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REVIEW ARTICLE

Cryogenic grinding for better aroma retention and improved quality of Indian spices and herbs: A review

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Abstract

Spices are very well-known for their characteristic aroma and peculiar taste from ancient time. Grinding of spices is an old practice using different grinding equipment suited as per prevailing conditions. In modern era, the popularity of quality processed products has increased in spices. Cryogenics has very important role to play in food sector. Liquid nitrogen is the preferred among all available cryogens to obtain desired low temperature in food grinding. Grinding of spices at very low temperature produced superior quality ground powder with better hygiene. In spite of a proven technology it is not being popular in developing countries including India due to high initial investment. Present review article brings together the original work done to realize physico-mechanical, thermal and grinding characteristics, aroma profile, and medicinally important compounds of selected spices for developing design of low cost cryo-grinder specifically for spices and its possible commercial application.

Practical applications

Cryogenic grinding of spices and herbs not only retain the volatiles with no loss as well as maintain the originality in flavor quality, thus has prospective commercial uses. Enhancement of pharmacological properties opens another important avenue for utilization of this technology for herbal grinding in Ayurveda and other traditional system of medicine. Particle size up to 50 μm may be achieved by cryogenic grinding which in turn will be more effective in medicinal or therapeutic use. Less quantity of herbal drugs will be required if ground cryogenically.

1 | INTRODUCTION

Due to varied agro climatic conditions India produces large variety of spices including perennials like black pepper, cinnamon, clove, cardamom, (small and large) and nutmeg while annuals like garlic, turmeric, chili, cumin, coriander, fennel, fenugreek, dill, ajwain, nigella, and so forth. Most of the Asian and Indian cuisine these spices are being used in varied proportions either as whole or ground form. Due to the pungent aroma cumin, coriander and black pepper are essential constituents of recipes with spicy touch. India is the largest producer and exporter of spices to rest of the world, however, majority of spices exported in its raw form (www.indianspices.com). Among value added products, ground powders of various spices individually or in the form of spice mix showed immense opportunities of their commercial exploitation. Extrinsic as well as intrinsic qualities of product are major concern for value addition. The extrinsic quality in case of spices relate to size, appearance, color, flavor, and odor. These characteristics of spices, though, vary depending on agro climatic condition, the harvest and post-harvest operation play important role in improving these qualities through proper grading, sorting, and packaging. Moisture, volatile, and fixed oil present in the spices determine the intrinsic quality. The value addition deals with all these aspects to obtain the greater benefits.

However, there are many possible form of value addition in spices but most common and important is ground powders of spices. Apart from taste and flavor ground powders of various spices also add preservative value to prepared food stuff.

Adding value to the processed spice product is largely depends on original flavor and medicinal properties present in the spices. Spice grinding is done to better utilize their flavor and taste characteristics. Particle size of ground powder of spices may vary from 50 to 850 μm depending on its end use and accordingly spice grinding utilizes hammer mill (Singh & Goswami, 1999a), an attrition mill (Goswami & Singh, 2003), or a pin mill (Murthy & Bhattacharya, 2008). Utilization of cryogenic grinding technology for spices certainly adds value to the ground spice powders in terms of improved flavor and its medicinal properties. Present review summarizes the usefulness of cryogenic grinding technology for Indian spices and the work done for design and development of indigenous cryogenic grinder especially suited for Indian spices. The studies on performance evaluation of developed cryo-grinder and validation of cryo grinding technology have been abridged for its potential commercial utilization.

2 | LIMITATIONS IN CONVENTIONAL GRINDING OF SPICES

Use of energy during grinding of any particle in to smaller size generated significant amount of heat (Wistreich & Schafer, 1962). This generated heat resulted in loss of product quality and quantity, however, this damage is varied per type of oil and moisture content in seeds during grinding but final product loose considerable volatile oil up to 30–40% and original color. Volatile oil loss in conventional grinding is reported for different spices, namely, nutmeg, mace, cinnamon, oregano, and caraway seed are 37%, 14%, 17%, 17%, and 32%, respectively (Andres, 1976; Pesek & Wilson, 1986; Pruthi & Misra, 1963; Wolf & Pahl, 1990). Such produce does not confirm to the international quality standards, hence, not accepted by the importer countries. Besides volatile oil most of the spices contains significant amount of fatty oils which melt due to heat and hinder continuous operation of grinder because ground powder stick on grinder surface due to melted fat. Melting of fat due to heat is another problem which hinder continuous operation of grinder because ground powder stick on grinder surface due to melted fat. Loss of volatile, however, may be reduced by slow rotating roller mills but it affects the energy efficiency of grinder and not suitable for heat sensitive and high fat content materials.

3 | POTENTIAL OF CRYOGENICS IN SPICE GRINDING

3.1 | Cryogenics

Cryogenics is the study of materials behavior at very low temperature. According to the International Institute of Refrigeration (1975), cryogenics deals with scientific and technological disciplines involving cryogenic temperatures, that is, below −153 °C. Cryogenic grinding or any related area which related to cryogenics usually use a very cold gas in the form of liquid only than it can make the sample to be ground brittle.

3.2 | Cryogens

The materials which lower the generated heat during grinding process known as cryogens includes liquid nitrogen, oxygen, argon, neon, krypton, xenon, hydrogen, helium, liquefied natural gas (LNG)/methane, and carbon dioxide. These fluids are used in various fields like LO_2 and LN_2 in chemical and metallurgical processes, LH_2 and LO_2 as cryogenic liquid propellants for rocket engines, and LH_2 as a clean energy vector in transportation. Several researchers have used cryogenics in the field of biology, viz., artificial insemination (Ostashko, 1963), freezing of biological systems (Peter, 1970), embryos preservation (Steponkus et al., 1990), grinding of soft tissues (Chan, Menovsky, & Ashley, 1996), teeth grinding for DNA extraction (Sweet & Hildebrand, 1998), and electron cryotomography (Cristina, Elizabet, Heymann, & Jensen, 2006). Kamogawa et al. (2001) pulverized a hair sample using cryo-milling to determine heavy metals while Katkov (2006) discussed cryo-preservation in reference to germplasm conservation of endangered, economically important plants and animal breeds. Sieme, Harrison, and Petrunkina (2009) has been reported about existing cryopreservation procedures, cryo-biological determinants, and mechanisms of cryo-injury and cryo-protectant action while Choi, John, and Bischof (2010) reviewed the biomaterial thermal properties in the cryogenics regime for the application in cryobiology.

3.3 | Cryogens in food sector

Improving shelf life, food preservation through quick freezing and food grinding are integral parts of food processing industries. Cryogenics proved a powerful tool in the food industry providing low temperature applications. Many researchers have worked on cryogenic freezing of food products for better quality, longer shelf life, and high throughput production capacity from as early as second half of 20th century (Arafa & Chen, 1978; Cowley, Timson, & Sawdye, 1962; Hoeft, Bates, & Ahmed, 1973; Streeter & Spencer, 1973). Davidge (1981) discussed technical and control systems methods to distribute LN_2 for economic feasibility of the processes while discussing the application of cryogenics in food industry. Kock, Minnaar, Berry, and Taylor (1995) reported that foods frozen under cryogenic conditions rapidly freeze the cellular starch as compared to slow freezing, thus produce better product quality. Awonorin (1997) evaluated different freezers with liquid nitrogen spray. Later, Miller and Roberts (2001) worked on how to minimize startup cost of cryogenic grinding system. Ramakrishnan, Wysk, and Prabhu (2004) evaluated grinding parameters for precise control on freezer using simulation modeling, thus better economics by augmenting its low setup costs, high flexibility, and benefits in food industry. In recent years, Goswami (2010) and Balasubramanian, Gupta, and Singh (2012), Balasubramanian, Kumar, and Singh (2012) compiled the information cryogenics in spice grinding.

Spices are largely produced and consume in India as indispensable ingredient of various foods and cuisine. For better acceptability of prepared delicacies, it is preferred to use spices in ground form. Presently ground spice powder either individually or in suitable proportion with other spices are main processed spice products. Quality and hygiene are the major concern in marketing of ground spice powder. Benefits of cryogenic grinding can better explore in spice processing industries. Therefore, researchers in the field of food technology initiated work on evaluating cryogenic grinding technology for quality enhancement in spices. Cryo ground spices retain original color when grinding is done at cryo temperature (Pesek & Wilson, 1986). Murthy, Krishnamurthy, Ramesh, and Srinivasa (1996) also found better product characteristics of black pepper when ground using laboratory scale cryo grinding system. Volatile oil was significantly more (2.61%) in cryo ground black pepper as compared to 1.15% in conventional grinding technology (Jacob, Kasthurirengan, & Behra, 2000).

Comparison of cryogenic grinding technology with established techniques have also been discussed by Singh and Goswami (1999b, 2000). In case of cumin grinding, Bera, Shrivastava, Singh, Kumar, and Sharma (2001) reported that the product temperature rose to 95 °C during conventional grinding cause substantial decrease in volatile compounds. Manohar and Sridhar (2001) ground turmeric rhizomes under cryogenic temperature and studied its effect on particle size and thermally sensitive compounds in oils of turmeric. At the same time, Gouveia, Lopes, Orlando, Rita, and Joaquim (2004) utilized cryogenic grinding technology for homogenization of breakfast cereals. The grinding resulted to be more efficient than the earlier traditional technologies. Cryogenic grinding technology was also applied in Byadagichilli by Mallappa, Sharankumar, and Roopabai (2015). They reported more retention of color, nutrients, and capsaicin content in produce of cryogenic grinder as compared to other traditional chili pulverizers. However, they also showed concerned over high initial and operating cost of cryogenic grinder.

4 | DESIGN PARAMETERS OF CRYOGENIC GRINDER

Pioneering work on developing design of cryogenic grinder specifically suitable for spices was done by Singh and Goswami (1999a) at Indian Institute of Technology, Kharagpur (WB). They designed a grinding system specifically for cumin and clove. They studied the effect of grinding temperature and number of ribs on grinding characteristics and quality of ground powders in terms of essential oil content and found cryogenic temperature during grinding was able to retain more volatile and improved quality of ground powder. Singh and Goswami (2000) while studying the effect of various grinding parameters on product quality of clove found sieve blockage at temperatures more than −50 °C. They noted that feed rate, rotor speed, sieve opening sizes is some important design parameters for developing cryogenic grinder for spices. Since then, some bench top models of cryo-grinders were developed by various researchers including Jacob et al. (2000) consisting pin mill with 120 kg/h capacity for black pepper. Goswami and Singh (2003) used an attrition mill for cumin seed grinding with varying temperature and feed rates. They found higher feed rate with ambient temperature resulted in temperature rise, coarser particles (105.9–158.2 μm) and lower specific energy consumption while finer particle size obtained with low temperature that is, −40 °C. Wilczek, Bertling, and Hintemann (2004) experimented with viscoelastic and plastic materials to improve grinding efficiency by making the material more brittle with the use of LN_2. Other grinding parameters viz., feed rates and product temperatures were studied by Murthy and Bhattacharya (2008) in black pepper by employing cryogenic pin mill. These two parameters have shown significant influence on volatile oil content as well its constituents. However, these laboratory scale cryogenic grinding systems cannot be directly scaled up because the phenomenon of gas circulation, heat and mass transfer, control systems for gas flow, type of grinder may be quite different for higher capacity. Despite of significant advantages of cryogenic grinding of spices over conventional grinding (listed in Table 1), due to higher investment of setting up the plant resulted in higher cost of final product. It was felt that a consortium of different Institutes working on the same line is needed to generate basic research information and data base for designing a commercial scale cryogenic grinding system. Hence, a mega project was formulated to study different aspects in designing of cryogenic grinder especially suitable for Indian spices and the same was sanctioned to Central Institute of Post-Harvest Engineering and Technology in 2009 under National Innovation Project (NAIP) supported by World Bank and implemented by Indian Council of Agricultural Research New Delhi, India. Main objective of the project was to create a data base of physico-chemical, mechanical, and thermal properties of some important Indian spices as well as to design and develop cryogenic grinding system for spices with commercial application. During the project period study was done on selected spices viz., coriander, fenugreek, black pepper, turmeric, and cinnamon in reference to their physical and thermal properties, grinding kinetics, particle size distribution, energy requirement, and quality attributes in

TABLE 1 Advantages of cryogenic grinding over conventional grinding

Parameter	Traditional grinding	Cryogenic grinding	Source
Energy requirement Grinding output Grinding of soft material Sieve clogging Motor capacity Fire risk Color of ground powder	High Low Very difficult Frequent High High Not original	Low High Possible No clogging Low No Retain original color	Singh and Goswami (1999a, 1999b, 2000) Meghwal and Goswami (2014); Murthy and Bhattacharya (2008); Goswami and Singh (2003)
Loss of essential oil Loss of total oil Composition of essential and total oil Retention of medicinally important compounds	Higher Significant Not original Less retention	Minimum Minimum As in intact seeds More retention	Andres (1976); Wolf and Pahl (1990); Saxena et al. (2010, 2014, 2015; Sharma et al. 2016)
Control on particle size	No control	Effective	Anon (1962); Gopalkrishnan et al. (1991); Miller (1951); Wistreich and Schafer (1962)
Air pollution Microbial load	Yes Possible	No Does not exist	http://spectracryogenic.tradeindia.com.

cryogenic and conventional grinding system to design and develop indigenous cryogenic grinder.

The data base on physical properties like size, shape, true density, coefficient of friction, angle of repose, thermal properties like thermal conductivity, specific heat, thermal diffusivity, freezing point and latent heat of fusion of the spices, the mechanical properties like force-deformation characteristics, brittle point/fracture point, flavor profile, and medicinal properties of the selected major spices have been generated during the project period. All these properties were useful in modeling of heat and mass transfer in grinding and designing a cryogenic grinding system. The literature on design and development of pre–cooling and liquid nitrogen injection system in a mill was not available. The design methodology on these systems for a spice grinder had added to the scientific knowledge and was a contribution in the area of spice processing. Another objective of the project was to apply the concept of heat transfer in liquid and gaseous zones, liquid consumption for initial cooling of grinding components, and grinding of different spices.

4.1 | Physico-mechanical properties of turmeric rhizomes, cinnamon bark, black pepper, fenugreek, and coriander seeds

Physical properties of three grades of turmeric (*Curcuma longa*) rhizome (*cv.IISR alleppey supreme)* and cinnamon (*Cinnamomum verum*) bark (*cv. Nityashree*) were determined by Balasubramanian and Mohite (2012a, 2012b) and Balasubramanian, Kumar, Singh, Zachariah, and Vikram (2013). The length, volume, surface area, porosity, and angle of repose varied significantly with respect to grades for both the spices. Studies on power and specific energy requirement, different energy law constants, size and oil content for ambient and cryogenic ground black pepper and temperature effect on thermal properties of black pepper was analyzed by Meghwal and Goswami (2010, 2011). They concluded that less specific energy and power is requirement, improved color and higher volatile in cryo ground black pepper powder. Balasubramanian et al. (2013) found geometric properties and porosity characteristics were genotype dependent and vary with moisture content in black pepper. Seed moisture content is another important parameter affecting grinding of spices. Physico-mechanical properties of fenugreek seeds (*Cv* AM-2 and RMt-1) showed a linear increase with increased seed moisture content (5.4–25.2% db). However, bulk and true density of both the cultivars decreased linearly (Barnwal et al., 2013; ICAR, 2014).

Seeds physical properties of two coriander genotypes (RCr-41 and ACr-1) were also determined at variable moisture level (3.7–14.3%, db) by Balasubramanian, Kumar, and Singh (2012). Later, coriander seeds and powder were also evaluated for grinding parameters, thermal characteristics and antioxidant potential as affected by different grinding techniques that is, pin and hammer mill by Barnwal et al. (2015a). Grinding with hammer mill was found better in terms of thermal conductivity and product yield. Moisture content in seeds of coriander, fenugreek, and black pepper affect thermal properties. A nonlinear increase was observed with increased moisture in seeds. Specific heat also increased with increased moisture level. Thermal diffusivity of black pepper, coriander, and fenugreek increased nonlinearly with increase in moisture level at 30 °C (ICAR, 2014).

4.2 | Development of cryogenic grinder for spices

Analysis of physico-mechanical properties including geometric mean diameter, sphericity, surface area, unit volume, bulk density, true density, angle of repose, coefficient of friction, hardness, rupture force, deformation and energy absorbed, and so forth of feeding material will be helpful in designing of feeder type, screw diameter and length, conveyor selection, residence time, grinder capacity, cooling load and optimization, feed rate, rotor speed, energy consumption, deformation pattern, fineness modulus of end product of cryogenic grinder (Balasubramanian, Gupta, & Singh, 2012; Balasubramanian, Kumar, & Singh, 2012). A lab model cryogenic grinder (M/s Hosakowa Alpine, Germany, Model 100 UPZ) was used by scientists of CIPHET, Ludhiana and IIT, Kharagpur for comparative evaluation of grinding parameters. This grinder consisted of liquid nitrogen (LN_2) dewar of 50 L capacity. Grinding of spice was performed at different feed screw speed. To carry out normal grinding, LN_2 dewar was detached during grinding. The grinding characteristics and value of energy constants, specific energy consumption, and particle size of spices like black pepper, fenugreek, coriander, cinnamon, and turmeric were less in cryogenic grinding as compared to ambient grinding. (ICAR, 2014). Barnwal, Singh, Kumar, and Zachariah (2013) found quadratic relationships with moisture content while studied thermal conductivity and diffusivity of cryo-ground black pepper powder. The specific heat was affected significantly with moisture content and temperature. Barnwal et al. (2014,b,c) also studied selected physico-mechanical characteristics of fenugreek, cinnamon and turmeric. They observed more thermal conductivity and better color in cryogenically ground turmeric with varying moisture contents. Studies have shown that cryogenic grinding is more energy efficient as compared to conventional grinding technology.

Meghwal and Goswami (2014) used different kind of mills and compared them for both the grinding techniques for seeds of fenugreek and black pepper. Rotor, hammer, and pin mills were found suitable for continuous grinding at a large scale whereas ball mill for small scale grinding. They reported significantly less specific power consumption during cryogenic grinding. During grinding at ambient temperature, seed oil and powder stuck with grinder's lid and clogging of sieves occur. The clogging of the sieve was found to decrease as the grinding temperature decreased for the same sieve opening and vice-versa. (ICAR, 2014).

Based on preliminary studies of grinding characteristics of selected spices a design was prepared for fabrication of cryogenic grinder at CIPHET, Ludhiana (India). In designing of cryogenic pre-cooling unit, the thrust was given on insulation material as LN_2 quickly evaporates at ambient temperature. Heat loss during cooling occurs due to feed and construction materials. Therefore, the outer casing kept properly insulated to avoid the cooling heat losses. In an earlier study, Singh and Goswami (1999) estimated 20% cooling heat loss during cryogenic pre-cooling process and cooling load in liquid and gaseous zone was about 70% and 30%, respectively. Apart from this retention time that is, time required to attain desired temperature of spices was also considered during designing of cryogenic grinder. The retention or freezing time was calculated using modified Plank's formula and the ability of the pre-cooling screw conveyor was derived using standard relation (Singh and Goswami 1999). Thermocouple and temperature controllers were used to control and monitor the temperature within the screw conveyer, grinding chamber, and collector pan of grinder.

A cryogenic spice grinding system (capacity: 30–35 Kg/h) with cryogenic pre-cooling unit (capacity: 30–35 Kg/h) was designed at CIPHET, Ludhiana. It is compact, novel, and unique system scientifically designed having provision of accommodating both hammer and pin mills. All the operational parameters could be controlled precisely through a control panel. The provision has been made to re-circulate the used LN_2 vapor to inlet of the pre-cooling system which saves the consumption of the LN_2 and makes the system economical. Adequate safety measures have been provided to protect the grinder from unforeseen circumstances. Figure 1, describes the schematic diagram and engineering drawing of cryogenic grinder and Figure 1 is the developed cryogenic grinder for spices at CIPHET, Ludhiana. Later, the performance of developed cryogenic grinder was assessed by co-workers of the project at ICAR-NRCSS, Ajmer, and ICAR-IISR, Calicut by evaluating quality and therapeutic potential of ground powders of various spices including coriander, fenugreek, cumin, ajwain, turmeric, cinnamon, and black pepper.

Comparative analysis of ambient ground and cryogenic ground spice powders was done for major spices. Saxena et al. (2014, 2015) took nine coriander genotypes and found significantly more phenolics and antioxidant contents in seed powder ground using cryogenic grinder. They also analyzed essential oil for its constituents of these genotypes. The major constituent linalool was significantly more in seed powder ground cryogenically.

Similar to the coriander, Sharma, Agarwal, Rathore, and Saxena (2016) analyzed the technology by grinding seeds of two contrasting genotypes of cumin, Gujarat Cumin-4 and RZ-209 at ambient and cryogenic temperature. They reported that cumin seeds loose significant proportion of volatile oil (18–19%) while ground at ambient

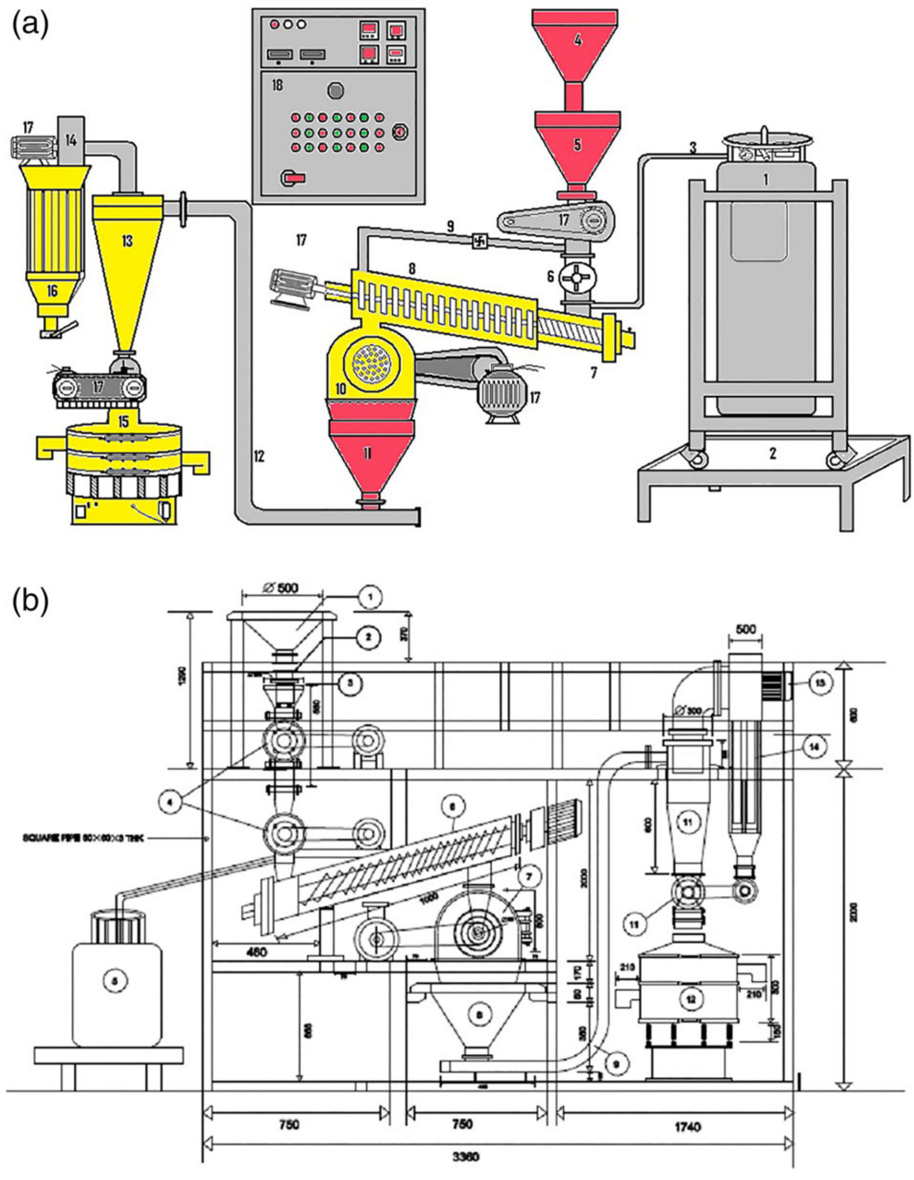

FIGURE 1 Continued on next page

FIGURE 1 (a) Schematic/line diagram of indigenous cryogenic spice grinding system (source: ICAR, 2014) (1. Liquid nitrogen cylinder, 2. Digital weighing balance, 3. Vacuum insulated pipe, 4. Feed hopper1, 5. Feed hopper 2, 6. Rotary valves, 7. Cooling screw conveyor, 8. Cryogenic pre cooler, 9. Recycling of LN2 vapor, 10. Dual mill [pin/hammer mill], 11. Collection hopper, 12. Pipe between collection hopper and cyclone, 13. Cyclone, 14. Blower, 15. Vibro sieving system, 16. Dust collector, 17. Electric motors, 18. Operators control panel) (source: ICAR, 2014). (b) Engineering drawing of cryogenic spice grinding system with cryogenic pre-cooler (source: ICAR, 2014). (c) Indigenous cryogenic spice grinding system (source: ICAR, 2014)

temperature which could be minimize in cryogenic grinding. Recovery of total seed oil also increased 28.28% in RZ-209 by cryogenic grinding. Later, Sharma et al. (2016) compared volatile oil and fatty oil constituents of cumin seed oil showed significant effect of cryogenic grinding. The compound cumineldehyde responsible for typical cumin oil flavor is found to increase on cryogenic grinding. Overall the oil extracted from cryo ground seeds powder was more fresh and pleasant. Similar results were obtained by Barnwal, Singh, Sharma, Choudhary, and Saxena (2015) while comparing ambient and cryogenic ground turmeric powder for its biochemical, antioxidant, and thermal properties.

Liu et al. (2013) also reported nonsignificant loss in color, flavor, and sensory qualities of different colored pepper on cryogenic grinding. The main flavor constituent is also better in this technology. Sharma, Agarwal, Meena, Rathore, and Saxena (2015) evaluated this technology for medicinally important compounds and antioxidant properties of ajwain genotypes. Volatile oil, total oil, total phenolics, and free radical scavenging percentage was significantly more in cryo ground powder irrespective of the genotypes. Effect of grinding technology was more in genotype AA-2 than genotype AA-93. Later Sharma et al. (2015) also found increased recovery of thymol content in *Trachyspermum ammi* seeds essential oil obtained from cryo ground seeds. Among 25 major compounds, recovery of monoterpene, thymol increased from 44.96 to 59.12% in AA-2 and from 39.91 to 60.12% in genotype AA-93 while another major constituent, γ- terpinene decreased from 33.61 to 22.67% in AA-2 and 39.83% to 28.17% in cryo ground samples of AA-93.

In another experiment, fenugreek an important seed spice better known for its medicinal properties was also ground with cryogenic and conventional grinding technology by Saxena et al. (2012). They analyzed the ground powder and reported more phenolics and free radical scavenging activity in cryo ground powder irrespective of the genotypes. It is reported that fenugreek seeds contain 0.1 to 1.5% diosgenin. Recovery of this commercially important compound from fenugreek seeds could be increased with cryogenic grinding. Saxena et al. (2013) analyzed diosgenin content from seeds of three genotypes of fenugreek namely AM-1, RMt-305, and RMt-1 ground by conventional and cryogenic grinding technology. Diosgenin percentage was significantly more in all three genotypes and ranging from 2.1 to 2.5% in cryo ground samples as compared to 1.3 to 1.5% in normal ground samples. They also found enhanced analgesic and antipyretic activities of *Coriandrum sativum* when ground with cryogenic technology (Saxena, Rathore, et al. 2014). Methanol seed extracts of coriander genotypes RCr-436 and Sudha administered as drug along with standard drug paracetamol-150. Seed extract cryo ground powder of genotype RCr 436 reduced the rectal temperature at par with paracetamol-150. They suggested that medicinal quality of coriander and similar herbs can be maintained at original level if this technology used in *Ayurveda* and other natural therapies for various ailments. Saxena (2015) also evaluated anti-cholestrolic potency of fenugreek seeds ground by conventional and cryogenic technology. High cholesterol diet was given for 15 days to different group of rats and the difference between various parameters were observed at 16th day. Control group rats were compared with standard drug simvastatin (100 mg/kg b.w.) and crude seed extract of fenugreek genotypes. The anti-cholestrolic activity was found in both the varieties of fenugreek but it was found more in cryo than in conventional ground extract of fenugreek.

Saxena (2015) also evaluated the acute effect of fenugreek seed extract (Var RMt 305 and RMt 1) per se on blood glucose level in alloxan-induced diabetic rats. Glucose level in control group rats with vehicle only was ranging from 92.51 to 93.34 mg/dL while alloxane induced diabetic rats showed maximum (296.86 ± 1.76 mg/dL) level of glucose after 4 hrs of administration. Alloxan (60 mg/kg, bw, p.o.) + Gilbenclamide (2.5 mg/kg bw, p.o.) administration showed lowering of blood glucose level from 279 mg/dL at 0 hrs to 212 mg/dL at 8 hrs. Seed extract of cryo ground seeds of fenugreek genotype RMt 305 was able to reduce the blood glucose level from 283.13 ± 1.53 mg/dL to 221.48 mg/dL which was higher than control and at par with common drug gilbenclamide. Ambient ground seeds extract was also producing similar results but with lesser magnitude.

Sharma (2017) conducted experiments with methanol and hexane crude seed extract of cumin and ajwain genotypes obtained after grinding with cryo and non-cryo ground technology. He evaluated crude seed extract of cumin and ajwain for anti-microbial, anti-inflammatory, anti-diabetic, hepatoprotective, and diuretic activities using albino mice. Findings were suggestive of superiority of cryogenic grinding technology over traditional grinding for retention of medicinal properties of seed spices. For antimicrobial properties, he took two gram-positive (*Staphylococcus aureus*, *Streptococcus pyogenes*) and two gram-negative bacteria (*E. coli*, *P. aeruginosa)* and measured zone of inhibition by seed extract and compared with standard antibiotic. The anti-fungal effects of the extracts were investigated using Agar Diffusion test (Sabouraud dextrose agar and PDA test) on two species of fungal strain *Candida albicans and Aspergillus clavatus*. Seed extracts of cryo ground technology proved better than noncryogenic grinding for both activities. As cryogenic grinding was able to retain more phenolic, flavonoid, and essential oil contents compared to non-cryo-ground seeds, thus showed considerably more antibacterial and antifungal properties.

Anti-inflammatory properties of cumin (*Cuminum cyminum* L.) and ajwain seed extract were also found to increase by cryogenic grinding technology. Carrageen induced acute inflammation study was conducted on male or female wistar albino rats-with a body weight between 150 and 200 g by Sharma (2017). Methanol extract of cryogenic ground seeds was more effective in reducing paw oedema volume than non-cryo ground seeds extract even at the dose of 200 mg/Kg. Similar results were obtained with genotype RZ-209. Where dose of 400 mg/Kg was able to reduce paw oedema volume up to 3.6 as compared to 6.7 in caragennan treated model. Similar results were obtained with ajwain genotype AA-2.

5 | CONCLUSION

Review of work done for application of cryogenics in the field of food processing especially spice grinding established the usefulness of this technology in value addition of spices. The series of experiments studied design parameters of grinder suitable for spices and comparative superiority of ground product and better acceptability in terms of color and particle size of final product. Major constituents of essential oil from most of the spices viz., cumineldehyde in cumin, linalool in coriander, anethol in fennel and anise, thymole in ajwain showed significant increase in cryo ground seed powder irrespective of the genotypes. However, more research is needed to cut down the initial cost of installation of cryo-grinder. Government initiatives are required to make the technology feasible for mass-scale production of cryogenic grinder for spices to boost up the domestic and the export market. For demonstration purpose, pilot plants may be established and operated on cooperative basis by group of spice growers and processors considering economics higher quality end-product characteristics with minimum price. This technology has immense potential in value addition in seed spices for domestic as well as export promotion.

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