Low temperature grinding of turmeric

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Abstract: The spices in India have been playing a great role in strengthening the economic conditions because of their characteristic aroma and presence of etheric oils which is mostly obtained after grinding. Grinding of spices generates heat which leads to loss of volatile oils and production of lower quality spice powders. To overcome this, cryogenic grinding system which uses liquid nitrogen or liquid carbon dioxide is developed. Being expensive, it isn't commercialized much in India. The main objective of this research was to study the effect of low temperature grinding of turmeric rhizome and development of pre-cooling unit for cooling turmeric. Performance evaluation was done at 5°C, 10°C and 15°C by circulating chill water through double jacketed pre-cooling chamber. The results revealed that volatile oil had been retained higher at 4.5% in 5°C for grounded sample. Similarly, energy consumption, time and increase in temperature during grinding were less while reducing the turmeric temperature before grinding.

Keywords: volatile oil, turmeric, grinding, cryogenic, low temperature grinding, India

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1 Introduction

India is a "land of spices". Indian spices are well-known all over the world for their taste and strong aromatic flavor. There are around 80 types of spices grown throughout the world but India alone produces about 50 types of them (Peter, 1998). The spices in India have been playing a great role in strengthening the economic conditions since ancient time period. Spices are among the most valuable items of trade in ancient and medieval times.

Spices impart aroma, color and taste to food preparations and sometimes mask undesirable odors. Volatile oils give the aroma and oleoresins impart the taste. Aroma compounds play a significant role in the production of flavourants, which are used in the food industry to flavor, improve and increase the appeal of their products. They are classified by functional groups, e.g. alcohols, amines, aldehydes, esters, ethers, ketones, terpenes, thiols and other miscellaneous compounds.

Turmeric is known as 'Golden spice' as well as 'the spice of life'. Turmeric (*Curcuma longa*) (Family:*Zingiberaceae*) is used as condiment, dye, drug and cosmetic in addition to its use in religious ceremonies. India is a leading producer and exporter of turmeric in the world. Andhra Pradesh, Tamil Nadu, Orissa, Karnataka, West Bengal, Gujarat, Meghalaya, Maharashtra, Assam are some of the important states that cultivate turmeric, of which, Andhra Pradesh alone occupies 35.0% of area and 47.0% of production. During 2013-2014, the country produces 837,200 tons of turmeric from an area of 186,000 ha.

Turmeric of commerce is the dried rhizome of the plant *Curcuma domestica* Val. Syn.C longa L. These dried rhizomes are grinded into powders and used in curry powder, chicken bouillon, sauces, gravies, dry seasonings, backing mixes, processed cheese pickles, relishes, breading soups, beverages and confections (Peter, 1999) in addition to the use in medicine, religious

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functions and as bio pesticide.

Grinding is one of the most common operations used to prepare turmeric powder for consumption and resale. The main aim of particular spice grinding is to obtain smaller particle sizes, with good product quality in terms of flavor and color.

There are different ambient grinding mills and methods available for this process; such as hammer mill, attrition mill and pin mill. In India, traditionally, plate mills and hammer mills are used for turmeric grinding. However, all operations are performed at high temperatures which create a lot of heat during grinding. Temperature ranging from 42°C-95°C, leads to the loss of flavor, aroma and volatile oil of the ground powder (Das, 2005). Moreover, the fat content of the spice poses problems of temperature rise; spices reduce a significant fraction of their volatile oil or flavoring components.

In order to overcome this, a cryogenic grinding system for spices is developed to reduce these volatile losses. However, due to the high cost of the equipment, it isn't commercialized much in India. Low temperature grinding is a technique that is used to decrease the temperature of the raw material and then subject it to size reduction in order to reduce the volatile loss during grinding of spices. Low temperature grinding is a novel and innovative grinding technique. This method helps in retaining good color, flavor, aroma and volatile oil of the product. The design and fabrication of grinding system needs statistical data and knowledge about thermal properties governing the heat transfer properties of the materials to be ground.

The earlier work on use of liquid nitrogen or liquid carbon dioxide for cryogenic grinding of spices mainly highlights the benefits of cryogenic grinding over the conventional grinding in ambient condition (Wistreich and Schafer, 1962). In the above studies, attempts are made to prove that cryogenic grinding of spices is better than conventional grinding in terms of higher retention of volatiles and flavouring components, color, particle size distribution of ground powder, free and continuous operation of grinder without any chocking, less energy requirement in grinding, etc. However, none of the above literatures report beneficial aspects of low temperature grinding system, grinding characteristics of the agricultural materials, optimization of grinding parameters. Hence, this present research has been taken up with the objectives: 1). to study the effect of grinding mill inlet temperature of turmeric on the quality attributes of powder; 2). to develop the batch type pre-cooling unit for turmeric; 3). to evaluate the performance of the developed system.

2 Materials and methods

2.1 Materials

The raw material, turmeric of mini Salem variety was purchased from a leading turmeric export company at Erode. It was stored in gunny bags at ambient temperature in a dry atmosphere to avoid the attack of insects and pests.

2.2 Pre-cooling

Turmeric sample was pre-cooled to different temperatures of 5°C, 10°C, 15°C& 20°C using deep freezer. For every batch of analysis 500 g of turmeric was weighed and filled into the glass bottles and kept inside the freezer for pre-cooling.

2.2.1 Deep freezer

The deep freezer used for cooling the turmeric was of 350 liter capacity, made of 304 food grade stainless steel. The temperatures 5°C, 10°C, 15°C& 20°C were set accordingly. When the set temperature was reached, bottles with turmeric were placed inside the deep freezer. The temperature was being monitored continuously with the help of a thermocouple and bottles were taken out for grinding once the desired temperature was reached in the core of the turmeric.

2.2.2 Temperature measurement

Thermocouple that was connected with the turmeric was attached to a 60 amp Alternate Current adapter for visualizing the core temperature attained in the turmeric sample. This was to ensure that the whole turmeric rhizome was cooled uniformly.

2.3 Grinding of turmeric

The pre-cooled turmeric sample was crushed and grinded using a combined pin and hammer mill. It was made of stainless steel, and the grinding chamber with pins and hammer was designed in it, to increase the efficiency of grinding. The pins were stationary while the four hammers were rotating at a high speed with the help of a motor. Sieves of different sizes can be fixed according to the product. The capacity of the milling unit was 40 kg h^{-1}.

The turmeric sample was fed into the feed hopper of the mill which was ground into a fine powder by impact force and shear. The rise in temperature during grinding was measured using IR Gun Thermometer. The time taken for grinding samples of different pre-cooled temperature was observed using a stopwatch. The ground sample then passed through the 0.45 mm sieve.

2.3.1 Energy consumption

The energy consumption was measured by connecting 3-phase energy meter to the grinding mill. The consumed energy for grinding the samples of different temperatures was determined directly from energy meter.

2.4 Quality attributes of the grounded turmeric

2.4.1 Volatile oil content

The volatile oil content of the ground spice was determined by using the clevenger's apparatus. A round bottom flask of 500 mL capacity, heating mantle, a condenser and clevenger's apparatus were taken. 20-50 g of ground turmeric powder was taken in the round bottom flask and about 300 mL water was added to the sample. Magnetic stirrer was kept inside which gives agitation and avoids settling of samples. The apparatus was set with an efficient water cooled condenser on the top. This set up was maintained for minimum of 6 h. The oil was collected in a top layer in graduated portion in the clevenger's apparatus above the water as the density of oil was less than that of the water. The volatile oil content in the ground turmeric samples was then calculated by using the Equation (1) and is expressed as % v/w.

$$\text{Volatile Oil (\% by weight)} = \frac{100 * V}{M} \quad (1)$$

where, V = Volume of water collected (mL); M = Weight of the sample.

2.4.2 Color value

The quality of the sample was evaluated based on the appearance. Thus, the color of the sample was determined by using Hunter color Lab, which scans the visible spectrum from 400-700 nm with 10 nm resolution for accurate measurement of sample color. Studies were conducted on color of the ground turmeric powders at different temperature and control samples whose L*, a*, b* values were displayed on the screen.

2.4.3 Particle size analysis

The particle size of the grounded sample was determined according to ASAE standards S319.3 using mechanical sieve shaker.

A 100 g of grounded turmeric powder was placed in a stack of sieves arranged from the largest to the smallest opening. The sieve series were selected based on the range of particles in the sample. The duration of the sieving was 5min. The mass retained on each screen were weighed to determine the average diameter of the particle (D_p) in the ground turmeric powder.

The average D_p was calculated by using the Equation (2) and (3).

$$\text{Fineness Modulus} = \frac{\text{Total weight fraction}}{\text{Weight of the sample taken}} \quad (2)$$

$$\text{Average } D_p = 0.135(1.366)^{FM} \quad (3)$$

2.5 Development of pre-cooling unit

2.5.1 Pre-cooling unit

The pre-cooling unit was a double jacketed structure made of stainless steel. It was connected to a chill water circulation unit and then chill water (coolant) was allowed to circulate through the jacket to pre-cool the sample.

2.5.1.1 Design of the pre-cooling unit

The pre-cooling unit was designed to hold a batch of 8 kg of turmeric. The design and the specifications of the equipment were given in the Table 1.

2.5.1.2 Components of the pre-cooling unit

I. Feed inlet

The feeding inlet is a rectangular structure having a dimension of 75 mm length and 100 mm width covered by a 1.6 mm thick lid. The turmeric samples were manually loaded into the pre-cooling unit through this feed inlet. Insulation is also provided around the lid to make the unit air tight.

II. Cooling chamber

The cooling chamber is a unit where the turmeric samples were loaded for pre-cooling. The batch pre-cooler was designed for a capacity of 8 kg. This chamber is also being provided with a gasket so that air doesn't come in contact with turmeric samples. The gasket has a thickness of 6 mm with inner and outer diameter of the gasket being 300 and 400 mm respectively. The bottom surface of this chamber is inclined at an angle of 45 degrees for easy unloading of the turmeric sample.

A double jacket is designed to circulate the coolant (chill water) around the pre-cooling chamber. The thickness of the wall between the outer and inner jacket of the cooling chamber is designed to be as low as possible i.e. 1.26 mm, so that more amount of heat transfer takes place between chill water and the turmeric. A provision for inlet and outlet water was provided, the specifications of which are mentioned in Table 1.

Table 1 Specifications of the developed pre-cooling unit

S.No	Parameters	Specification
1	**Cylinder** • Diameter • Height • Capacity	 300 mm 300 mm 8 kg
2	**Stainless Steel Shell (Top)** • Inner Top Shell • Middle Top Shell • Outer Top Shell	 1.26 mm 1.26 mm 1 mm
3	**Stainless Steel Shell** • Inner Top Shell • Middle Top Shell • Outer Top Shell	 1.26 mm 1.26 mm 1.6 mm
4	**Lid** • Thickness	 1.6 mm
5	**Gasket** • Thickness • Inner Diameter • Outer Diameter	 6 mm 300 mm 400 mm
6	**Agitator (5 Nos.)** • Diameter • Length of fins • Width of fins • Thickness of fins	 20 mm 80 mm 25 mm 2 mm
7	**Water Inlet and outlet** • Diameter	 1.25 cm
8	**Feeding Point** • Length • width	 100 mm 75 mm
9	**Leg** • Diameter • Length	 32 mm 112 cm
10	**External Centre Shaft** • Diameter	 25 mm
11	**Angle of cone at Bottom**	45 degrees

The pre-cooling unit is insulated with cotton wool around the cooling chamber to avoid the heat loss to the surroundings. With reduction in this heat loss, the time period for cooling the sample will be reduced which is an added advantage.

III. Chill water circulation unit

A water circulation unit is attached to the double jacketed pre-cooling unit. It has two parts namely the refrigeration unit where water is cooled to a set temperature and a circulation unit where submersible pump is used to circulate the cooled water. The height of the circulation water unit is 1.5 m and it has a maximum flow rate of 80 liter per hour.

I. Agitator assembly

An agitator is present inside the pre-cooling chamber. It helps to increase the heat transfer between the chill water and the turmeric sample so that the time period for cooling the turmeric gets reduced. There are totally five fins in the agitator attached to a central shaft of diameter 20 mm with length and width being 80 mm and 25 mm respectively. This agitator is driven by the 2 hp motor fixed at the top of the cylindrical chamber.

II. Feed outlet

The pre-cooled turmeric is unloaded through a feed outlet provided at the bottom of the chamber. The feed outlet is provided with a sliding metal sheet which can be pulled or pushed to unload the sample after it is being cooled.

3 Results and discussion

Low temperature grinding of dried turmeric rhizome was done at different temperatures of 5°C, 10°C, 15°C, 20°C and ambient temperature. Volatile oil content, color, time, temperature, sieve analysis, energy required to grind the sample were analyzed for grounded sample. The pre-cooling unit was developed based on the results obtained and performance evaluation of the developed equipment was done, the results of which are discussed.

3.1 Volatile oil content

The volatile oil content was analyzed for ambient and pre-cooled turmeric sample after grinding. The values of the volatile oil content were shown in Table 2. It was found that the volatile oil content was higher in 5°C grounded sample when compared to other samples. Before grinding died raw turmeric volatile oil content was 6%. Whereas, after grinding volatile oil retention was higher in the 5°Cpre-cooled sample (4.5%) whereas ambient temperature grounded had only 3% of the volatile oil retention. It was because, heat would be generated during grinding and it caused the volatiles to evaporate. The same results coincided with the research finding of Singh and Goswami (1998) in the design of cryogenic grinding system for spices.

Table 2 Effect of turmeric rhizome temperature on volatile oil content, energy consumption, particle size & temperature increase during grinding

S.No	Turmeric temperature (°C)	Volatile oil (%)	Energy consumed (Wh)	Particle Size (µm)	Temperature during grinding (°C)
1	5 (Low)	4.50	37.00	0.299	41
2	10	4.00	41.93	0.306	43
3	15	3.33	57.50	0.317	45
4	20	3.05	59.50	0.327	44
5	25	3.00	60.00	0.332	51
6	30 (Ambient)	2.50	62.00	0.350	70

3.2 Energy consumption

The energy required to grind the turmeric sample after pre-cooling at different temperatures were shown in Table 2. It was found that the energy consumption ranged between 37.00 Wh to 62.00 Wh. It was also observed that the energy required to grind turmeric was decreased in turmeric temperature. It was due to the fact that as the turmeric samples were pre-cooled, the sample became more and more brittle. The hammer in the grinding mill thus needed less energy to break the turmeric with impact force. The same results coincided with the research conducted by Barnwal et al. (2014) in effect of cryogenic and ambient grinding on grinding characteristics of cinnamon and turmeric.

3.3 Particle size

The average diameter of the particle obtained after the sieve analysis for turmeric powder obtained from different temperatures was shown in Table 2. It was observed from the table that as the raw turmeric temperature decreased the average Dp had also decreased. The least particle size 0.299 mm was recorded in the grounded powder obtained from the 5°C raw turmeric whereas maximum average particle size (0.332 mm) was recorded in the grounded powder obtained from the ambient temperature turmeric. The fineness of the grinded sample increased with decrease in raw material temperature.

3.4 Color

The color of the ground powder was determined using Hunter color lab and the ΔE value was found out between ambient and five different cooled temperature. The L*, a*, b* values of turmeric powder were obtained from the different raw material temperature. The L* and b* values of the turmeric powder obtained from the pre-cooled turmeric were found to be higher than the control sample. It indicated that the yellowness was more for powder obtained from pre-cooled turmeric than the control sample. A similar result had also been reported by Pesek and Wilson (1986) on the effect of cryogenic & ambient grinding on color.

3.5 Temperature during grinding

Increase in temperature during grinding of raw turmeric with different temperatures (5°C, 10°C, 15°C, 20°C and ambient temperature) was observed during grinding and given in Table 2. It was observed that increase in temperature was less when raw material temperature decreased. The maximum temperature of 71°C was recorded in the turmeric powder obtained from the 30°C turmeric whereas minimum temperature of 63°C was observed in the powder obtained from the 5°C turmeric. This was because that the cooled samples became brittle and were easily broken due to the impact force and shear during grinding. Also, heat generated during grinding reduced by the low temperature of the sample which in turn reduced the temperature of the turmeric during grinding.

3.6 Performance evaluation of the pre-cooling equipment

Performance evaluation of the developed pre-cooling unit was done by circulating the 5°C, 10°C, and 15°C chill water in the pre-cooling unit and the time taken for cooling the turmeric was recorded and given in the Table 3.

It was observed that turmeric cooling rate was higher at 5°C chill water circulation followed by the 10°C and 15°C. It was due to the rate of heat transfer is higher in

5°C (90.126 kJ s^{-1}) followed by 10°C (64.891 kJ s^{-1}) and 15°C (46.931 kJ s^{-1}).

Table 3 Effect of chill water temperature on turmeric cooling

S.No	Time (min)	Turmeric		
		Water temperature (5°C)	Water temperature (10°C)	Water temperature (15°C)
1	0	30	28	28
2	15	27	26	24
3	30	24	25	23
4	45	22	23	22
5	60	20	22	20
6	75	18	20	19
7	90	16	19	19
8	105	15	18	18
9	120	14	17	17
10	135	12	16	16

From the above results, it can be concluded that low temperature grinding is viable using chill water as a coolant. The volatile oil content retention is more when the sample is grinded at 5°C or lesser. Also, the energy consumption during grinding was lesser in low temperature grinding when compared to the normal grinding. The grinding time and temperature increase is also less in low temperature grinding.

4 Conclusions

From the above research and findings, it can be concluded that low temperature grinding provides superior quality product compared to the ambient temperature grinding, and is more economical than cryogenic grinding.

5 Suggestions for future research

- The pre-cooling unit developed can be attached to a grinding unit which may be served as a continuous low temperature grinding system.
- The equipment design can be done considering all spices.
- Different coolant like propylene or ethylene glycol can be used instead of water as a coolant.
- Since there is condensation problem, vacuum pre-cooling chamber can be developed.

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