conditions often lead to reduced flavor quality, suggesting that quality management should be shifted upstream to orchard-level control (Bacelar et al., 2024). Future development should integrate environmental monitoring, non-destructive detection, and decision-support models to enable real-time regulation of fruit quality and risk (Masuda et al., 2023; Qi et al., 2024). At the breeding level, combining multi-omics approaches with genomic selection will facilitate the development of new cultivars that possess both stress resistance and high quality (Fan et al., 2025; Hayat et al., 2025).

8 Concluding Remarks

Cultivation conditions are key determinants of peach fruit quality, mainly acting through their effects on canopy microclimate, tree carbon allocation, and fruit development. Preharvest factors such as cultivar-rootstock combinations, crop load, training systems, irrigation regimes, nitrogen supply, and temperature during fruit development can individually or interactively regulate key quality traits, including dry matter content, soluble solids concentration (SSC), acidity, firmness, color, and nutritional-functional components. The light environment within the canopy, regulated by tree architecture and pruning, significantly influences fruit size, coloration, and sugar-acid balance. Open canopies and upper canopy positions typically exhibit higher light interception, resulting in increased SSC, dry matter content, and improved color. In addition, moderate deficit irrigation and optimized fertilization can enhance SSC, firmness, polyphenol, and mineral content, whereas excessive vegetative growth or high temperatures often reduce fruit sweetness and size, despite accelerating ripening. These findings indicate that fruit quality is not a fixed varietal attribute but a highly plastic phenotype jointly shaped by environmental conditions and cultivation practices. Achieving stable, high-quality production therefore requires regionally adapted and integrated cultivation strategies.

Under varying cultivation conditions, the complexity and plasticity of peach fruit quality traits make multidimensional evaluation systems indispensable. Reliance on single external indicators, such as peel color or fruit size, is insufficient to ensure consumer satisfaction and has contributed to declining peach consumption in some markets. Modern research suggests that robust evaluation systems should integrate physical, chemical, functional, and sensory dimensions, including dry matter, SSC, titratable acidity, sugar-acid ratio, firmness, color metrics, bioactive compounds, and, where appropriate, microbial stability and storage characteristics. Multi-index evaluation frameworks, combined with multivariate statistical analysis, sensory evaluation, and advanced non-destructive technologies such as Vis/NIR and hyperspectral imaging, enable consistent characterization of fruit quality across different cultivation systems, climatic conditions, and postharvest treatments. At both breeding and production levels, such integrated systems facilitate the identification of superior genotype-management combinations, support marker-assisted and genomic selection, and provide a unified technical standard for producers, processors, and regulators. Establishing standardized, multidimensional quality evaluation systems is therefore essential for enhancing industry credibility and meeting consumer expectations.

Future progress in regulating peach fruit quality under diverse cultivation conditions will depend on deeper mechanistic understanding and the integration of emerging technologies. Multi-omics approaches—including genomics, transcriptomics, metabolomics, volatilomics, and phenomics—are increasingly revealing how sugars, acids, pigments, and secondary metabolites respond to crop load, light, water status, temperature, and postharvest stresses. Integrating these molecular insights with high-throughput, non-destructive phenotyping platforms (such as NIRS, Vis/NIR, imaging technologies, and electronic noses), along with environmental and management data, will enable predictive models of quality formation, more precise genomic selection, and improved decision support for harvest and storage. At the same time, climate change and the demand for sustainable production require that quality-focused research be embedded within adaptive training systems, deficit irrigation strategies, nutrient management, and disease control frameworks, ensuring both yield and eating quality under complex conditions. The development of integrated databases combining multi-environment trials, multi-omics data, sensor information, and sensory evaluation, along with intelligent decision-support tools for breeders and growers, will be crucial for advancing high-quality, consumer-oriented peach production systems.