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Application of cryogenics in grinding of spices for value addition: A Review

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Abstract

Since time immemorial, India is the leading producer and exporter of spices. They have both nutrient and medicinal values. Today, apart from value addition of spices by cleaning and packing, there are a variety of mix masalas available in the market. An inevitable part of mix masalas and powdered spices is the grinding, a process where the particle size is reduced there by increasing the surface area leading. This also helps in increasing the availability of constituents such as oil inside the cells. However, the major problem in such a process is the heat generated, which results in temperature rise; which is one of the major drawbacks of the conventional grinding process which lowers the quality of ground spices. Hence it is very important to maintain controlled temperature surroundings during grinding. Cryogenic grinding is a process where low temperature is maintained within the grinder which appreciably minimizes the loss of volatile oils, moisture and colour due to which flavour of the spice is also retained. The colour and other properties of the products of cryogenically ground products will be better compared to ambient grinding in terms of their flavour and nutritional values. Such cryogenically ground spices being of higher quality, they would naturally have high demand in the domestic and international markets. This review is undertaken to study the influence of temperature of grinding and its significance in retaining the quality and favourable properties of a variety of spices. The paper also discusses the technologies and parameters having significant role in cryogenic grinding.

Keywords: Spices, thermal damage, grinding, cryogenics, liquid nitrogen

Introduction :

Spices :

Spices are very important ingredients of food and cuisines in India and apart from using them for household purposes, they find wide variety of applications at restaurants, hotels, eateries and food processing units. Indian spices have been playing a great role in bringing good strength to the country's economy with their characteristic aroma and presence of etheric oils obtained after grinding. Some of the spices possess antioxidant properties, while others are used as preservatives in some foods like pickles and chutneys. Along with medicinal properties, many of the spices possess strong anti-microbial activities and have an intense effect on human health. Among 70-80 spice varieties grown in various regions of the earth, In India, most of them are grown. Spices may include different components of plant and are mostly classified as shown in table 1.

Table 1. Classification of Spices

Category	Spices
Major spices	Chilli, Black pepper, ginger, turmeric, cardamom, vanilla
Major seed spices	Cumin, coriander, fennel, fenugreek
Minor Seed Spices	Celery, Ajowan, black cumin, parsley, dill caraway, black caraway

Major tree Spices	Nutmeg, clove, cinnamon, tamarind, allspice, kokum, curry leaf.
Minor tree Spices	Bilimbi, carambola
Herbal Spices	Basil, marjoram, rosemary, sage, oregano, etc.
Others	Saffron, asofoetida, etc.

During 2017 to 2018, there is an increasing trend in the export of Indian spices and achieved an all-time record in terms of value and volume. An amount of 17929.55 crores were gained by exporting 10,28,060 tonnes of spices and related products from the country whereas in 2016-17 the total earning by the export of 9,47,790 tonnes of spices was 17664.61 crores thereby recording a growth of 8% in terms of volume, 1% in terms of rupee and 6% in terms of dollar value. The growth rate in the export of Indian spices over the years is shown in figure 1[1].

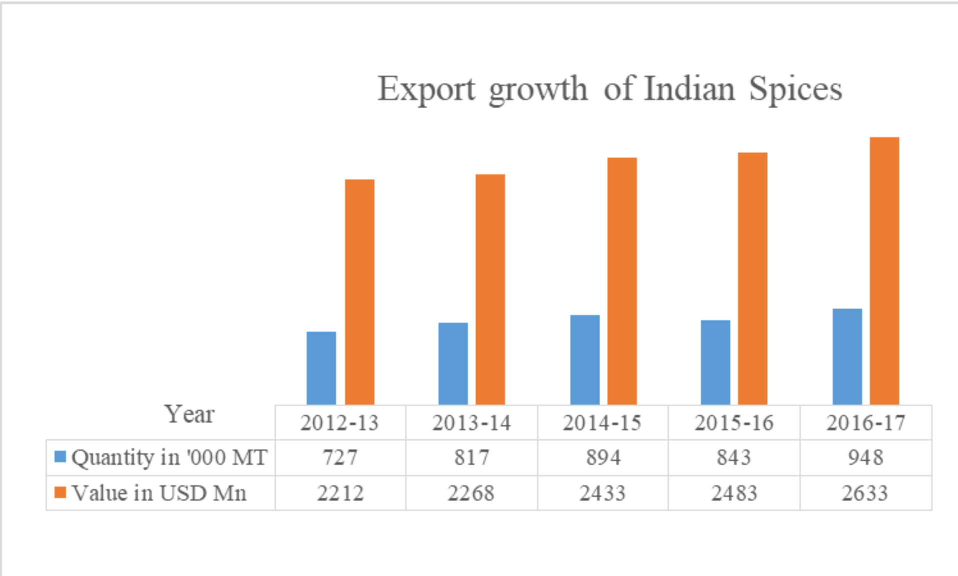


Figure 1. Export growth of Indian spices [1]

Spices are chief agricultural commodities in the entire world in terms of high unit price and therefore, necessary to give due attention to this commodity with particular reference to quality and value addition.

Grinding of Spices :

In the food industry, powders may be treated as either intermediate products or end products in between different stages of operation [2]. The process called grinding consists of different operations using apparatus like crushers, mincer, mills, cutters, shredders, grinders, homogenizers and disintegrators [3, 4]. Grinding needs material tearing or breaking by mechanisms namely impact, compression, attrition or cutting and shearing [5]. Using size-reduction mechanisms, large number of fine particles are obtained from food materials in solid state and then powders are produced by grinding. Many numbers of mechanical forces act on the material during the grinding process which leads to the formation of finer particles [6, 7]. If the amount of force applied is higher, size of the particles in the end products will be finer [6]. The grinding is a very energy intensive operation. Of the energy given to the material which is useful in breaking of bonds between the particles is only 1%. 99% of remaining part of energy is evolved in the form of heat which increases the powdered product temperature. In normal or conventional grinding operation, temperature rises like 42 to

93^{0}C which leads to evaporation of the volatile matter in the spices and thus leading to deterioration of medicinal and nutritional components. Sometimes, oil comes out from the material and makes the spice powder sticky and gummy which results in blocking of product passage sieves [8].

Cryogenic Grinding :

During normal grinding process, the raising temperature can be minimized with the aid of cryogenic fluids like nitrogen in its liquid state (LN_2). This low temperature makes the material brittle. When the process of grinding progresses this helps in obtaining finer particles in the end product. This also permits to increase the rate of feeding and reduced power consumption during grinding phenomena. [8]. On the other hand, lower values of temperature during grinding helps to defeat other undesirable changes such as oxidation and discoloration. Spice cryogenic grinding (cryo-grinding) is fairly an advanced technology and therefore there are very few units presently operating in India.

To achieve an end product with retained volatile oil content, freezing and chilling are the possible modes. Low temperature can also be obtained via external circulation of refrigerant or chilled water around the grinding apparatus or mixing whole spice with solid CO_2 or dry ice and then carrying out the process of grinding. However, for large scale industrial operations such methods are not feasible because of inefficient rates of heat transfer [8]. Hence this is a challenge.

In cryogenics the behavior of material under low temperature conditions is studied and it deals with the temperatures of the order below -150^0 C. The very low temperature is obtained by using substances known as cryogens like liquid helium, liquid nitrogen, argon, neon, krypton, methane, hydrogen, natural gas in liquid form etc. At ambient temperatures and pressures all cryogenic liquids are in gaseous state and hence these gases need to be cooled to the temperature below atmospheric to liquefy them. The cryogens boil at temperature less than -150^{0}C. The vessels which are used to keep cryogens are referred as dewar flask with which enough insulation is provided. The important properties of some of the cryogens are listed in the table 2.

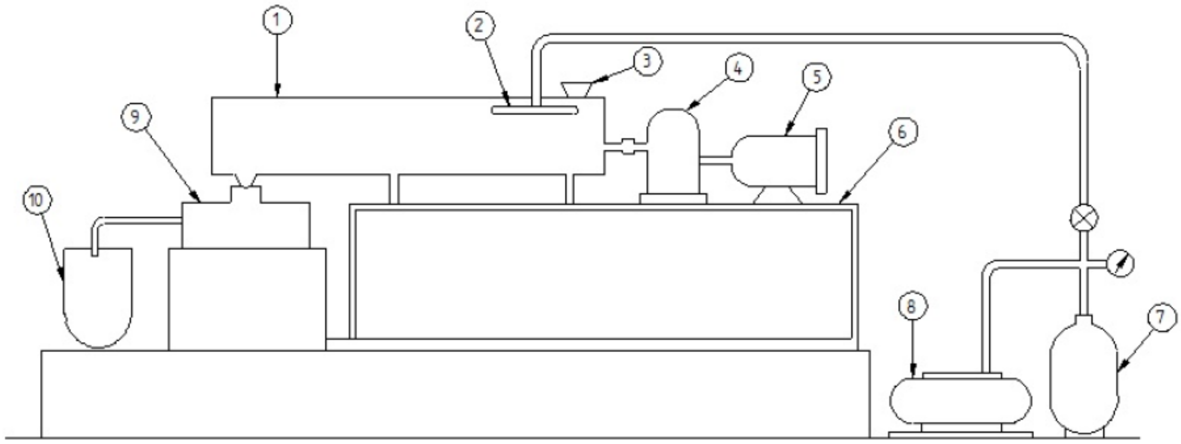
Table 2. Properties of Cryogenic Fluids Used in Food Systems. [9]

Properties of Cryogens	**LN_2**	**CO_2**	**Freon-12**
Density (kg/m^3)	784	464	1485
Boiling point (^{0}C)	-196	-78.5	-29.8
Heat conductivity (W/m k)	0.29	0.19	0.10
Specific heat of liquid (kJ/kg k)	1.04	2.26	0.98
Enthalpy of evaporation (kJ/kg)	358	352	297
Refrigeration effect (kJ/kg)	690	565	297

The Cryogenic Grinding process :

Cryogenic grinding is further called as freezer grinding or cryo-milling and is a method where the size of solid materials is reduced in the cooling environment created by cryogens to retain quality of ground product. This process is considered as an effective mode of cooling or refrigerating many products in the food industry. In this process, the cryogen in liquid state around -195.6^{0}C gives the cooling effect required for pre-cooling the spices in order to keep up the required low values of temperature by taking away the heat produced during the process of grinding. Liquid nitrogen not only maintains the low temperature but also vaporisation of it to the gaseous form produces dry and an inert atmosphere by which it adds protection to the spice quality. The raw spice pre-cooling as well as maintaining uninterrupted low temperature inside the grinding mill minimizes moisture loss and loss of volatile oils; hence holding maximum strength of flavour per unit quantity of spice in order to achieve a good quality end product.

The research findings on cryo-milling and properties of spices would help to realize the phenomenon of grinding and develop an effective grinding system. The principle of working of a typical low temperature or cryo-grinding system is represented in figure 2. The compressor is run before the start of grinding. The exit valve of the compressor is slightly opened in order to obtain the necessary pressure in the vessel of liquid nitrogen (LN_2) based on the temperature to be kept while grinding. LN_2 is made to enter into the distribution system of the screw conveyor assembly. The grinder and the assembly of screw conveyor are cooled to the required of grinding temperature of the order -160 to -70^{0}C. Using D.C. motor of variable speed, the speed of conveyor may be selected according to the required feed rate to the grinder. The grinder is put into operation once the sample material is sent to the inlet of the screw conveyor system. Once the material passes through the pre-cooler it is allowed to pass into the grinder. The grinding happens at the predefined temperature in the range of -160 to -70^{0}C. If temperature goes up during powder preparation or grinding, it is desirable to increase the rate of flow of liquid cryogen. The powder is collected at the outlet of the grinder in a bag attached to the system and the nitrogen vapours are allowed to go out [10].



1. Conveyor 2. LN_2 Distributor 3. Hopper 4. Gear Box 5. Motor 6. Plat form 7. LN_2 Cylinder

8. Compressor 9. Grinder 10. Collecting Bag

Figure 2. A typical Cryogenic Grinding system [10]

Advantages of Cryogenic Grinding System :

Some of the advantages of low temperature grinding are as follows

- Natural quality attributes of the spices are preserved
- Minimum thermal fatigue and risk of fire
- Enhanced production capacity
- Good control over the particle size and fineness of about 50 Microns
- Less wear and tear of the equipment

Disadvantages of Cryogenic Grinding System :

The following are the drawbacks of grinding with cryogenic technology.

- The use of cryogen in humid atmosphere may form ice around the system piping which carries cryogen and may cause the stoppage of liquid cryogen delivery.
- The process has economic considerations that should be solved.
- Maintenance cost high.
- Operation cost is high.

Advantages of Liquid Nitrogen as Cryogen :

LN_2 is the most commonly used cryogen. The use of LN_2 as cryogenic fluid has the following advantages [11]

- Faster reduction in temperature
- Higher retention of volatile oils
- Prevention of oxidation and rancidity
- Increased throughput
- Less consumption of electricity
- Reduction in microbial load
- Possibility of fine grinding of difficult spices
- Controls gumming up
- Uniformity in final product

Results and Discussion :

Several studies are conducted in the area of cryo-grinding of spices with the aim of comparing cryo-ground and conventionally ground variety of spices. This section reviews the studies conducted. The scope of the review is to explore the various aspects of cryo-ground spices such as volatile oil retention, quality, colour and size of particles obtained, power required in the process, potential health hazards during the process, the cryo-grinding equipment etc. for various spices.

On cumin seed studies were carried out on grinding at ambient and different cryogenic temperatures to notice its effect on particle size distribution, volatile oil and its related components, specific energy consumption and volume mean diameter. From the study it is reported that, for the low temperature range of -160 to -70^{0}C, no appreciable effect was noticed in the yield of volatile oil whereas for the grinding temperature range of 40 to 85^{0}C significant reduction in volatile oil from 2.86 to 2.26 ml/100g was observed. Also, for the temperature rise from -160 to -70^{0}C for 12 number of rotor ribs, the volume mean diameter of powder was increased from 129 to 164µm and the specific energy consumption was increased from 72 to 108 kJ/kg. [10] (Table 3). Thus at lower temperature the specific energy consumption is lower, and the volume mean diameter is much lesser.

A study was made on cryogenic and ambient grinding using black pepper with liquid nitrogen as the cryogenic fluid and the parameters such as power, specific energy, color, volatile oil, particle size etc. were analyzed and the results indicated that the atmospheric grinding requires 8.92% more power and 14.5% more specific energy compared to cryogenic grinding. Further analysis on particle size showed that the coarser particles were produced in cryogenic grinding. 2.15 ml/100g of volatile oil content was seen in cryo-milling and also the powder of good freshness, less whiteness (40%) and higher or more yellowness (14%) indices were recorded for freezer grinding [12].

Performance of grinding in a pin mill was evaluated while grinding of coriander seeds at 10^0C and -50^0C with 5, 10 and 15 rpm of conveyor screw speeds. It was noted that, the amount of antioxidant and volatile oil content was higher for seeds of coriander powdered at -50^0C which was significantly greater than the respective values obtained at 10^0C. From the study it was felt that the good quality cryogenically obtained coriander powder would yield the domestic as well as international market [13].

The particle size analysis was made on fenugreek powder obtained by grinding with cryogenic and ambient means and different grinding parameters were analyzed. The powder obtained by cryogenic means was comparatively finer as per the sieve analysis. More grinding time and specific energy requirement was found for conventional grinding and time requirement was less for cryogenic grinding. There was an increase in specific surface area for increasing moisture content in both cryogenic and ambient grinding but for both the grinding methods, for the increase of moisture content the feed rate was decreased [14].

In making coriander powder, the effect of grinding method i.e. cryogenic and ambient on average particle size, specific heat, color parameters, thermal diffusivity, thermal conductivity, volatile oil, glass transition temperature, total phenols, flavonoids, and antioxidant activity were investigated. All the parameters were varied remarkably with the method of grinding. With respect to temperature, the specific heat, heat conductivity and diffusivity followed the second order polynomial relationship. The cryo-ground coriander powder acquired almost doubles the total phenols and antioxidant activity as compared to ambient grinding; denoting that the cryo-grinding of spices hold their unique flavor and medicinal values [15].

A comparative study was made on ambient and cryo-milling of black pepper using a pilot plant model pin mill with different values of feed rates and temperatures to analyse the different quality parameters. When compared to cryogenic grinding, there is 50% loss of volatile oil in ambient grinding. The loss in terms of monoterpenes was also high in conventional grinding. In terms of the retention of monoterpenes the technique of cryogenic grinding was superior in comparison with ambient method of grinding. The study indicated that, the optimum cryogenic conditions were 47 to 57 kg/h of feed rate, and -20 to -15^0C of product temperature for obtaining maximum volatile oil with reasonable quantity of monoterpenes [16].

Using two cumin genotypes, the effect of cry milling on the yield of total phenolics, volatile oil, oleoresin, flavonoid content and antioxidant properties were analyzed and reported that in the cryogenically ground product apart from retaining the volatiles in both the varieties, recovery was also increased. On the other hand, there was a loss of 18-19 % of volatile oil was found in both the genotypes in normal grinding at atmospheric temperature. Total flavonoid and phenolic content was also higher in cryo-ground seeds of both the genotypes. The study reported that cryogenic grinding method is superior to normal grinding with respect to antioxidant properties and flavour retention of cumin irrespective of the genotype [17].

The effect of cryo-grinding on the yield of volatile oil, total phenolics, oleoresin, antioxidant properties and flavonoid content of two ajwain genotypes were studied. In both of the genotypes, there was a notable increase of oleoresin and essential oil recovery in cryogenically ground seeds. For the extraction of flavonoid and phenolic contents from ground seeds, hexane and Dimethyl sulfoxide (DMSO) were proved to be better among different solvents used. Total antioxidant content was also high in seed extract of cryo ground samples [18].

The effect of cryo-grinding over ambient or normal grinding was studied to evaluate the optimal grinding condition for obtaining best quality cumin powder. The study indicated that with an increase of feed rate, decrease of sieve size and temperature was observed with more volatile oil retention. For 5–7 kg/hr of feed rate, sieve size of 0.8 mm and the grinding temperature of -30^{0}C, cumin powder obtained was of premium quality with maximum volatile oil retention of 3.3% by cryo-milling. Volatile oil obtained in case of cumin powder of Gujarat cumin-4 cultivar which was cryogenically ground had 29.61% cuminaldehyde. Both ambient and refrigerated storage samples of cryo-ground cumin powder retained more than 96% of the volatile oil even after 90 days of storage [19].

The characteristics of turmeric and cinnamon were investigated in both ambient and cryogenic grinding. The samples were ground using a pin mill set up in the laboratory. From the study on turmeric and cinnamon, the properties such as volume surface mean diameter, average particle size and mass mean diameter were observed to be lower in low temperature grinding in comparison with conventional grinding. For the sample of cinnamon, energy values i.e., Rittinger's and Kick's constants were obtained as 26.8 and 29.6, and 54.0 and 50.7 KWh / tonne for cryogenic and ambient grinding conditions, respectively. It is also reported that for cryog-grinding compared to ambient grinding the specific energy consumption was less. The characteristics of turmeric and cinnamon were found superior in terms of quality compared to ambient grinding [20].

With cryo-grinder, Spice and low temperature pulverizer, dried byadagi chillies were ground. Compared to low temperature pulverization and chilli pulverization, the nutrients retention was more in cryogenic grinder. The protein, moisture, crude fat, crude fiber, total minerals and carbohydrate content of chilli powder milled in cryogenic grinder was reported to be 16.85%, 10.08%, 12.21%, 26.54%, 8.25%, and 25.96% respectively. From the cryogenic grinder, much better colour was obtained in chilli powder compared to low temperature and chilli pulverization. More content of capsaicin was retained in cryogenic grinder than that in other milling types. The grinding cost of low temperature pulverizer milling method was Rs.33.47 per hour or 1.34Rs. Per kg, whereas it was Rs. 49.20 per hour or Rs. 4.92 per kg in cryogenic grinder due to its high initial and operating cost [21].

Using a laboratory scale ball mill the effect of cryogenic and ambient grinding on powder quality of king chilli was investigated. The powder quality was evaluated by measuring the properties like densities, Hausner ratio, color change, compressibility index, particle size distribution, mineral compositions and microstructural changes. The bulk density and tapped density of ambient ground powder was 483 kg/m^3 and 556 kg/m^3 respectively and they are comparatively more than that of cryo-ground powder where the bulk density and tapped density was 414 kg/m^3 and 480 kg/m^3 respectively. The surface morphology for cryo-ground powder was smoother, shape was regular and size of particles were comparatively smaller. On the other hand, the main mineral (K) content and the color i.e., yellowness, redness, and lightness were relatively superior for cryo-ground powder. The overall study indicated that the cryogenic grinding provides a better and finer quality ground powder than the conventional grinding methods. It was felt that the results of this study will provide an opportunity to the spice industries in selecting the optimum grinding method [22].

The studies on cry milling of herbal medicinal plants of china revealed that using liquid air or nitrogen as the cryogen, Chinese herbal medicines can be powdered below their brittle temperature. It was also reported that the color and other properties of the cryogenically ground material were not changed and the nutrients and flavor of the medicines were not lost [23].

In the process of cryogenic grinding of clove, the influence of parameters such as rotor speed, grinding temperature, feed rate and sieve size on sieve clogging characteristics, particle size distribution, energy consumption, volatile oil content and volume mean diameter was observed. It was seen that the clove could be powdered at temperatures lower than -50^{0}C without any accumulation over the surface of the sieve. The rise of temperature in the range of ‐ 110 to -50^{0}C shown no remarkable effect on the content of volatile oil, whereas for the temperatures in the range of 55 to 85^{0}C significant reduction in the volatile oil content from 11.0 to 9.3 ml/100g was observed. Hence, cryogenic grinding resulted in 29.5% more volatile oil in comparison to that of ambient grinding. When grinding temperature was increased from -110 to -50^{0}C, the specific energy consumption during grinding increased quadratically from 62 to 81 kJ/kg with increase in grinding temperature from -110 to -50^{0}C at a typical feed rate of 1.5 kg/h, rotor speed of 69 m/s and sieve size of 0.5 mm. The specific energy consumption increased quadratically from 62 to 85 kJ/kg with the increase in feed rate from 1.5 to 6 kg/h with constant grinding temperature of -110^{0}C, rotor speed of 69 m/s and sieve opening size of 0.5 mm [24].

The volatile oil loss can be effectively minimized by cry milling technique using liquid nitrogen at -195.6^{0}C which gives the cooling effect desired to precool the spices and maintain the required low temperature by taking away the heat evolved during the operation of grinding. Apart from maintaining the low temperature, liquid nitrogen vaporization to gaseous state creates dry and an inert atmosphere for extra protection of spice quality. Continuously maintaining low temperature environment within the mill minimize the loss of volatile oils and moisture hence retaining most of the flavor strength per unit mass of spice [25].

The effect of direct spraying of liquid carbon dioxide while grinding pepper in a turbo mill was studied and it was said that almost all experiments without chilling caused clogging of sieve and ultimately breakdown of the mill [26].

Black pepper was powdered at four different feed temperatures namely 24^{0}C, 40^{0}C, 10^{0}C and -120^{0}C, using hot or chilled water circulation through the grinder jacket or direct injection of liquid nitrogen (LN_2) into the mill along with the feed. The volatile oil content of the product shown that chilled water and LN_2 cooled conditions retained almost same quantity of volatiles and powder fineness was greater in the latter [27].

At temperature values of 40^{0}C and 60^{0}C pepper volatile oil was extracted with supercritical fluid CO_2 at pressures of 8 and 10 MPa. It was observed that pepper oil obtained with supercritical fluid CO_2 at 10 MPa and 60^{0}C was superior to steam-distilled oil [28].

Using cumin seed and coriander seed, an experimental investigation was carried out on cryogenic and conventional grinding and the effect of product quality in terms of moisture content, volatile oil, non-volatile ether etc. were studied. With the time temperature studies made on spices during grinding at atmospheric temperature and cryogenic temperature it is reported that, volatile oil content for cumin seed is increased by 43.3% and for coriander seed is increased by 172.7% compared to conventional grinding. On the other hand, Non-volatile ether extract content for cumin seed is increased by 107.7 % and for coriander seed is increased by 45.4% compared to conventional grinding. From this it is concluded that loss of quality & flavor can be reduced by cryogenic grinding technique. [29]

Table 3. Summary of findings on cryo-grinding

Spice	**Parameter**	**Advantage of cryo-grinding/ Description**	**Temp.**	**Remarks**	**Ref.**
Cumin seeds	VMD	164 microns	-70 C		[10]
Cumin seeds	SEC	108 kJ/kg	-70 C		[10]
Cumin seeds	VMD	129 microns	-160 C		[10]
Cumin seeds	SEC	72 kJ/kg	-160 C		[10]
Cumin seeds	Quality			Improved flavour and quality	
Cumin seeds	VOR	43.3%↑	-		[29]

Spice	Parameter	Advantage of cryo-grinding/ Description	Temp.	Remarks	Ref.
Coriander seeds	VOR	172.7%↑	-		[29]
Coriander seeds	NVEE	45.4%↑	-		[29]
Cumin seeds	NVEE	107.7 %↑	-		[29]
Cumin seed	Quality and flavour	↑	-		[29]
Coriander seed	Quality and flavour	↑	-		[29]
Black pepper seeds	Power	8.9%↓	-60 to -110C		[12]
Black pepper seeds	SEC	14.5%↓	-		[12]
Black pepper seeds	Color, particle size	-	-	Coarser particles, Good freshness, less whiteness, more yellowness	[12]
Black pepper seeds	VOR	2.15ml/100g volatile oil	-		[12]
Coriander seeds	VOR	↑	-50 C		[13]
Coriander seeds	AOA	↑	-50 C		[13]
Fenugreek seeds	PS	Finer powder	-30 to -70 C	Lesser grinding time and energy consumption Lesser speed requirement	[14]
Coriander seeds	AOA	100%↑	< -50 C		[15]
Coriander seeds	VOC	100%↑	< -50 C		[15]
Black pepper seeds	VOR	50%↑	-20 to -15 C		[16]
Cumin seed	VOR	18-19%↑	-		[17]
Cumin seed	AOP	↑	-		[17]
Cumin seed	Flavour retention	↑	-		[17]
Ajwain seeds	VOR	18-19%↑	- 30 C		[18]
Ajwain seeds	AOP	↑	- 30 C		[18]
Cumin seeds	VOR	↑	-30 C		[19]
Turmeric & cinamon	VSMD	↓	< - 50 C		[20]
Turmeric & cinamon	APS	↓	-		[20]

Spice	Parameter	Advantage of cryo-grinding/ Description	Temp.	Remarks	Ref.
Turmeric & cinamon	MMD	↓	-		[20]
Turmeric & cinamon	SEC	↓	-		[20]
Turmeric & cinamon	Quality	Superior	-		[20]
Byadgi chilli	NR, Color	Improved	-	Increased cost of cryo-grinding	[21]
King chilli	PQ	-	-	Smoother powder, smaller, superior color	[22]
Herbal medicinal plants	PQ	-	-	No change in nutrients, flavour. Better color & shelf life	[23]
Cloves	VOR	29.5%↑	-50 C	No sieve clogging	[24]

Legend: VOR-Volatile oil retention, NVEE= Non-volatile ether extract, VOC= Volatile organic content, AOP=Antioxidant property, NR=Nutrients retention, SEC=Specific energy consumption, VSMD=Volume surface mean diameter, VMD= Volume mean diameter, MMD=Mass mean diameter, APS=Average particle size, PQ=Powder quality, ↑=Improved, ↓=Decreased

While most papers discussed hitherto LN_2 was used as cryogen. However, there are also studies which report that the via media between cryo-grinding and conventional grinding which have certain advantages. The same are also discussed here. These studies consider cooling media like atmospheric grinding with coolant, chilled water and dry ice.

The quality aspects were studied during the process of grinding chillies by the use of evaporative cooling of water. Chilli pods were sprayed with atomized water before being sent to the mill. The comparison was made against conventional grinding with respect to the measured values of colour, temperature and moisture content of the powdered product and the values. The study indicated that, as a coolant, water can be successfully used to reduce the rise of temperature and retain the quality of chilli during the process of grinding [30]. (Table 4)

A pre-cooling unit for cooling turmeric was developed to study the effect of low temperature grinding. Performance was evaluated in the environment of 5^0C, 10^0C and 15^0C by chilled water circulation. The results showed that, while grinding at a temperature of 5^0C, the amount of volatile oil retained was higher for grounded sample. On the other hand, power consumption, increase in temperature and grinding time were less for the sample of turmeric whose temperature was reduced before grinding and it is concluded that low temperature grinding provides superior quality product compared to the ambient temperature grinding, and is more economical than cryogenic grinding [31].

The influence of feed temperature while grinding black pepper was studied. Different temperatures were achieved by placing black pepper in the refrigerated space of 4^0C to feed the spice in the range of 7.9 to 21.2^0C and for getting temperatures from -3.33 to 12.86^0C dry ice was mixed at different ratios. The temperature of -3.33 to -1.25^0C was the optimum feed temperature on the basis of volatile oil components. The study revealed that, at lower range of temperature values, the powdered black pepper possesses increased volume surface mean diameter. For refrigerated samples, grinding time was increased when feed temperature was decreased. Increased time of grinding and specific energy for increased feed temperature was noted in dry ice mixed sample. Volatile oil was lower for higher values of temperature of grinding and retention of volatile oil was higher by 17% and 15% in dry ice mixed and refrigerated sample respectively, in comparison with ambient sample [32].

Table 4. Summary of literature on non-cryo low temperature spice grinding

Spice	Parameter	Result	Temp.	Cooling method	Remarks	Ref.
Cumin seed	VOR	2.86 ml/100g	40 C	AG with coolant		[10]
Cumin seed	VOR	2.26 ml/100g	85 C	AG with coolant		[10]
Turmeric	VOR	-	5 C	Chilled water	Chilled water method is economical than cryo-grinding	[31]
Turmeric	Power consumption, grinding time, temperature rise	↓	5 C	Chilled water		[31]
Turmeric	Product quality	↑	5 C	Chilled water		[31]
Black pepper seed	VOR	17%↑	-3.33 to 12.86 C	Dry ice	-3.33 to -1.25 C is optimum temperature	[32]
Black pepper seed	VOR	15%↑	7.9 to 21.2 C	Refrigeration		[32]

VOR=Volatile oil retention, AG=Atmospheric grinding

Apart from the aspects of volatile oil retention, quality and other parameters discussed above, several miscellaneous aspects pertaining to various other parameters of cryo-grinding are also discussed here.

Some important aspects such as screw length, total time of freezing and cryogenic system capacity were calculated while grinding fenugreek and coriander seed. At 5 different screw speeds ranging from 3 to 15 rpm, the screw length as well as pre-cooler capacity were evaluated for constant values of pitch and screw diameter. The study revealed that the capacity and screw length of pre-cooler for coriander and fenugreek seeds increased linearly with increase of 3 to 15 rpm of cooling screw speed [33].

It is reported that, choking of sieve was a serious issue in atmospheric grinding. For grinding temperature of -60 to -110^{0}C, the required amount of LN_2 was between 1 to 1.4 kg/kg. It was felt that the low temperature grinding does not pose the problems such as nose watering, sneezing and eye burning and it is a healthy novel technique. [12]

In the process of making coriander powder, effect of grinding with pin and hammer mills and moisture content on the quality features like colour parameters, grinding parameters, specific heat, thermal diffusivity, thermal conductivity, essential oil, total phenolic content, glass transition temperature etc. were analysed.

The study indicated that the geometric properties such as minor, medium, major dimension, sphericity, arithmetic and geometric mean diameter, surface area and volume of coriander seeds increased notably with an increase of moisture from 6.4–13.6 % on dry basis. The parameters like average particle size, volume mean diameter and surface mean diameter of coriander powder increased notably with increasing moisture in the range 6.4–13.6 % on dry basis. Thermal conductivity varied proportionately with moisture content and temperature [34].

In order to bring down the temperature of spices before sending them for grinding and also to keep the temperature in the cryogenic range in the grinding area, a grinding system was made and the experiments conducted while grinding cumin seed indicated that, it could be successfully powdered below -70^{0}C and above this temperature, choking of sieve was observed. When the value of temperature is increased from -160^{0}C to -70^{0}C, there was a remarkable increase in the size of particles in the end product along with specific energy consumption. Also, there was a variation in the volatile oil content in the range of 3.30-3.26 ml/100 g with an increase of -160^{0}C to -70^{0}C of temperature [35].

The evaluation was made on quality aspects of fenugreek and black pepper powders with respect to different modes of grinding and packaging materials. Black pepper and fenugreek powders obtained from grinding by cryogenic and normal method were packed using steel jar, glass jar, aluminium bag, plastic jar and poly bags and it was found that, with the storage time the powder loses in its colour, aroma, odour and flavour at different rates based on the materials used for packing. Activities of antioxidants were decreased with respect to the storage time. When ambient and low temperature ground powders were compared, powder which was ground cryogenically possessed greater antioxidant activities. Steel and glass jar were proved to be good packaging materials for studied spices may be due to their compactness, good barrier property and inertness. The studied spice powders kept in plastic containers in cool and dry place at ambient temperature for 2.5 years were seen to be spoiled by biological actions. Based on the retention of the quality of powder, the order of materials that may be considered for packaging are as follows: Poly bag < Plastic jar < Aluminium bag < Steel jar < Glass jar [36].

Conclusions :

Thermal damage of spices is the great disadvantage of conventional grinding because of which volatile oil compounds, natural flavour and aroma of spices will be lost. Cryogenic grinding using LN_2 as cryogen is not only the effective method of reducing thermal damage of spices in ambient grinding but also it retains colour, antioxidant activity, aroma and flavour properties of the materials thereby improving the product quality and shelf life. Cryogenic grinding also provides advantage of lesser health hazards to the operators. Being expensive, cryo-grinding is not commercialized much in India. Still, cryogenic freezing may be feasible for high-cost foods and from the point of improved product quality. It is also reported that instead of using cryo-grinding, low temperature grinding has advantage from economy point of view. There is huge scope for more research in the area.

CONFLICTS OF INTEREST :

The authors have no conflicts of interest to declare.

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