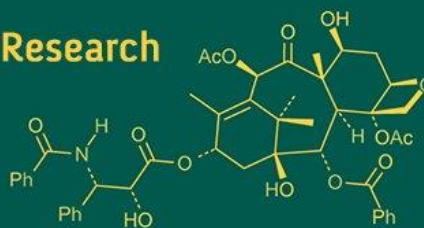
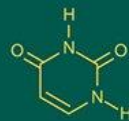
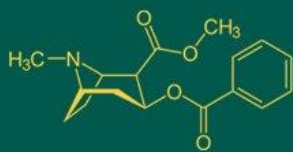


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Grinding characteristics of cryogenic and ambient ground dried ginger at different moisture contents

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Abstract

Ginger (*Zingiber officinale* Roscoe) is a widely used spice in India, valued for its culinary and medicinal properties. During conventional grinding using hammer mills, the product temperature rises significantly, resulting in the loss of volatile compounds, oleoresins, and colour. To overcome these drawbacks, a cryogenic grinding system was evaluated and compared with ambient grinding. Dried ginger samples of three moisture contents (7%, 12%, and 18%) and three slice thicknesses (1.5 mm, 3 mm, and 4.5 mm) were prepared, yielding nine sample combinations. Preliminary grinding experiments were conducted at ambient temperature using a small-scale grinder to evaluate power consumption, fineness modulus, and colour values. The best performance was obtained for ginger slices of 1.5 mm thickness and 7% moisture, with power consumption of 65 W, fineness modulus of 5.04, and colour values of $L^* = 83.7$, $a^* = 2.8$, $b^* = 33.84$. This optimized condition was further evaluated in large-scale ambient and cryogenic grinding using a hammer mill. Cryogenic grinding consumed less power (960 W) than ambient grinding (1440 W) and produced lighter, more colour-stable powder ($L^* = 89.79$, $a^* = 3.88$, $b^* = 32.08$). The volatile oil yield was also higher under cryogenic conditions (1.0 mL per 50 g) compared to ambient grinding (0.75 mL per 50 g). The fineness modulus was 4.34 and 4.5 for cryogenic and ambient grinding, respectively, indicating finer and more uniform powder in the former. Overall, cryogenic grinding enhanced product quality through lower energy consumption, improved colour retention, and higher volatile oil yield.

Keywords: Cryogenic grinding, ambient grinding, volatile oil, fineness modulus

1. Introduction

India is the leading producer and exporter of spices. Spices are natural plant products enriched with the history of being used as herbal medicine for prevention of diseases. India is also known as the 'Land of Spices'. Out of 109 spices recognized by the International Organization for Standardization (ISO) more than 52-60 spice crops are grown in India. The major spices exported by India are turmeric, cumin, coriander, fenugreek, ginger and peppers, etc. The major issue with spices is their handling and storage.

Ginger, scientifically known as *Zingiber officinale* Roscoe, is a member of the Zingiberaceae family. As a perennial flowering plant, its distribution ranges mostly in tropical and subtropical countries (Shahidi and Hossain, 2018) [11]. The underground stem, also known as the rhizome, has been used fresh, ground as a spice, or dried for the manufacture of oils and oleoresins (Rasheed, 2020) [9]. Its extensive application is mostly found in culinary and medicinal purposes, which makes it an important horticultural crop. The dried ginger rhizome is composed of fatty oils, proteins, carbohydrates, raw fibre, ash water and volatile oil. Ginger owes its pungent taste and aromatic flavour to the phenolic components found mostly in the essential oil and oleoresins (Wohlmuth *et al.*, 2006; Panpatil *et al.*, 2013) [13, 8].

Grinding is a high-energy operation that uses just 1 or 2 per cent of the input energy to reduce particle size and wastes the rest as heat. In ambient grinding (Bera *et al.*, 2001) [3] product temperatures of up to 90 °C were measured. Cryogenics is a method of cooling materials by direct contact with fluids with extremely low boiling temperatures. It can freeze materials and make them brittle. The material to be ground is cryogen-precooled before being transferred to grinding, where cryogen is employed to keep the temperature constant (Russo, 1976) [10].

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The fat and oil content of the spice will be frozen, and no evaporation or melting will occur, preventing filter clogging. Cryogenic grinding is a modern technique used to process spices at very low temperatures to retain heat-sensitive compounds such as volatile oils, oleoresins, and pigments. Studies consistently show that cryogenic grinding preserves more flavor and color while improving energy efficiency compared to traditional ambient grinding.

Gaurav *et al.*, (2022) ^[5] demonstrated that ginger processed at -70°C had a higher oleoresin content and brighter color than ginger ground at room temperature. Badiwal and Jain, (2022) ^[1] found a similar trend in turmeric, where cryogenic grinding at -70°C preserved more curcumin and yielded a lighter-colored powder. For black pepper, Murthy and Bhattacharya, (2008) ^[7] noted a 50% reduction in volatile oil loss compared to ambient grinding, resulting in a fresher-smelling product.

Muhammad Subtain *et al.*, (2024) ^[12] conducted experiments to yield oleoresins extraction after cryogenic grinding method. Ginger rhizomes were cleaned and reduced in size prior to grinding. Just before grinding, liquid nitrogen was sprayed on ginger and mixed properly. Due to less heat production during grinding process due to liquid nitrogen, oil content of ginger was solidified and after grinding moisture was again adjusted to 12% prior to extraction process. Petroleum ether was used as organic solvent for extraction purpose.

Energy consumption is another benefit: Meghwal and Goswami, (2010) ^[6] and Banarwal *et al.* (2014) ^[2] reported that cryogenic grinding uses less energy and produces finer, more uniform particles across spices like turmeric, cinnamon, and cumin. Overall, this technique is widely recognized for maintaining superior sensory and nutritional quality in spice powders, with less energy use and better product uniformity.

This aim of the study is to explore the physical properties of fresh and dried ginger (such as bulk density, colour, moisture content) to compare the properties at ambient and cryogenic grinding.

2. Materials and Methods

2.1 Raw material

Fresh ginger was procured from a local market in Sangareddy, Telangana. The rhizomes were cleaned, partially peeled, and sliced into different thicknesses (1.5 mm, 3 mm, and 4.5 mm). The samples were dried in a tray drier at 60°C to achieve desired moisture levels (7%, 12%, and 18%).

2.2 Equipment

2.2.1 Mills

Two types of mills were used for grinding (Table 1). A domestic and a commercial hammer mill was used to conduct the experiments.

Table 1: Specifications of mills used in the experiment

Parameter	Hammer mill	Domestic grinder
Phase	Single phase	Singel phase
Power	2 Hp	0.8 Hp
Rpm	2880 rpm	10000 rpm
Capacity	230 V	230 V
Volts	25 kg/h	1 kg/h

2.3 Measurements

2.3.1 Moisture content: Moisture content of ginger is determined using Axis ATS moisture meter (Fig. 1) by placing the ginger pieces uniformly to read the moisture content.

2.3.2 Colour: The colour of ginger can be measured using the Hunter Lab spectrometer. The instrument was calibrated using standard white and black tiles to ensure accurate measurements. The collected data is processed to calculate color values based on CIE color space (L^* , a^* , b^*) as shown in the fig.2.

2.3.3 Bulk density (kg/m^3): The bulk density of ginger is measured taking the ratio of weight by volume using a 250 ml volumetric cylinder.

2.3.4 Energy consumption: The energy consumed for grinding is measured as a product of voltmeter and ammeter readings.



Fig 1: Moisture measurement using Axis ATS moisture meter

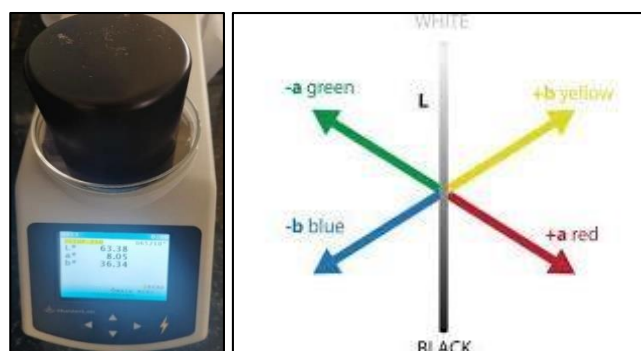


Fig 2: Hunter Spectrophotometer for measurement of colour.

2.3.5 Volatile oil yield: Volatiles refer to the essential oils and aromatic compounds responsible for its distinctive aroma and flavour. These volatile compounds can easily evaporate at room temperature, giving its characteristic pungency and scent. Volatile oil can be extracted using hydro distillation method. Clevenger's apparatus is used for hydro distillation method (Fig.3). Clevenger's apparatus consists of a boiler, condenser and a separator. The ginger is placed in a flask with water heated by a mantle. The heat causes the cell walls of ginger to rupture, releasing essential oils and volatile compounds into steam. This steam passes through condenser where it is cooled and separated in separator.



Fig 3: Clevenger's apparatus for volatile oil extraction.

2.3.6 Fineness modulus: Mechanical sieve shaker is used to automate the sieve analysis process, ensuring more consistent and reliable particle size distribution measurements (Fig. 4). Set of sieves used are 355 μm , 300 μm , 250 μm , 212 μm , 180 μm , 150 μm , 125 μm , 106 μm , 90 μm , 75 μm and pan. Arrange sieves in ascending order of



Fig 4: Measurement of fineness modulus size using sieve shaker

2.4 Sample Preparation

Gently wash the fresh ginger roots with water to eliminate dirt, dust and other impurities. Section the ginger into uniform thickness according to the specified dimensions (1.5 mm, 3 mm, and 4.5 mm). Dry the ginger slices using tray dryer at 60 °C, until it reaches the specified moisture content (7%, 12%, and 18%) (Fig. 5).

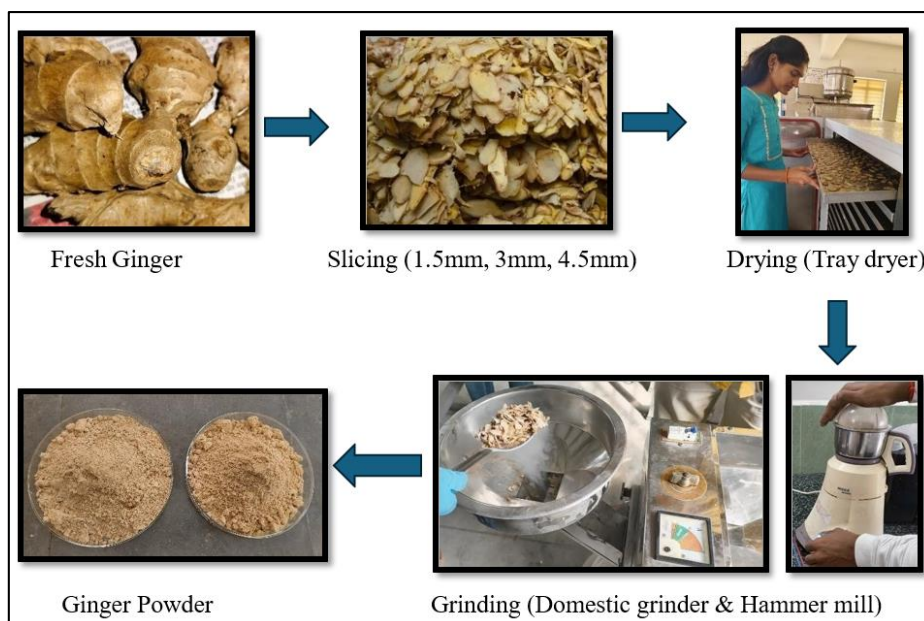


Fig. 5: Step wise procedure for obtaining the ginger powder from raw ginger.

2.5 Ginger grinding

Ambient grinding: Dried ginger slices were ground in ambient conditions using two grinders i.e. a domestic mixer grinder and a hammer mill.

Cryogenic grinding: Cryogenic grinding was done by soaking the dried ginger slices in liquid nitrogen for pre-determined time. The required amount of ginger was taken in a heat insulated container and liquid nitrogen is poured into the box until the ginger is completely immersed. Liquid nitrogen cools the material to extremely low temperatures (-196 °C). Liquid nitrogen makes the material brittle, reducing toughness and facilitating grinding. It also prevents oxidation, moisture absorption, and contamination.

2.6 Experimental design

2.6.1 Experiments on domestic grinder in ambient grinding conditions

Preliminary experiments were carried out with a domestic grinder to find out the optimum thickness (1.5 mm, 3 mm, and 4.5 mm) and moisture content (7%, 12%, and 18%) at which fine powder is obtained. A 30 grams of dried sample was taken and ground in a mixer grinder with a constant grinding time of three minutes at ambient conditions. Total 09 experiments were conducted with 02 replications each as shown in Table. 2. and determined the fineness modulus, colour and power consumption. Then selected the best sample from these 9 experiments.

Table 2: Experiments conducted with domestic grinder at ambient conditions

S. No	Variables		Levels			Replications
1	Independent variables (X)	Thickness(t), mm	1.5	3	4.5	2
		Moisture content (M.C) %	7-8	12-13	17-18	2
2	Dependent variables (Y)	Colour Power consumption Fineness modulus				

$f(X) = Y$. Where, X and Y are independent dependent variables f(t, M.C). Fineness modulus, colour and power consumption depends on initial moisture content and thickness of dried ginger.

2.6.2 Experiments on domestic grinder in cryogenic grinding conditions:

Table 3: Experiments was conducted in domestic grinder in cryogenic conditions:

S. No	Variables		Levels	Replications
1	Independent variables (X)	Thickness(t), mm	1.5	2
		Moisture content (M.C) %	7-8	
		Time of soaking in liquid nitrogen (minutes)	1,3,5	
2	Dependent variables (Y)	Colour Power consumption Fineness modulus		

2.6.3 Experiments conducted with large scale hammer mill

In continuation of the experiments conducted from domestic grinder, the conditions which gave good results are taken for further testing in a hammer mill. A feed rate of 4 kg/hr was

conducted with different soaking times with liquid nitrogen. A 50 gram sample is taken in a thermocol box and soaked in liquid nitrogen for three different soaking times (1,3,5 min). Total 03 experiments were conducted with 02 replications each as shown in Table.3

maintained throughout the experiments. To obtain cryogenic grinding the dried ginger is soaked in liquid nitrogen for 5 minutes, then it is fed into the hammer mill. Total 02 experiments were carried out with two replications as showed in Table 4.

Table 4: Experiments conducted in hammer mill at both ambient and cryogenic conditions

S. No	Variables		Levels		Replications
1	Independent variables (X)	Thickness (t), mm	1.5		2
		Moisture content (M.C),%	7-8		
		Temperature	Ambient grinding	Cryogenic grinding	
2	Dependent variables (Y)	• Colour • Power consumption • Fineness modulus • Volatile oil			

3. Results and Discussion

The outcomes of various experiments conducted to evaluate the grinding characteristics and energy consumption of ambient and cryogenic grinding at different moistures are enunciated and discussed in this section.

3.1 Physical properties of fresh ginger

Table 5. presents the physical properties of the fresh ginger such as bulk density, Moisture content and colour.

Table 5: Physical properties of fresh ginger

Physical properties	Values
Bulk density	473.15 kg/m ³
Moisture content	86.1%
Colour	L*-63.3, a*-8, b*-36

3.2 Effect of moisture and thickness on grinding at ambient conditions

3.2.1 Fineness Modulus

Fineness modulus for the nine experimental samples that were formulated in domestic grinder was present in Fig. 6. Lesser the moisture content and lesser the slice thickness resulted in to lower fineness modulus of 5.04. Among all the nine experiments the best sample in small scale grinding was found to be 1.5 mm with 7 % moisture content which has a fineness modulus of 5.04.

3.2.2 Colour: The colour of samples ground in domestic grinder in ambient conditions that determined through spectrometer as mentioned are presented in Table6. It showed there were no considerable variation in the colour values among all the experiments.

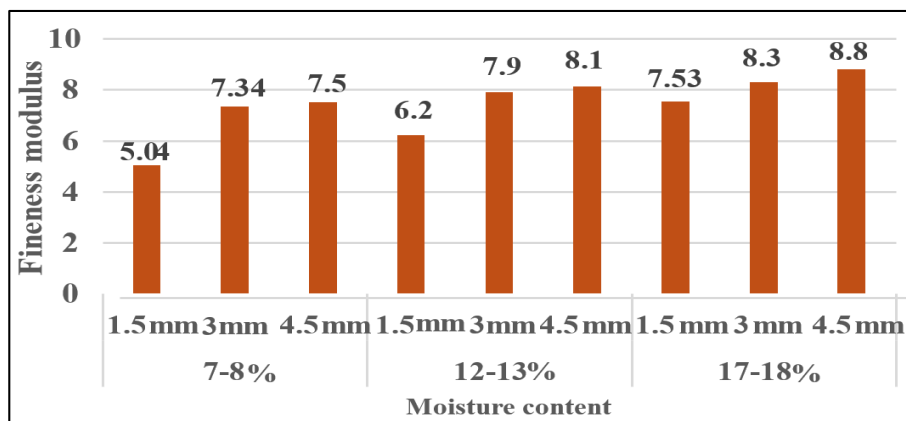


Fig 6: Fineness modulus of ambient ground samples

Table 6: Colour values of samples ground at ambient conditions in domestic grinder

Sample no.	Sample Thickness, mm	Moisture content, %	L*	a*	b*
1	1.5	7-8	83.7	2.8	33.84
2	3	7-8	80.02	5.09	36.15
3	4.5	7-8	81.36	5.02	33.4
4	1.5	12-13	86.2	4.25	32
5	3	12-13	87.51	3.99	31.85
6	4.5	12-13	85.09	4.67	34.52
7	1.5	17-18	80.36	4.67	35.43
8	3	17-18	84.32	6.04	36.85
9	4.5	17-18	81.69	6.67	36.13

3.2.3 Power Consumption: The power consumed among all the samples were presented in Fig. 8. It showed that power consumption is low at low moisture content and

lower thickness of the ginger slices. Power consumption for small scale grinding for 9 formulated samples measured and represented in the graph given below (Fig 7)

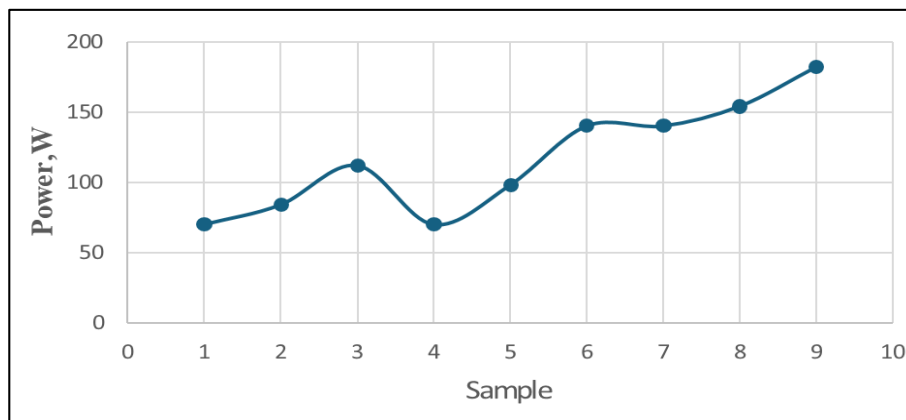


Fig 7: Power consumption for small-scale ambient grinding

3.3 Effect of soaking time during grinding at cryogenic conditions

Fineness modulus and colour values of dried ginger at three different soaking periods in liquid nitrogen ground in domestic grinding were present in Table 7 & 8 respectively. It can be inferred from the results that the soaking time of 5 minutes in liquid nitrogen yields lower fineness modulus and good colour values.

Table 7: Fineness modulus of dried ginger at three different soaking periods

Time of soaking (minutes)	Fineness modulus
1	6.72
3	6.5
5	6.4

Table 8: Colour values of cryogenically ground samples in domestic grinder

Time of minutes	soaking in,	L*	a*	b*
1		67.74	3.7	27.68
3		68.43	3.26	27.66
5		68.69	2.86	26.99

Power consumption for small scale cryogenic grinding was found to be 96 watts for the 1 min, 3min, and 5 min soaking periods.

3.4 Comparison of Ambient and Cryogenic Grinding (Hammer Mill)

Cryogenic grinding produced finer, lighter-coloured, and more aromatic powder while consuming 33% less energy

than ambient grinding (Table 9). The higher volatile oil yield confirms that lower grinding temperatures prevent losses due to vaporization. Similar observations were

reported by Barnwal *et al.* (2014) ^[2] and Ghodki & Goswami, (2016) ^[4]

Table 9: Comparison of volatile oil yield

Grinding method	Volatile oil yield (ml) per 50 g sample	Fineness modulus	Colour values	Power consumption, in watts
Ambient grinding	0.75	4.5	L*-84.55, a*-4.96, b*-34.92	1440
Cryogenic grinding	1	4.34	L*-89.79, a*-3.88, b*-32.08	960

Lower the value of fineness modulus indicates that the powder is more finely ground, which could affect its flowability, mixing, and dispersion properties in various applications. Fineness modulus value was found less for cryogenic grinding of sample with 1.5 mm thick & 7% moisture content, this indicates that the particles are uniformly distributed. Hand feel of cryogenic ground powder was observed to be fine compared with ambient grinding. However, the same was not captured by sieve analysis due to several inherent limitations associated with the powder's characteristics. Sieve analysis by other methods like "Laser Diffraction". Laser diffraction (LD) is a common method for analysing the particle size distribution of powders and dispersions. Its principle is based on the angle and intensity of light that scatters from the particles from larger particles, light scatters at a smaller angle and higher intensity than from smaller particles.

It can be seen from the table that the luminance (lightness) of ambient ground sample is less compared to cryoground samples which means it is darker than the latter. The increase in a* value shows that the ambient ground powder was tend to be more reddish than the cryoground powder. The decrease in b* value of ambient ground powder indicates that its yellowness is less when compared to grinding at cryoground powders. Overall, the colour of ginger powder obtained from grinding at cryogenic conditions resulted in superior colour when compared to ambient conditions.

4. Conclusion

Cryogenic grinding of dried ginger significantly improved product quality and energy efficiency compared to ambient grinding. The optimized condition—1.5 mm slice thickness and 7% moisture—yielded the best results. Cryogenic grinding reduced power consumption by 33%, improved colour retention ($L^* = 89.79$), and enhanced volatile oil yield (1 mL per 50 g). Thus, cryogenic grinding is a superior alternative for producing high-quality ginger powder with improved aroma, colour, and stability.

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