

processes, thereby regulating the accumulation of sugars, organic acids, and aroma compounds (Shin et al., 2023; Zhen et al., 2025). Meanwhile, management practices—including cultivar selection, pruning methods, crop load regulation, irrigation and fertilization, and protected cultivation—also significantly affect fruit quality. However, complex interactions among genotype, environment, and management (“G × E × M”) result in substantial variation in quality expression under different conditions, while existing studies largely focus on single factors, lacking systematic investigation. At the same time, quality evaluation methods are evolving from traditional physicochemical indices toward multi-index integration and non-destructive detection. Technologies such as visible–near infrared (Vis/NIR) spectroscopy and multivariate models provide new tools for rapid quality assessment (Mosie et al., 2025), supporting the development of standardized evaluation systems and high-quality production.

This study focuses on peach fruit quality traits under different cultivation conditions, aiming to elucidate their components and variation patterns, with particular emphasis on the mechanisms by which environmental factors and horticultural practices influence quality formation. Furthermore, it summarizes current methods for evaluating fruit quality and maturity, and explores the application potential of multi-index comprehensive evaluation and non-destructive detection technologies in peach quality research, production regulation, and postharvest grading. By integrating agronomic, physiological, and analytical perspectives, this study seeks to provide a theoretical basis and technical support for optimizing peach cultivation, improving quality stability, and promoting the high-quality development of the peach industry.

2 Types of Peach Fruit Quality Traits

2.1 External quality

External quality is the primary basis for consumers to evaluate the commercial value of peaches, directly influencing market acceptance, grading outcomes, and price. For fresh peaches, attributes such as fruit size, shape, color, surface integrity, and firmness at purchase are the first perceived quality cues and are therefore key indicators in commercial grading and distribution. Fruit shape is an important component of external quality, commonly including round, flat-round, oblong, and flat (donut) types. Significant differences in shape index (length/width ratio) are observed among cultivars and cultivation conditions (Figure 1). Studies have shown that different peach types, such as peaches, nectarines, and flat peaches, vary greatly in morphological traits including length, width, thickness, and geometric mean diameter. These differences affect not only visual uniformity and packaging suitability but also their suitability for fresh consumption or processing (Wang et al., 2023). Generally, fruits with regular shape, balanced development, and high uniformity are considered high-quality products, whereas irregular or inconsistent fruits reduce commercial grade and market value (Petrucelli et al., 2023).

Fruit color is another key external attribute affecting consumer preference. Peach skin and flesh colors typically range from white and yellow to varying degrees of red blush, mainly determined by the accumulation of anthocyanins, carotenoids, and other pigments. In recent years, CIELAB color parameters such as L^* , a^* , b^* , hue angle (h°), and chroma (C) have been widely used to quantify color characteristics (Masuda et al., 2023; Petrucelli et al., 2023). Anthocyanins are closely associated with red skin coverage, while carotenoids contribute to yellow flesh and background color. Light conditions play a critical role in color development, with sufficient light promoting anthocyanin synthesis and uniform coloration. Conversely, practices such as fruit bagging alter light exposure and significantly affect color expression. It is important to note that although a high proportion of red coloration enhances visual appeal, its correlation with eating quality or internal flavor is not always significant, indicating limitations in evaluating quality based solely on appearance (Masuda et al., 2023).

Fruit size is another important indicator of commercial value, typically expressed as fruit weight, diameter, or volume. It is influenced by both genetic traits and cultivation factors such as crop load, water and nutrient supply, and tree resource allocation. Studies have shown that reducing crop load can significantly increase fruit weight, size, and coloration, but may reduce firmness at harvest, reflecting a trade-off between improved appearance and texture retention (Wang et al., 2023). Therefore, production should not focus solely on large fruit size but instead balance shape uniformity, coloration, firmness, and internal quality. Although firmness is often classified as an