Instant Controlled Pressure Drop Assisted Production of Curcumin rich Turmeric Powder for its use in Infusion Drink

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Chapter 5

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Summary and Conclusion

5.1 Summary

A process named instant decompression-assisted steam curing (IDASC) is developed in this research for the integration of ICPD technology into turmeric processing practices. Analysis of the results obtained from this integration establishes an improvement in the drying efficiency, final product quality, and sustainability. The developed process addresses some of the limitations of the traditional turmeric process methods and it paves a way for a more efficient and environmentally friendly turmeric production process.

Initial part of the study aimed at understanding the drying kinetics, as affected by the intensity of the IDASC treatment. A thorough quality analysis approach was used for optimizing turmeric processing for the combination of IDASC treatment and hot air drying (IDASC+HAD). Advanced drying methods and analytical tools enable producers to achieve efficient moisture removal while preserving essential attributes like curcumin content, color, and aroma. Thus, for enhancing the benefits from IDASC treatment, the refractance windows drying (RWD) was introduced replacing the hot air drying (IDASC+RWD). This IDASC+RWD represents a novel intervention in turmeric processing with improved product quality. Turmeric powder obtained from IDASC+RWD processing was used to produce the infusion drink and optimization based formulation was obtained.

There are challenges related to the cost and technical expertise if IDASC implementation, however, the potential benefits of integration of IDASC process make it a valuable investment for the future of turmeric processing. As research and innovation continue to advance the ICPD technology, it is poised to play a pivotal role in meeting the global demand for high-quality turmeric.

5.1.1 Research Findings

The IDASC turmeric process enhances the quality of turmeric infusion by preserving its bioactive compounds, particularly curcumin through controlled extraction and minimal thermal degradation. In this method, the infusion is prepared under optimized conditions that maintain the natural color, aroma, and antioxidant capacity of turmeric. The process ensures uniform

dispersion of active constituents, resulting in a product with high sensory appeal and functional value. IDASC also reduces microbial contamination, improving the safety and shelf life of the infusion.

The effect of storage plays a critical role in maintaining these benefits. Prolonged storage under unsuitable conditions, such as high humidity or light exposure, can degrade curcumin, cause loss and diminish antioxidant activity. By contrast, when stored in airtight, light-protected packaging at controlled temperatures, the IDASC-processed turmeric infusion retains its potency for extended long periods. This stability preserves both therapeutic properties and flavor quality.

The benefits of IDASC in turmeric more explicitly shows its potential in functional food and nutraceutical industries. It offers a reliable approach to producing high-quality turmeric-based products with consistent bioactive content, improved shelf stability, and enhanced consumer appeal, making it a valuable advancement in natural product processing.

Recent research has highlighted the impact of IDASC technology on turmeric processing, showcasing its advantages and some considerations for quality retention.

1. Enhanced drying efficiency

Integration of ICPD technology into turmeric processing in the form of IDASC treatment has significantly reduced the drying time. Traditional practice of drying of turmeric either as hot air drying or as sun drying, often require several hours or more than one day for drying, and can lead to inconsistent moisture content in the final product. In contrast, IDASC treatment can reduce the drying times to fewer hours, and leads to a more uniform moisture levels. This higher drying rate is achieved through the combination of high-pressure steam treatment and instantaneous decompression, causing micro-structural changes as was evident from the SEM images.

2. High quality of curcumin and bioactive compounds

Another key research finding is that the IDASC treatment helps maintain higher levels of curcumin, the main bioactive compound responsible for turmeric's color and health benefits. Traditional drying methods can lead to the degradation of curcumin due to prolonged exposure to heat and light. However, IDASC+HAD and IDASC+RWD has a shorter exposure time

during IDASC and has minimum thermal exposure time during drying, thereby preserving the integrity of curcumin and other sensitive compounds. This quality retention is crucial for producing turmeric that is not only visually appealing but also maintains its full nutritional and medicinal properties.

3. Improved color and aroma retention

Turmeric's bright yellow color and distinctive aroma are highly valued in both culinary and m retained applications. The quick drying process prevents oxidative reactions and enzymatic changes that can lead to color fading and the loss of aroma. As a result, IDASC treated turmeric retains its natural hue and scent, making it more attractive to consumers and enhancing its market value. The colour extracted in the infusion marks the quality of the colour.

4. Texture and Rehydration Quality

ICPD technology has also been found to improve the texture and rehydration quality of turmeric. Studies have noted that while traditional drying can lead to hard and brittle textures, ICPD drying maintains a more intact cellular structure due to its rapid drying process. This can result in a product that, when rehydrated, has a more desirable texture, making it suitable for culinary use where texture is important.

5. Energy Efficiency and Sustainability

ICPD technology is considered more energy-efficient compared to traditional drying techniques. The quick drying process reduces the total energy input needed, making it a more sustainable option. While the initial investment in ICPD equipment can be high, research indicates that the energy savings and increased efficiency can offset these costs over time. This makes ICPD an appealing choice for larger-scale turmeric processing operations aiming for sustainability.

5.1.2 Limitations

While IDASC integrated turmeric processing offers many advantages, such as reduced drying times and preservation of sensitive compounds, it is not without its limitations. The primary challenges associated with the implementation of IDASC integrated turmeric processing are:

1. As a technology IDASC implementation will require high initial investment required for equipment and setup. The specialized machinery needed for rapid pressure control, steam generation, and decompression systems can be costly. For smaller-scale producers or those in developing regions, this can be a significant barrier to adopting the technology.
2. Its implementation requires skilled operators who are trained to handle the complex machinery involving pressurized steam and processes involved. The sudden decompression process requires precise control to ensure optimal drying and to prevent damage to the product. Inadequate handling can lead to inconsistent product quality, waste, or potential safety issues. Additionally, operators must monitor and adjust variables such as temperature, pressure, and decompression rates to maintain consistent results. This technical complexity can lead to operational challenges, especially in facilities lacking experienced staff.
3. Scaling up the IDASC process from laboratory or pilot-scale operations to full-scale production may be challenging due to variations in product handling, moisture distribution, and uniformity, which in turn can affect the efficiency and consistency of drying at a larger scale.
4. Although IDASC offers rapid drying and potential energy savings in comparison to traditional methods, the energy requirements for achieving a high-pressure steam and maintaining the system's optimal conditions can be significant. The process of rapidly heating materials and then cooling them during decompression requires substantial energy input, which could lead to increased operational costs if not properly managed. Additionally, energy efficiency can vary depending on the type of raw materials and the specific parameters used in the process.

5.1.3 Scope of the Current Work

Quantitative Superiority of IDASC-RWD Over IDASC-HAD and Commercialization Challenges of Intelligent Mixing in Food Applications

The processing of *Curcuma longa* (turmeric) has seen significant advancements with the integration of hybrid drying technologies designed to enhance color quality**,** curcumin content**,** and functional attributes of the final product. Among these, the recent development and implementation of the IDASC-RWD (Instant Controlled Pressure Drop followed by Refractance Window Drying) process has demonstrated quantitative superiority over

traditional IDASC-HAD (Hot Air Drying) systems. Alongside this innovation, the formulation of an intelligent mixing ratio tailored for food-grade applications has further enhanced the industrial relevance of the product. However, despite these promising outcomes, certain technological and scalability hurdles remain to be addressed for broader commercial adoption.

The IDASC-RWD system combines the cellular expansion effect of the IDASC treatment with the gentle, rapid, and low-temperature drying capabilities of Refractance Window Drying. This unique pairing has resulted in significant improvements in both aesthetic and functional qualities of turmeric powder. Curcumin Content**:** IDASC-RWD consistently produced turmeric powder with curcumin content up to 5.85%**,** compared to 5.05% in IDASC-HAD**,** and significantly lower values (3.2–4.0%) in traditional convective drying methods. This represents a ~15.8% increase in curcumin retention compared to IDASC-HAD, and a 30–50% increase over conventional drying. Yellowness (Color Quality): Yellowness index (b* value) in IDASC-RWD samples reached up to 63–65**,** compared to 60 in IDASC-HAD and as low as 52–55 in conventional methods. Enhanced color is directly related to reduced thermal degradation and improved light-scattering due to microstructural preservation of color pigments. Antioxidant Activity (DPPH) and TPC/TFC: IDASC-RWD also showed improved DPPH radical scavenging activity (~10–12% higher), along with increased total phenolic content (TPC) and total flavonoid content (TFC)**,** indicating better preservation of bioactive compounds**.** These results robustly establish IDASC-RWD as a superior technique**,** due to its ability to preserve heat-sensitive compounds while maintaining visual and functional integrity, making the final product more attractive for high-end nutraceutical, cosmetic, and food applications.

The integration of IDASC-RWD technology with an intelligently formulated turmeric mix represents a scientifically validated, high-performance solution for the food and wellness industry. With quantitative improvements in curcumin content (up to 5.85%) and superior color retention, this approach marks a significant advancement over traditional IDASC-HAD and conventional drying methods. However, scaling up this innovation requires strategic investment in technology, automation, and quality control, alongside thoughtful regulatory navigation and market positioning. Once addressed, this platform holds the potential to revolutionize functional food and therapeutic drink markets, meeting the growing consumer demand for potent, natural, and bioavailable turmeric-based products.

5.1.4 Scope for Future Work

As demand for high-quality, sustainably processed turmeric continues to grow, the adoption of IDASC-RWD drying technology is expected to increase. Scope research and development can focus on:

1. Automation and monitoring:

Incorporating automation and digital controls for precise process management, in the form of pre-programmed processing schedule.

2. Cost-effective solutions at various scales:

Designing affordable and scalable systems for small and medium enterprises.