

conditions should be reasonably optimized according to product type, so as to ensure sufficient release of functional components such as flavonoids and polyphenols while maintaining elegant floral aroma and a mild taste.

Drying and flavor preservation are key technologies in Hangbaiju tea beverage processing. Studies have shown that the developmental stage of floral materials and drying methods significantly affect the levels of polyphenols, amino acids, and volatile compounds in floral beverages, and suitable drying conditions contribute to better sensory quality (Xu et al., 2024). Hot-air drying, vacuum freeze-drying, and medium- to low-temperature drying can reduce damage caused by high temperatures to active components and aromatic substances to varying degrees, improving color retention, rehydration performance, and aroma stability. Among them, freeze-drying can better preserve the original structure and natural aroma of flowers, making it suitable for high-end Hangbaiju tea beverages and premium flower tea products. Hot-air drying is more suitable for large-scale production, where the balance between cost and quality can be achieved through temperature and time optimization.

Flavor preservation is also important during tea beverage production and storage. The characteristic fragrance of Hangbaiju mainly comes from volatile aromatic compounds, which are prone to loss through oxidation, light exposure, and temperature fluctuations during processing, concentration, sterilization, and storage. Research indicates that extraction temperature, extraction time, tea-to-water ratio, and mixing procedures are core parameters affecting the sensory quality of tea beverages; improper control may weaken characteristic aroma and lead to an imbalance among bitterness, sweetness, and umami (Moreira et al., 2024). Therefore, microencapsulation, low-temperature concentration, aseptic filling, antioxidant protection systems, and improved packaging can be used to reduce aroma loss and enhance clarity, color, and flavor stability during shelf life (Liang et al., 2021; Liang et al., 2022). In the development of compound Hangbaiju tea beverage products, analytical chemistry and sensory evaluation should also be combined to optimize the ratio of Hangbaiju with tea leaves, fruit juice, or medicinal and edible ingredients, thereby forming a rich and stable flavor system (Geng et al., 2026).

3.3 Product quality and safety control technologies

As consumers pay increasing attention to food safety and the quality of functional beverages, establishing a complete quality and safety control system has become an important guarantee for the development of the Hangbaiju tea beverage industry. High-value Hangbaiju tea beverages should meet multidimensional quality requirements covering chemical composition, microbiological indicators, contaminant levels, and sensory quality. At the raw material stage, testing for pesticide residues, heavy metals, microorganisms, and exogenous contaminants should be strengthened to ensure compliance with food safety standards. Emerging methods such as spectroscopy, electrochemical detection, nanozymes, computer vision, and chromatography can rapidly, cost-effectively, and non-destructively or minimally destructively determine physical, chemical, and contaminant indicators in tea products, and can be applied throughout the whole process from fresh raw material intake to final product evaluation (Yu et al., 2020; Bhargava et al., 2022). Among them, advanced chromatographic techniques can precisely quantify pesticides, heavy metals, and other exogenous risks, providing technical support for the safety control of Hangbaiju tea beverages.

At the processing stage, Good Manufacturing Practices (GMP), Sanitation Standard Operating Procedures (SSOP), and the Hazard Analysis and Critical Control Point (HACCP) management system should be strictly implemented to monitor key links such as raw material acceptance, pretreatment, extraction, concentration, blending, filling, sterilization, packaging, storage, and transportation throughout the process. Studies have shown that HACCP can identify critical control points and critical limits through hazard analysis, and control biological, chemical, and physical risks through monitoring and corrective measures, making it an important tool for tea-producing enterprises to improve food safety management (Kristiningrum et al., 2023). For Hangbaiju tea beverages, key control points should include raw material contamination, microbial load of extracts, sterilization intensity, packaging sealability, and storage and transportation temperature. Automated production equipment should also be used to reduce human contamination and improve product consistency.