In addition, multi-environment GWAS studies in stone fruits have enabled researchers to distinguish between environment-shared QTLs and environment-specific QTLs, and have shown that some loci may have antagonistic effects across environments (Serrie et al., 2025). These results further demonstrate that G×E interactions are not only common but may profoundly influence quality breeding and the development of region-specific cultivation strategies. Incorporating G×E into QTL analysis, GWAS, and genomic prediction models can help identify stable trait loci and screen superior cultivars and management schemes suitable for different ecological regions. Therefore, a deeper understanding of G×E interaction mechanisms is of great importance for achieving precise matching between cultivars and environments, improving quality stability, and optimizing cultivation management. Future peach quality research needs to shift from "single-environment, single-trait" analysis toward a collaborative framework of "multi-environment, multi-omics, and multi-model" analysis in order to more comprehensively reveal the true sources of quality variation.

5 Methods for Evaluating Peach Fruit Quality

5.1 Physicochemical and sensory evaluation methods

Traditional methods for evaluating peach fruit quality mainly include physicochemical measurements and sensory evaluation. Physicochemical indicators are important for characterizing both internal and external quality and commonly include fruit size and weight, shape, density, peel and flesh color, firmness, soluble solids content (SSC, °Brix), titratable acidity (TA), pH, and sugar-acid ratio. These indicators are usually measured on harvested fruit. For example, calipers or image analysis are used to obtain fruit dimensions, shape index, and diameter; colorimeters are used to measure CIELAB color parameters; penetrometers or texture analyzers are used to determine firmness; refractometers are used to measure SSC; and titration is used to determine TA and pH. SSC is often regarded as an approximate indicator of sweetness, while TA and pH are used to characterize acidity. Firmness reflects not only texture status but is also closely related to harvest maturity and postharvest performance. Studies have shown that these physicochemical traits often vary significantly among cultivars or maturity stages. For example, late-ripening cultivars may have larger fruits and brighter coloration, but not necessarily the highest SSC or perceived sweetness (Farina et al., 2019).

To improve the interpretability of quality assessment, some studies have developed derived indices based on physicochemical measurements, such as sweetness index, total sweetness index, maturity index, and sugar-acid balance index, to integrate complex physicochemical composition into more interpretable quality scores (Popova et al., 2021). These approaches help move traditional physicochemical data from "single-trait measurement" toward "comprehensive quality characterization," making them valuable for cultivar comparison and maturity evaluation. However, whether a fruit is ultimately accepted by consumers still depends on actual sensory experience. Therefore, sensory evaluation serves as an important bridge linking physicochemical indicators with eating quality. Sensory evaluation is usually performed by trained panels or consumer panels, which quantitatively score attributes such as aroma, sweetness, sourness, bitterness, astringency, juiciness, texture characteristics (e.g., firmness, crispness, fibrousness, mealiness), and overall acceptability, commonly using 9-point or 15-point scales (Table 1) (Felts et al., 2019; Sun et al., 2023). Studies have shown that SSC and TA are good predictors of sweetness and sourness perception, but more complex sensory attributes—such as fruity aroma, flavor intensity, and flavor harmony, still require direct sensory evaluation. For example, higher firmness is often associated with sourness and unripe flavor, while larger fruit tends to be perceived as juicier or more overripe (Felts et al., 2019).

In recent years, with the development of comprehensive quality evaluation concepts, researchers have increasingly tended to integrate physicochemical and sensory data. Through principal component analysis (PCA), cluster analysis, or comprehensive scoring methods, it is possible to identify cultivar types that exhibit "good appearance but average flavor" or "ordinary appearance but outstanding internal flavor," thereby providing more refined criteria for breeding and cultivation management (Muto et al., 2022). Therefore, physicochemical measurements and sensory evaluation are not mutually substitutive but together form the basic framework for peach fruit quality assessment.