key indicators such as DMC, SSC, and maturity, and are expected to be embedded into standardized grading systems, thereby realizing an evaluation mode of "unified methods but adjustable models" across different regions (Minas et al., 2023).

7 Existing Problems and Development Trends

7.1 Current limitations

Although significant progress has been made in peach fruit quality research across multiple disciplines, the lack of unified evaluation systems remains a major bottleneck limiting result comparability and practical application. Differences in indicator selection, sampling stages, maturity criteria, and measurement methods are common among studies. Even when the same indicators (e.g., SSC, acidity, firmness) are used, inconsistencies in scales and standards reduce comparability and reproducibility. At the same time, research-oriented evaluation systems tend to be complex, whereas industry practices still rely mainly on appearance or a few simple indicators. This disconnect between research and industry affects quality stability and consumer experience (Mosie et al., 2025). In terms of mechanism studies, current research still focuses largely on phenotypic and physicochemical traits, with limited understanding of the molecular regulation underlying flavor harmony, aroma formation, and texture changes. Although GWAS and QTL studies have identified numerous loci associated with quality traits, many causal genes and regulatory pathways remain unresolved (Fan et al., 2025; Hayat et al., 2025). In addition, studies on multi-factor interactions are still insufficient. In practice, fruit quality is jointly influenced by genotype × environment × management, yet most existing research focuses on single-factor analysis, limiting systematic understanding of quality formation mechanisms and stability.

7.2 Application of emerging technologies

The development of multi-omics technologies has greatly enhanced the ability to elucidate the mechanisms underlying peach fruit quality. At the genomic level, high-density SNP arrays, resequencing, and GWAS approaches have enabled the identification of key genomic regions associated with quality traits, providing a foundation for molecular breeding. Meanwhile, integrated metabolomic and transcriptomic analyses have revealed key pathways involved in the formation of sugars, acids, and aroma compounds, and have identified molecular markers related to flavor and antioxidant capacity (Feng et al., 2024). Research on aroma improvement is increasingly integrating metabolite profiles, gene regulatory networks, and consumer preferences, providing theoretical support for flavor-oriented breeding (Cao et al., 2024). On the phenotyping side, intelligent detection technologies are developing rapidly. Techniques such as Vis/NIR spectroscopy, hyperspectral imaging, electrical property sensing, and electronic noses have been applied for rapid assessment of fruit quality and maturity (Qi et al., 2024), while deep-learning-based machine vision enables simultaneous prediction of multiple traits and shows strong potential for automated sorting (Masuda et al., 2023). Compared with traditional methods, these technologies offer advantages in high throughput and objectivity, making them more suitable for modern fruit production systems. Moreover, a convergence trend is emerging between multi-omics and intelligent detection technologies: the former provides molecular-level explanations, while the latter enables rapid field-level assessment. Their integration is expected to establish predictive systems linking "molecular mechanisms-field phenotypes-market quality," thereby promoting a more systematic and dynamic approach to quality research (Fan et al., 2025; Hayat et al., 2025).

7.3 Climate change and precision cultivation strategies

Climate change has profound impacts on peach fruit quality. Rising temperatures, altered precipitation patterns, and more frequent extreme weather events influence phenology, metabolism, and pigment formation, thereby affecting fruit flavor and quality. For example, high temperatures may inhibit anthocyanin accumulation and accelerate ripening, while abnormal rainfall can dilute SSC and increase disease risk. These effects vary by region and cultivar, making it difficult for traditional cultivation systems to maintain stable quality (Deori et al., 2024). Therefore, precision cultivation has become an important strategy to address climate change. By regulating canopy structure, crop load, rootstock-scion combinations, and planting density, it is possible to optimize light utilization and carbon allocation, thereby improving quality stability. Studies indicate that favorable environmental conditions support optimal metabolic regulation and high-quality fruit formation, whereas adverse