and high-performance liquid chromatography (HPLC) for sugars and organic acids, have provided important data for studies on fruit quality formation.

Traditional sensory evaluation systems and standardized analytical methods remain important references in Chinese bayberry quality research. In studies on Chinese bayberry juice, evaluators trained according to Chinese GB/T and ISO standards used quantitative descriptive analysis to establish flavor descriptors such as sourness, sweetness, bitterness, and astringency. Combined with analyses of nine organic acids, three sugars, and total polyphenol content, partial least squares analysis was used to establish relationships between sensory flavor characteristics and key chemical compounds. In addition, manual sensory evaluation can also be used to determine thresholds for "off-flavor" formation during storage, such as identifying the transition point from normal flavor to deteriorated flavor under different storage temperatures (Gao et al., 2024). However, traditional methods generally suffer from limitations including sample destructiveness, time-consuming procedures, high labor intensity, and strong subjective variability, making them insufficient for the modern Chinese bayberry industry's demand for high-throughput, online, and rapid grading technologies.

### 5.2 Modern detection technologies

With the development of sensing technologies, spectral analysis, and chemometrics, modern detection technologies have been increasingly applied in Chinese bayberry quality research. In particular, non-destructive optical detection, electronic sensing, and volatile fingerprint analysis have provided faster, more objective, and data-driven approaches for quality evaluation. Color difference analysis objectively evaluates fruit color changes through comprehensive color parameters such as L, a, and b values. Digital image analysis, combined with image acquisition and computer processing, can rapidly analyze fruit size, shape, coloration, and surface defects, thereby improving the standardization of external quality evaluation.

Visible/near-infrared (Vis/NIR) spectroscopy is one of the earliest and most mature non-destructive technologies used in Chinese bayberry detection. Reflectance spectra within the 325-1075 nm range have been used to establish partial least squares models for rapid prediction of acidity and pH in intact Chinese bayberry fruit, showing high model correlations. Near-infrared transmittance spectroscopy has also been applied to predict titratable acidity, malic acid, and citric acid contents in different cultivars, demonstrating good application potential under temperature-controlled conditions. In recent years, hyperspectral imaging has further integrated spectral and spatial image information, allowing simultaneous prediction of single-fruit weight and soluble solids content, even for packaged fruit. After feature selection, PLS modeling, and model transfer correction, prediction stability across batches can be significantly improved (Yuan et al., 2025).

Electronic sensing technologies rapidly identify flavor quality by simulating human olfactory and gustatory systems. Electronic noses use multi-gas sensor arrays to monitor volatile flavor changes during storage. Combined with sensory evaluation and GC-MS analysis, they can identify stages of off-flavor formation and key volatile markers. Studies have shown that electronic nose response patterns change regularly with prolonged storage time and increasing temperature, allowing identification of off-flavor fruit stored for more than 2 days at 20 ℃ or more than 7 days at 10 ℃, which is associated with the accumulation of ethanol, benzaldehyde, octanoic acid, and other volatiles (Gao et al., 2024). By combining electronic noses with stochastic resonance signal processing and regression models, indicators such as firmness, color, pH, total soluble solids, and reducing sugars can also be predicted, demonstrating potential for low-cost and rapid overall quality evaluation.

Electronic tongues are mainly used to analyze taste characteristics such as sweetness, sourness, bitterness, and astringency. In Chinese bayberry juice analysis, electronic tongues combined with sensor arrays and discriminant analysis effectively differentiated juices from different origins and cultivars, while correlating electronic tongue signals with organic acids, sugars, total polyphenols, and sensory scores. In addition, HS-GC-IMS technology can establish volatile fingerprint profiles during storage of Chinese bayberry juice and NFC products, identifying off-flavor markers such as ethanol and ethyl acetate, thereby providing a new approach for monitoring processing quality and early warning of flavor deterioration (Xuan et al., 2022). Low-cost portable Vis/NIR devices have also