[1] & M N Dabhi[2]

[1]*Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh, Gujarat.*

[2]*AICRP on Post-Harvest Engineering and Technology, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh, Gujarat.*

Email: parthsaparia0@gmail.com

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Abstract

Turmeric (*Curcuma longa*) rhizome (var. *Salem*) sample was ground according to two different grinding parameters *viz.,* four grinding methods and two feed temperatures. The effect of grinding methods and feed temperature on some functional and physical properties was evaluated. The average values of the flow property *viz.,* bulk density (506.78 to 537.94 kg/m^3), tapped density (611.35 to 635.72 kg/m^3), Hausner ratio (1.150 to 1.225) and compressibility index (13.07 to 18.34%) and functional property *viz.,* water absorption index (3.88 to 4.46), water solubility index (16.17 to 26.51%), water holding capacity (268.40% to 307.19%) and oil absorption index (210.57% to 258.04%) with respect to different grinding methods and feed temperatures varied. The ground sample with chilled water circulation method with the ambient temperature feed (L_2T_0) was found the most suitable for better flow parameters and functional properties.

Keywords: Turmeric, low temperature grinding, physical properties, functional properties.

Introduction

The grinding process is significant in many areas of the food industry; it is an unit operation action for reducing material size. Many food processing activities require particle size reduction, which is accomplished by applying pressure to make particles of certain sizes and shapes. Size reduction, which is strongly related to chemical and microbiological stability and convenience, is one of the most essential and energy-intensive operations in the food sector. Powders are utilised as both end products and intermediate products between unit activities in the food industry. Grinding entails breaking or tearing the materials by compression, impact, attrition, or shear forces, as well as cutting. Size-reduction procedures disintegrate solid food into a large number of little particles. Grinding is a time-consuming and energy-intensive process for converting a hard substance into granules. The amount of energy used to reduce the size of a range of agricultural and food commodities increases as the size of the screen aperture varies from coarse to fine and as the moisture content or material hardness increases (Richardson *et al.,* 2002).

Turmeric (*Curcuma longa*) is a plant belonging to *Zingiberaceae* family. Rhizomes usually come in the form of bulbs, fingers, or splits. The mother rhizome's offshoot branches are known as fingers. More than thirty turmeric varieties are available in India (Anon, 2022).

When energy is utilised to crush a particle into smaller sizes in the typical grinding process, heat is generated. The product's temperature frequently increases above 40°C. (Perry and Hall, 1965). The vaporization of volatile oil in spices is mostly caused by the rise in temperature of spices subjected to grinding; resulting in the reduction of aromatic characteristic of spices (Buttery *et al.*, 1973). Volatile oil is extracted from material during grinding of spices with a high oil content, making the ground product gummy and sticky and clogging the sieves through which the product moves (Singh and Goswami, 1999). To avoid this difficulty, spice grinding is usually done in conditions that reduce both the air flow rate and the temperature (McCabe *et al.,* 1985).

Cryogenic grinding is a novel technique in which material is fed with a cryogenic gas which reduces its temperature below freezing temperature and then ground to preserve its volatile oil (Barnwal *et al*., 2014). However, it is generally considered an expensive method due to the high cost of cryogens *i.e.* liquid nitrogen and carbon dioxide (Balasubramanian *et al*., 2012). Another technique is to pre-cool the material to be ground by keeping it in the refrigerated condition prior to grinding for one or two days to lower its temperature (Shanmugasundaram *et al.*, 2018). The low temperature grinding of turmeric which involved the circulation of coolant around the grinding chamber has been effective in reducing the cost of grinding while achieving the better quality of ground powder to the ambient grinding (Shelake *et al.*, 2017). Apart from that, exhaustive information is available on cryogenic grinding but very limited research information is available on grinding with cooling system methods.

The flow properties viz. bulk density, tapped density, Hausner ratio and compressibility index help in a better understanding to design the equipment for handling, conveying, feeding, processing, mixing, packing, and transportation processes. The influence of a temperature–time combination on flowability of grinding to powder characteristics aids in the reduction of grinding costs for powder manufacturing industries (Singh *et al.*, 2018). The water solubility index and water holding capacity provide a broad picture of fibre hydration and can be used to enhance fiber-rich diets (Guillon and Champ 2000). Swelling capacity, water holding capacity, water retention capacity, and oil holding capacity are essential hydration attributes because high water holding capacity appears to be linked to intestine regulation and impacts nutritive value and behaviour when employed as food ingredients in product development.

The physical and functional qualities of ground powder are largely determined by the temperature inside the grinding chamber. There is a lack of research on powder qualities and the effects of various grinding parameters, such as grinding temperature, feed temperature, and so on, when considering different grinding processes. Keeping this in view, a comparison between low temperature and ambient grinding of turmeric rhizome was carried out, focusing on powder properties such as bulk density, tapped density, Hausner ratio and compressibility index, as well as functional properties such as water holding capacity, water solubility index, water absorption index and oil absorption capacity.

Materials and methods

Grinding of turmeric rhizomes

Experiments on grinding of turmeric was conducted in a self-developed hammer mill with a double rotor type available at the Department of Processing and Food Engineering, Junagadh Agricultural University, Junagadh, Gujarat. A centrifugal pump (Type: WJ-201-X-DM; Power: 0.55 KW) was used to circulate fluid into the jacket while a chilling unit (Model: CR22K6M-TFM-111DM, Refrigerant: R-22, Cooling capacity: 1.5 tonnes) maintained the temperature of chilled water and the coolant. The coolant utilised was propylene glycol, the precooled feed's temperature was about 4 °C and the ambient temperature was about 31 °C. The turmeric powder's final grinding temperature ranged from 35 to 45 °C. A sieve with a size of 0.57 mm was chosen and kept constant for all treatments.

Dried turmeric rhizome of Salem variety was procured from the local market of Junagadh, Gujarat. Turmeric powder was prepared by different grinding methods viz. L_0= Ambient grinding at 31 ℃ ± 2 ℃, L_1= Grinding with ambient temperature water circulation through jacket, L_2= Grinding with chilled water (2 ℃ ± 1 ℃) circulation and L_3= Grinding with coolant circulation. To check the effect of precooling, two different methods of feed were selected by varying the feed temperature *viz*., T_0=Ambient feed temperature at 31 ℃ ± 2 ℃. and T_1=Low temperature feed at -10 ℃ ± 2 ℃. For the low-temperature feed, the rhizome was kept in a refrigerated condition overnight before grinding to reduce its temperature. The rhizome was fed to the low-temperature grinding mill and powder from the mill was collected. The ground powder was sieved and packed in self-sealing zip-lock plastic bags. All the samples were replicated thrice for the determination of physical and functional properties.

Determination of physical properties of turmeric powder bulk density

The bulk density was calculated by the method described by Singh *et al*. (2018). The turmeric powder was poured into a rectangle box having dimensions of 7.2 mm×7.8 mm×7.6 mm using a regular funnel up to the top level of the box and the upper layer was flattened carefully by using an iron strip. The volume and the weight of powder in the box were marked and measured cautiously and the bulk density of turmeric powder was calculated by using Eq. (1):

$$\rho_b=\frac{m_p}{V_p} \quad \text{.... (1)}$$

where ρ_b is the bulk density (kg m^{-3}), m_p is the mass of the powder (kg), V_p is the volume of the powder (m^3).

Tapped density

Similarly, the tapped density was determined as per Singh *et al*. (2018) using the same cylinder of volume 100 ml and pouring the powder carefully into the cylinder up to the fixed level and then manually tapping the cylinder vertically by hand for six minutes (100 taps). Tapping was stopped at the time when the height of powder in the cylinder did not change with further tapping. The tapped density of turmeric powder was measured by using Eq. (2):

$$\rho_t=\frac{m_t}{V_t} \quad \text{.... (2)}$$

where ρ_t is the tapped density (kg m^{-3}), m_t is the tapped mass of the turmeric powder (kg), Vt is the tapped volume of the turmeric powder (m^3).

Hausner ratio (H_r)

Hausner ratio of turmeric powder was obtained by the ratio of the tapped density of powder to the bulk density of turmeric powder (Singh *et al.*, 2018) as per the Eq. (3):

$$H_r=\frac{\rho_t}{\rho_b} \quad \text{.... (3)}$$

Where H_r is the Hausner ratio (dimensional number). This ratio relates with the flowability of the powder.

Compressibility index (CI)

The flow characteristics of the powder can be determined by compressibility index and can be presumed as an alternative measure of bulk density, surface area, size and shape, and the materials cohesiveness because all the mentioned properties affect the value of CI. Both CI and H_r were determined by estimating both the bulk density and tapped density of the ground powder. CI value (dimensionless) was measured using the Eq. (4) given by Singh *et al.* (2018):

$$CI=\frac{100}{100\text{-}H_r} \quad \text{.... (4)}$$

Determination of functional properties of turmeric powder

Water absorption index

The water absorption index (WAI) measures the volume occupied by the granule or starch polymer after swelling in excess of water (Anderson *et al.,* 1969). The pre-weighed ground powder was suspended in distilled water at room temperature for 30 minutes, gently stirred during this period and then centrifuged at 3000 rpm for 15 minutes. The supernatant liquid was poured carefully in to tared evaporating dish. The remaining gel was weighed and WAI was calculated (Eq. 5) as grams of gel obtained per gram of solid.

$$WAI=\frac{\text{Weight of sediment, g}}{\text{Weight of dry solid, g}} \quad \text{.... (5)}$$

Water solubility index (WSI)

Water solubility index determines the amount of polysaccharides or polysaccharides released from the granule on the addition of excess of water. WSI was expressed as the weight of dry solids in the supernatant from the water absorption index test as percentage of the original weight of the sample (Anderson *et al.,* 1969) from the Eq. (6)

$$WSI\ (\%)=\frac{\text{Weight of dissolved solid in supernatant, g}}{\text{Weight of dry solid, g}}\times 100 \quad \text{.... (6)}$$

Water holding capacity (WHC)

Water holding capacity of turmeric ground sample was measured according to the method given by Traynham *et al*. (2007). Five g turmeric powder was weighed in pre-weighed 30 mL plastic centrifuge tubes. For each sample 10 mL of distilled water was added and mixed well with the sample and kept at room temperature

(22 ± 2°C) for 30 min. The mixture was centrifuged at 1200 g for 30 min and the supernatant was carefully decanted and the new mass of the sample was recorded. WHC (g water/g dry powder) was calculated as per Eq. (7):

$$\text{WHC (\%)} = \frac{\text{Weight of water, g}}{\text{Weight of dry solid, g}} \times 100 \qquad \text{.... (7)}$$

Oil absorption index (OAI)

Oil absorption index was measured according to the method given by Traynham *et al*. (2007). Around five g of turmeric powder was weighed in pre-weighed 30 mL plastic centrifuge tube. For each sample, 20 mL of refined groundnut oil was added and mixed well with the sample using a vortex mixer at the highest speed, the samples were subsequently allowed to stand at room temperature (22 ± 2°C) for 30 min. Sample-oil mixture was centrifuged at 1200 g (3709 rpm) for 30 min and the supernatant was carefully decanted and the new mass of the sample was recorded. OAI (g oil/g dry powder) was calculated as per Eq. (8):

$$\text{OAI (\%)} = \frac{\text{Weight of oil, g}}{\text{Weight of dry solid, g}} \times 100 \qquad \text{.... (8)}$$

Statistical analysis

All the experimental data were analysed statistically using the statistical software Design Expert (State-ease, USA, Version 11). For designing the experiment, a Factorial Completely Randomized Design (FCRD) was selected with two factors and eight treatments. The significant difference among the mean values was analysed using ANOVA (Analysis of variance). The experiments were performed in triplicates.

Results and discussion

Measurement of physical properties of turmeric powder

Bulk density

The bulk density of ground powder varied from 506.78 to 537.94 kg/m^3 (Table 1). The bulk density of ambient ground powder (L_0) was comparatively lower than ground powder in the chilled water circulation method (L_2) and coolant circulation method (L_3). This may be attributed to the finer particle size due to the lower temperature inside the grinding chamber. As the temperature of grinding method reduced according to grinding method, the bulk density of powder increased. Similarly, the bulk density of ambient temperature fed sample was higher than in the low temperature fed sample in similar grinding methods (Table 1). The individual effect of grinding method and feed temperature was found extremely significant on bulk density ($p<0.001\%$). The interaction effect of grinding methods and feed temperatures was also found significant ($p<0.05\%$).

Table 1. Effect of grinding method and feed temperature on physical properties of turmeric powder

Feed temperature (T) (°C)	Grinding method (L)	Bulk density (kg/m^3)	Tapped density (kg/m^3)	Hausner ratio	Compressibility index
Ambient temperature feed (T_0)	L_0	507.56	611.35	1.205	16.976
	L_I	530.91	616.39	1.161	13.861
	L_2	536.53	617.22	1.150	13.073
	L_3	537.94	621.47	1.151	13.429
Low temperature feed (T_1)	L_0	506.78	620.64	1.225	18.339
	L_I	529.66	627.29	1.184	15.562
	L_2	534.42	631.95	1.183	15.430
	L_3	529.42	635.72	1.201	16.719
S.Em	L	0.77	2.346	0.005	0.355
	T	0.55	1.659	0.003	0.251
	L*T	1.09	3.318	0.007	0.502
C.D.	L	2.34***	7.095*	0.015***	1.073***
	T	1.65***	5.017***	0.011***	0.759***
	L*T	3.31**	NS	NS	NS
C.V. %	L*T	0.36	0.923	1.05	5.64

[***Significant at p<0.001%, **Significant at p<0.01%, *Significant at p<0.05%, NS = Non-significant]

Tapped density

Tapped density of ground sample varied from 611.35 to 635.72 kg/m^3 (Table 1). For both ambient and low temperature feed individually; the tapped density of ambient ground powder (L_0) and ambient ground with water circulation (L_1) was comparatively lower than the chilled water circulation method (L_2) and coolant circulation method (L_3). As the temperature of grinding method was reduced, the tapped density of powder was found to increase. Similarly, the tapped density of ambient temperature fed sample was lower than the low temperature fed samples. During low temperature grinding, structure of powder was finer, hence the tapped density was higher than the ambient temperature fed sample. The individual effect of grinding method was significant and feed temperature was found significant (p<0.05%) and extremely significant on true density (p<0.001%), respectively. However, the interaction effect of grinding methods and feed temperature was found non-significant.

Hausner ratio

Hausner ratio is the indication of flowability of powder. Generally, the lower Hausner ratio an indicator of highly flowable powder which may be helpful in designing material handling equipment. The Hausner ratio of low temperature feed without circulation was found to be the highest (1.225). The lowest Hausner ratio was observed for the powder obtained by chilled water circulation (L3) and coolant circulation (L2) and was 1.150 for ambient feed temperature (Table 1). This shows that low temperature grounded sample had highly free flowing characteristic. Decreasing temperature led to increase in Hausner ratio. This may be attributed to decreasing temperature of fed samples which increases the moisture content of powder. The individual effect of grinding method and feed temperature were both found extremely significant ($p<0.001\%$) on the Hausner ratio. However, interaction effect of grinding method and feed temperature was non-significant.

Compressibility index

Compressibility index of ground turmeric samples showed similar trend as Hausner ratio (Table 1). The lower compressibility index is desirable for free-flowing characteristic. The lowest percentage was found in ambient temperature fed chilled water circulated ground powder (L2T0 – 13.073) followed by the ambient temperature fed coolant circulated ground powder (L3T0 – 13.429). The ambient ground powder without circulation had lower compressibility index than low temperature ground powder without circulation. Similarly, the low temperature fed ground sample had higher compressibility index than the ambient ground samples. The individual effect of grinding method and feed temperature were both found extremely significant ($p<0.001\%$) on the Hausner ratio. However, there was non-significant effect of interaction of grinding method and feed temperature.

Functional properties of turmeric powder

Water absorption index

Water absorption index is the indicator of swelling of gelatinized starch in excess of water. The water absorption index of turmeric powder varied from 3.88 to 4.46. The water absorption index of ground powder was found to increase as the grinding temperature decreased for ambient feed temperature except chilled water circulation method and it decrease with decrease in grinding chamber temperature for low temperature fed sample except coolant circulation method (Table 2). The ambient temperature fed sample for all grinding methods had higher water absorption index than the low temperature fed sample for respective grinding methods, which may be attributed to the comparatively high temperature of the powder which tends to absorb more water due gelatinization of starch at higher temperature. Khalid et al. (2003) also reported similar finding for water absorption index. The individual effect of grinding method and feed temperature was found highly significant on water absorption index ($p<0.001\%$). The interaction effect of grinding methods and feed temperature was also found significant.

Water solubility index

Water solubility index is the indicator of amount of soluble fractions starch in excess of water. The water solubility index of turmeric powder varied from 16.17% to 26.51%. The water solubility index of ground powder was found to increase as the grinding temperature increased. Falade and Okafor (2015) reported that high temperatures weaken the starch granules resulting in increased solubility. The ambient temperature fed sample had higher water solubility index than the low temperature fed sample for similar grinding methods (Table 2), which may be attributed to the moisture content and release of soluble starch at higher temperature. The individual effect of grinding method and feed temperature was found extremely significant on water solubility index ($p<0.001\%$). The interaction effect of grinding methods and feed temperature was also found significant ($p<0.05\%$).

Table 2. Effect of grinding method and feed temperature on functional properties of turmeric powder

Feed temperature (T)(°C)	Grinding method (L)	Water absorption index	Water solubility index, %	Water holding capacity, %	Oil absorption index, %
Ambient temperature feed (T_0)	L_0	4.03	26.51	272.20	216.77
	L_I	4.14	22.47	268.40	210.57
	L_2	4.46	22.48	272.40	258.04
	L_3	4.37	21.76	307.19	222.78
Low temperature feed (T_1)	L_0	3.98	21.04	279.16	225.93
	L_I	3.91	20.58	281.11	224.82
	L_2	3.88	16.90	277.91	223.85
	L_3	3.95	16.17	293.81	214.45
S.Em	L	0.011	0.495	2.056	0.023
	T	0.008	0.3497	1.454	0.016
	L*T	0.016	0.699	8.793	0.033
C.D. at 5%	L	0.034***	1.495***	6.217***	0.07***
	T	0.024***	1.057***	NS	NS
	L*T	0.049***	2.115*	2.908**	0.099***
C.V. %	L*T	0.683	5.770	1.7891	2.530

[***Significant at p<0.001%, **Significant at p<0.01%, *Significant at p<0.05%, NS = Non-significant]

Water holding capacity

Water holding capacity of the ground turmeric sample varied from 268.40 to 307.19% (Table 2). The water holding capacity of ground powder was found to increase as the grinding temperature decreased. The water holding capacity of all three grinding methods except the coolant circulation method had similar trend of water holding capacity, coolant circulated ground powder (L3 – 307.19) had the highest water holding capacity compared to other methods. The water holding capacity of ambient temperature fed sample was lower than low temperature fed samples except in case of coolant circulated condition. The individual effect of grinding method was found extremely significant on water holding capacity (p<0.1%). The individual effect of feed temperature was found non-significant. The interaction effect of grinding methods and feed temperature was also found significant (p<1%).

Oil absorption index

The oil absorption index of the ground turmeric sample varied from 210.57 to 258.04% (Table 2). The oil absorption index of different grinding methods was slight variation except in the case of chilled water circulation method (L2). The oil absorption index of ambient temperature fed with chilled water (258.04%) and coolant circulation (222.73%) ground powder was marginally higher than the low temperature fed with chilled water (223.72%) and coolant circulation ground powder (214.44%) shown in Table 2. This variation may be attributed to the slightly higher moisture content of the ground powder in the low-temperature grinding methods (L2 and L3) than in the ambient grinding methods. The oil absorption index values were consistent with those reported by Emelike (2020). The individual effect of the grinding method was found extremely significant on the oil absorption index (p<0.1%).

The individual effect of feed temperature was found non-significant. The interaction effect of grinding methods and feed temperature was also found significant ($p<0.1\%$).

Conclusion

Varying the grinding temperature by varying the grinding condition such as the application of coolant surrounding the grinding chamber and the different feed temperatures was found to alter the physical as well as the functional properties of turmeric powder. The low-temperature grinding had a positive effect on the flowability of the powder sample and its functional properties. The feed temperature was also found to be significantly affecting the different properties of the ground sample. Among the grinding methods, ambient grinding methods had a negative effect on product properties compared to chilled water circulation and coolant circulation methods.

The sample ground by chilled water circulation method with the ambient temperature feed (L2T0) had the highest flowability parameter *i.e.,* Hausner ratio and compressibility index, better functional properties such as water and oil absorption index compared to other grinding methods.

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