Abstract

Turmeric (Curcuma longa L.), a vital spice and medicinal plant, is prized for its bioactive compound curcumin, known for its antioxidant and therapeutic properties. However, preserving curcumin during processing is a significant challenge, necessitating innovative techniques to enhance quality while optimizing efficiency. This study explores the potential of Instant Decompression-Assisted Steam Curing (IDASC) in combination with Hot Air Drying (HAD) to improve turmeric powder quality. By integrating advanced methodologies, such as Response Surface Methodology (RSM) and Particle Swarm Optimization (PSO), the research aims to enhance the drying efficiency, curcumin retention, and color quality of turmeric powder while minimizing drying time and energy consumption. The IDASC treatment involves high-pressure steam exposure followed by a rapid decompression, which induces porosity and facilitates moisture removal. Turmeric slices, after undergoing IDASC, were subjected to optimized drying conditions using HAD to achieve ideal moisture levels. Process parameters treatment pressure, treatment time, and drying temperature were fine-tuned through a hybrid RSM-PSO approach to achieve optimal outcomes. The study identified 3 atm pressure, 50 seconds of treatment time, and 57°C drying temperature as the best conditions, resulting in a drying time of 325 minutes, a yellowness value of 60, and curcumin content of 5.05%. These results underscore the efficacy of IDASC-HAD in producing high-quality turmeric powder.

Comparative analysis revealed that turmeric processed through IDASC-HAD demonstrated superior functional properties, including enhanced antioxidant activity, total phenolic content, and flavonoid levels, compared to conventional boiling water curing and HAD (CBWC-HAD). Microstructural analysis using scanning electron microscopy (SEM) revealed expanded granular structures in IDASC-treated samples, attributed to the instant pressure drop during decompression, which increased surface area and improved moisture diffusivity during drying. This modification not only accelerated drying but also minimized degradation of bioactive compounds, enhancing curcumin preservation and yellowness value. The findings of this study emphasize the potential of IDASC-HAD as an advanced processing technique for turmeric and other bioactive-rich materials. The hybrid optimization approach further demonstrates its ability to streamline processes for maximum efficiency and quality.

The processing of *Curcuma longa* (turmeric) has undergone notable advancements through the integration of hybrid drying technologies aimed at enhancing color quality, curcumin concentration, and functional attributes. Among these, the IDASC-RWD (Instant Controlled Pressure Drop followed by refractance window drying) process has emerged as a superior alternative to the earlier IDASC-HAD (hot air drying) system. Coupled with the development of an optimized mixing ratio for food-grade applications, this innovation significantly boosts industrial relevance, although challenges in scalability and technology deployment remain.

The IDASC-RWD method merges the cellular expansion benefits of IDASC with the gentle, rapid, low-temperature drying of refractance window drying. This combination yields turmeric powder with up to 5.85% curcumin content about 15.8% higher than IDASC-HAD (5.05%) and 30–50% higher than conventional convective drying (3.2–4.0%). In terms of color, the yellowness index (b* value) reached 63–65, surpassing IDASC-HAD's 60 and the 52–55 range of traditional methods, a result of reduced thermal degradation and better pigment preservation. Functional properties also improved, with antioxidant activity (DPPH) increasing by approximately 10–12%, alongside higher total phenolic (TPC) and flavonoid content (TFC). By preserving heat-sensitive compounds while maintaining visual appeal, IDASC-RWD produces turmeric suited for high-end nutraceutical, cosmetic, and food applications. Integrating this technology with an intelligently formulated turmeric mix presents a scientifically validated, high-performance solution for the food and wellness industries.

Fuzzy logic sensory evaluation offers a precise method for assessing the complex sensory profile of a turmeric-based infusion mix containing honey, vanilla, lemon, piperine, and rock sugar. Traditional sensory scoring often struggles to capture nuanced perceptions, while fuzzy logic translates subjective responses into quantifiable data. Panelists evaluate attributes such as color, aroma, taste balance, mouthfeel, and aftertaste using linguistic scales, which the fuzzy model converts into membership functions and aggregated scores. In this drink, honey and rock sugar enhance sweetness, vanilla adds warmth, lemon imparts freshness, piperine boosts pungency, and turmeric provides earthy depth. Fuzzy analysis enables ranking of overall acceptability while identifying optimal ingredient ratios. This approach ensures consumer-driven refinement, supporting product development for functional, palatable, and market-ready turmeric drink.