Cryogenic Grinding: The Future of Spice Processing for Maximum Flavour Retention

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Introduction

Spices are integral to cuisines worldwide, adding distinct flavours, aromas and medicinal properties to food. The processing of spices particularly significantly impacts their grinding, quality. Traditionally, spices were ground using a stone mortar and pestle, where the heat generated by friction was absorbed by the stone, allowing the spices to retain their full flavour and aroma. In modern times, spices are ground mechanically in grinders and mixers, where there is no mechanism to reduce the heat generated by friction, resulting in a loss of flavour and aroma. This is why food prepared with freshly ground spices is often tastier than that made with pre-packaged spices, which lose their aroma and taste due to large-scale grinding and packaging. In today's fast-paced lifestyle, people rarely have the time to grind their spices fresh and therefore opt for packaged ones. To counteract the loss of aromatic compounds caused by heat, cryogenic grinding can be employed, as it effectively eliminates this issue. Traditional grinding methods generate heat $(42^{\circ} \text{ to } 93^{\circ} \text{ C})$ due to friction, leading to the loss of volatile essential oils, reduced flavour and degradation of active compounds (Harichandra bp, 2021). To counter these issues, cryogenic grinding has emerged as a revolutionary technology in spice processing. This method ensures the retention of essential oils, oleoresin content and anti-oxidant properties (Saxena et al., 2013 and Sharma et al., 2014). It also enhances shelf life and preserves the natural aroma and colour of spices. As demand for high-quality spice powders increases, cryogenic grinding is becoming the preferred technique for spice manufacturers. It is energy efficient method, reduces waste and leads to circular economy (Kotyal K., 2023).

Cryogenic Grinding

Cryogenic grinding is a process where spices are ground at extremely low temperatures (-196°C) using liquid nitrogen or dry ice (-78.5°C) to prevent the loss of volatile compounds. This method is highly effective in retaining the essential oils and active components of spices, ensuring superior product quality compared to conventional grinding techniques. Major seed spices like cumin, coriander, black pepper, ajwain, fennel, fenugreek, mustard, dill, cinnamon, turmeric, celery and caraway are suitable for cryogrinding. By utilizing cryogenic grinding for these seed spices, manufacturers can significantly enhance product quality, ensuring superior flavour, aroma and shelf life in spice powders used for culinary and medicinal applications. Cryogrinding retains the colour of the spices like turmeric and cinnamon compared to the normal grinding (Barnwal *et al.*, 2014).



Fig. 1. Process of Cryogenic Grinding

Cryogrinding involves several steps as shown in the Figure.1 to control the temperature rise the spices are pre-cooled using liquid nitrogen or dry ice and then it is subjected to grinding. Due to the low temperature the spices become brittle and grind easily. Based on the size of the particle they ground mixture separated by sieving and packed. In large scale industries the principle remains same and it has well mechanized grinding system as shown in Figure 2.



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Advantages of Cryogenic Grinding

Cryogenic grinding offers several advantages over conventional grinding methods:

1. Retention of Aroma and Flavour

The primary benefit of cryogenic grinding is that it retains the essential oils and flavour compounds of spices, ensuring a more intense and aromatic final product.

2. Improved Product Quality

Spices processed using cryogenic grinding maintain their natural colour, texture and nutritional value, making them superior in quality.

3. Extended Shelf Life

By preventing oxidation and microbial contamination, cryogenic grinding extends the shelf life of spices, reducing the need for artificial preservatives.

4. Energy Efficiency

Traditional grinding requires excessive mechanical energy to break down spices, generating heat. Cryogenic grinding reduces energy consumption by making the spices brittle, leading to efficient grinding with less effort.

5. Reduced Waste and Losses

Heat-sensitive components are preserved, reducing wastage and ensuring maximum utilization of raw materials. It leads to zero wastage and hence leads to circular agriculture and economy (Kotyal K., 2023).

Applications of Cryogenic Grinding in the Spice Industry

Cryogenic grinding is widely used in the spice industry for processing various heat-sensitive spices, including:

- 1. **Black Pepper:** Retains piperine content, responsible for pungency.
- 2. Cardamom: Preserves its aromatic compounds.
- 3. **Cumin:** Prevents loss of essential oils and strong flavour.
- 4. **Turmeric:** Enhances curcumin retention, known for its medicinal properties.
- 5. **Ginger:** Maintains its pungency and active biocompounds.
- 6. **Cloves:** Ensures the preservation of eugenol, its primary flavour compound.

Beyond the spice industry, cryogenic grinding is also applied in pharmaceuticals, food processing and

herbal medicine production, where temperaturesensitive ingredients require special handling.

Challenges and Limitations of Cryogenic Grinding

While cryogenic grinding offers numerous benefits, it also presents some challenges:

1. High Initial Investment

The cost of cryogenic grinding equipment and liquid nitrogen storage systems is higher than conventional grinding setups, making it a significant investment for small-scale spice manufacturers.

2. Handling and Safety Concerns

The use of liquid nitrogen requires careful handling and specialized training to prevent accidents or injuries.

3. Availability of Liquid Nitrogen

Access to a steady supply of liquid nitrogen can be a logistical challenge in some regions, affecting the feasibility of large-scale adoption.

Despite these limitations, the long-term benefits of cryogenic grinding outweigh its challenges, making it a viable solution for producing premiumquality spice powders.

Future Prospects of Cryogenic Grinding

With increasing consumer demand for highquality, natural and preservative-free food products, the future of cryogenic grinding in the spice industry looks promising. Research and technological advancements are focused on:

- 1. Developing cost-effective cryogenic grinding systems for small and medium-sized enterprises.
- 2. To reduce the operational cost integrating with automation and AI (Kotyal *et al.*, 2024) can reduce the cost of production.
- 3. Expanding cryogenic grinding applications to other food products, pharmaceuticals and nutraceuticals.
- 4. Sustainable alternatives for liquid nitrogen to reduce environmental impact and opting sustainable agriculture (Beleri, P., 2023).

As awareness about food quality and safety grows, more manufacturers are expected to adopt cryogenic grinding to enhance their product offerings and maintain a competitive edge in the market.

Conclusion

Cryogenic grinding is a game-changing technology in the spice industry, ensuring maximum

retention of flavour, aroma and nutritional properties. By addressing the limitations of conventional grinding methods, it provides a superior alternative for processing heat-sensitive spices. Despite initial costs, the long-term advantages in terms of quality, efficiency and shelf life make it a worthwhile investment. Adapting a climate smart strategy also leads to sustainability. As the demand for high-quality spice powders continues to rise, cryogenic grinding is poised to become the future of spice processing, offering consumers and manufacturers a sustainable and effective solution.

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