

7.2 Instability of drying process parameters for Hangbaiju and optimization strategies

A second problem is the instability of Hangbaiju drying parameters, because different methods change active compounds, antioxidant properties, color, volatiles, and energy use in different directions. Drying process significantly affected bioactive constituents and antioxidant properties in Xiaobaiju and Taiju, and the suggested optimal oven conditions already differed by harvest type: 60 °C for Xiaobaiju and 70 °C for Taiju. More broadly, medicinal chrysanthemum studies found that the best oven temperature was about 55~65 °C, while optimal microwave power, microwave time, steam kill-enzyme time, and kill-enzyme time each had different windows (Shi et al., 2017). The absence of a single best method is reinforced by metabolomics showing that shade drying and heat drying produced significantly different flavonoids, phenolic acids, and terpenoids, with most key flavonoids and phenolic acids higher after shade drying (Chen et al., 2024).

Optimization should focus on process stabilization by product type, not one uniform drying recipe. For quality retention, moderate or staged heating performs better than excessive heat: multi-stage pulsed-vacuum drying better protected color, chlorogenic acid, luteolin, total phenolics, total flavonoids, and antioxidant capacity than higher-temperature schedules (Xu et al., 2022b). Targeted process intensification can further improve consistency, because tempering-incorporated infrared-assisted hot-air drying reduced drying time and energy use while increasing chlorogenic acid, luteolin, total phenolics, total flavonoids, antioxidant capacity, and volatile number (Xu et al., 2023). Pretreatment control is also critical: high-humidity air impingement kill-green shortened subsequent drying time by up to 46.15%, improved color through faster PPO and POD inactivation, and retained more phenolics, sugars, amino acids, and volatiles than steam kill-green (Xu et al., 2024). For premium products, microwave-hot air, pulsed vacuum, or freeze-drying can be selected when the priority is bioactive retention rather than lowest cost (Wang et al., 2019; Sun et al., 2021; Fan et al., 2024).

7.3 Incomplete quality evaluation system for Hangbaiju and optimization strategies

A third problem is that the Hangbaiju quality evaluation system is still incomplete, because traditional judgment by habitat or processing history alone neglects bioactive ingredients and functional quality. A spectrum-effect study on *Chrysanthemum morifolium* concluded that evaluation strategies based mainly on habitat and processing can deviate from true quality, and identified chlorogenic acid, 3,5-O-dicaffeoylquinic acid, 4,5-O-dicaffeoylquinic acid, and kaempferol-3-O-rutinoside as candidate Q-markers. Fingerprint similarity among 30 chrysanthemum samples ranged widely, and cluster analysis could divide them into multiple classes, showing substantial heterogeneity even within commercial materials (Lu et al., 2022). Methods that integrate chemical data with sensory traits are more discriminating: electronic tongue captured overall solution characteristics, and in Fubaiju the higher-grade group showed stronger saltiness and astringency together with better antibacterial activity (Yang et al., 2025).

Optimization should build a multi-indicator comprehensive evaluation model for Hangbaiju. A strong template is the combined use of chromatographic fingerprinting, multi-component quantification, antioxidant assays, and spectrum-effect relationships to define Q-markers and rank samples (Lu et al., 2022). Weighting methods such as analytic hierarchy process, followed by clustering, can convert multiple quality dimensions into comprehensive scores and grade categories (Zhao et al., 2022). Rapid instrumental models can support implementation: near-infrared hyperspectral imaging predicted luteolin and quercetin well in fresh and dry Hangbaiju, and newer clustering frameworks for edible chrysanthemum were proposed specifically to avoid information loss from using too few indicators (Xu et al., 2022b; Jing et al., 2024). In practice, the best strategy is to screen harvest-drying combinations against a weighted panel that includes marker compounds, antioxidant activity, aroma or sensory data, morphology, and where needed antibacterial or other functional endpoints.

8 Conclusion and Prospects

An appropriate harvest period is the basis for high-quality production of Hangbaiju because the flowering stage directly determines the accumulation of phenolic acids, flavonoids, volatile substances, antioxidant capacity, and even the sensory identity of the final product. Studies on Hangbaiju showed that harvest stage significantly affected functional constituents, with total flavonoids and chlorogenic acid highest at the Hualei stage,