Bioscience Evidence 2026, Vol.16, No.4, 221-234
http://bioscipublisher.com/index.php/be

Review and Outlook Open Access

Orchard Management Practices Affecting Peach Fruit Quality

Aiqing Zhu [1,2]
1 Yiwu Baishengyuan Agricultural Development Co., Ltd., Yiwu, 322002, Zhejiang, China
2 Zhejiang Agronomist College, Hangzhou, 310021, Zhejiang, China
Corresponding email: 15857975066@139.com

Bioscience Evidence, 2026, Vol.16, No.4 doi: 10.5376/be.2026.16.0017
Received: 05 Jun., 2026
Accepted: 04 Jul., 2026
Published: 15 Jul., 2026

Preferred citation for this article:
Zhu A.Q., 2026, Orchard management practices affecting peach fruit quality, Bioscience Evidence, 16(4): 221-234 (doi: 10.5376/be.2026.16.0017)

Abstract Peach fruit quality is a key factor affecting the competitiveness of fresh peaches and consumers' willingness to purchase them again, and orchard management plays a major role in determining fruit quality. This review summarizes the effects of major orchard management practices, including canopy management, flower and fruit thinning, irrigation management, nutrient regulation, ground cover, and fruit protection, on fruit appearance, skin color, fruit size, soluble solids, sugar–acid ratio, firmness, and nutritional quality. It also discusses how light distribution, source–sink balance, water supply, and mineral nutrition influence fruit quality formation. Based on typical case studies from the major peach-producing regions of Zhejiang, Shaanxi, Jiangsu, and North China, the review further summarizes practical orchard management strategies and their effects under different ecological conditions. Integrated practices such as optimizing canopy structure, proper flower and fruit thinning, precise water and fertilizer management, and grass cover can improve the orchard microclimate, promote sugar accumulation and fruit coloration, enhance fruit quality consistency, and increase both resource use efficiency and ecological sustainability. In the future, greater attention should be given to precision monitoring, intelligent orchard management, and climate-adaptive cultivation technologies to promote more digital, precise, and environmentally friendly peach production, providing technical support and practical guidance for producing high-quality peaches and achieving sustainable industry development.

Keywords Peach fruit quality; Orchard management; Canopy management; Water and nutrient management; Precision cultivation

1 Introduction

Peach is one of the most important temperate fruit crops in the world. China is currently the largest peach producer, with an annual production of about 15 million tons, while Spain, Italy, Greece, and the United States are also major producing countries. Over the past few decades, fresh peach consumption has declined in several major producing regions. One of the main reasons is not low production, but inconsistent or unsatisfactory fruit quality, which reduces consumers' willingness to purchase peaches again (Anthony and Minas, 2022). Fruit quality is mainly determined during orchard production, while postharvest handling can only maintain quality rather than fundamentally improve its internal characteristics. Therefore, optimizing cultivation practices, tree architecture, and resource management before harvest has become a key strategy for improving the market performance of fresh peaches.

Fruit appearance, size, skin color, and firmness are the most direct indicators of quality. Among these traits, fruit size is a major commercial value indicator, while sensory characteristics such as yellow flesh and red skin are generally more attractive to consumers (Sutton et al., 2020). However, flavor and eating quality usually determine consumer satisfaction. Sweetness, acidity, the balance between sugar and acid, aroma, and texture strongly influence whether consumers will buy peaches again. Poor sweetness, mealiness, and flesh browning have been recognized as important reasons for the decline in fresh peach consumption (Nava et al., 2022). Fruit firmness, dry matter content, maturity, and skin color are also closely related to the optimum harvest stage, shelf life, and transport performance. Among these factors, accurate control of fruit maturity is particularly important when evaluating the effects of different orchard management practices (Mazzoni et al., 2022).

Light conditions and canopy structure are the basis for achieving uniform fruit quality. Training systems, pruning methods, branch distribution, and fruit position within the canopy all influence light interception and light distribution, which in turn affect fruit size, skin coloration, soluble solids content, dry matter accumulation, and firmness (Ligouri et al., 2013). Moderate deficit irrigation can increase fruit firmness, dry matter, soluble solids, and some phenolic compounds. The timing and supply of nitrogen, phosphorus, potassium, and other mineral nutrients also have significant effects on fruit weight, sugar accumulation, acidity, skin color, and mineral composition. In addition, ground management practices such as mulching and cover cropping can improve soil fertility and soil moisture, leading to higher sugar content, a better sugar-to-acid ratio, and lower fruit acidity.

Based on these findings, this review discusses the major orchard management practices that influence peach fruit quality. It focuses on the effects of tree training and canopy management, crop load regulation, irrigation and fertilization, and soil and ground management on fruit appearance, flavor, texture, and nutritional quality. It also examines the relationships among these management practices and highlights the importance of evaluating management effects at the same fruit maturity stage. The goal is to provide a scientific basis for developing productive, high-quality, and sustainable peach orchard management systems. By integrating the effects of different orchard management practices on fruit quality formation, this review aims to support more precise orchard management and contribute to the production of more uniform, high-quality peaches with greater market acceptance and improved economic returns.

2 Orchard Management Factors Affecting Peach Fruit Quality

2.1 Canopy management and light distribution

Tree architecture directly determines light interception, light distribution within the canopy, and the fruit microclimate. These factors further affect fruit size, skin color, soluble solids content, dry matter accumulation, and firmness. Modern peach orchards are gradually shifting from traditional low-density, three-dimensional tree forms to high-density, two-dimensional fruiting walls or compact tree systems. The main goal is not simply to increase planting density, but to improve land and labor use efficiency while optimizing light distribution and achieving more consistent fruit quality.

Planar canopies and central leader systems provide more uniform light conditions, resulting in larger fruit, higher soluble solids content, and greater efficiency in pruning, thinning, and harvesting. A comparison between the 2D fruiting wall and the 3D Quad-V system showed that the 2D fruiting wall maintained higher photosynthetic efficiency and a more uniform light environment in the lower canopy. In some cultivars, it also improved fruit firmness, skin color, dry matter content, and yield per unit area (Chatzieffraimidis et al., 2025).

2.2 Crop load management and fruit thinning

Competition among fruits, as well as between fruits and other sink organs, limits the growth potential of individual fruit. Therefore, the main purpose of fruit thinning is to improve fruit size and internal quality by adjusting the source–sink relationship. In general, a higher crop load increases total yield per tree but reduces individual fruit weight, fruit diameter, and several quality traits. In contrast, reducing crop load usually improves soluble solids content (SSC), total sugar, the sugar-to-acid ratio, fruit coloration, and fruit maturity.

Under different crop load treatments, reducing the number of fruits increased the weight of mature fruit by 24.52%, 39.73%, and 51.68% compared with the non-thinned control. SSC increased by 30.78%, 37.63%, and 49.69%, while the sugar-to-acid ratio and fruit color also improved (Wang et al., 2023). However, the effectiveness of thinning depends on both cultivar and growing region. The timing and intensity of thinning should therefore be adjusted according to local conditions. Flower thinning during bloom reduces competition at an early stage and maximizes fruit growth potential, but it may lead to excessive yield loss in areas with unstable fruit set or high weather risk. Fruit thinning at about 21 days after full bloom or before pit hardening is generally considered a more reliable strategy because it balances fruit enlargement with yield stability (Sutton et al., 2020; Mazzoni et al., 2022).

2.3 Irrigation management and water supply

Irrigation is essential for maintaining tree health and yield, and it also directly affects fruit size, firmness, soluble solids content, organic acids, phenolic compounds, and mineral composition. Therefore, water management should aim to maintain stable yield, improve water use efficiency, and enhance fruit quality.

In an early-season peach orchard in southern Tunisia, both continuous deficit irrigation at 50% ETc (DI) and partial root-zone drying at 50% ETc (PRD50) produced positive results. These treatments increased fruit dry matter and firmness. The DI treatment achieved the highest SSC of 14.3°Brix, while reducing some organic acids and increasing several phenolic compounds, anthocyanins, and mineral elements. Moderate water stress can therefore be an effective strategy for saving irrigation water and improving commercial fruit quality in dry regions. However, its long-term effects still require multi-year evaluation, and attention should be given to the risks of soil salinization and tree decline caused by poor-quality irrigation water (Toumi et al., 2022). In a late-season peach orchard under semi-arid conditions, reflective ground covers reduced water loss and maintained or even increased net photosynthesis, yield, and fruit size, although only about 50% of the normal irrigation amount was applied (Losciale et al., 2020).

2.4 Nutrient management and fertilization

Nitrogen, phosphorus, potassium, and mineral elements such as Ca, B, Fe, and Mn determine the nutritional status of peach trees. They also influence fruit quality by affecting fruit development, carbohydrate accumulation, and organic acid metabolism. Nitrogen deficiency reduces flower bud quality, weakens root growth, and limits water and nutrient uptake. In contrast, excessive nitrogen promotes excessive vegetative growth, increases pruning costs, reduces fruit quality, and raises the risk of disease. Therefore, nitrogen management should always be balanced with other nutrients and adapted to local growing conditions.

In commercial peach orchards located in warm regions, an appropriate split application of N, P, and K improved both yield and fruit quality. Higher nitrogen supply during the S2 growth stage favored higher yield, while higher nitrogen and potassium supply during the S3 and S4 stages was generally associated with greater fruit weight, larger fruit diameter, and higher SSC. In contrast, phosphorus supply was negatively correlated with total sugar content (Maatallah et al., 2024). A soil mineral prediction model further showed that available B, Ca, N, and K had the greatest influence on fruit weight, whereas available Fe, K, B, and Ca were the most important factors affecting SSC. These results suggest that precision fertilization should focus on coordinated management of multiple nutrients rather than single-element application (Sun et al., 2022).

2.5 Bagging cultivation and fruit protection measures

Fruit protection practices, including ground cover, fruit bagging, and protective facilities, influence peach fruit quality by changing the orchard microclimate. Regarding ground management, clean cultivation often reduces soil fertility and damages the orchard ecosystem, which can indirectly decrease both yield and fruit quality. In contrast, grass cover, especially hairy vetch (Vicia villosa), improves soil nitrogen availability and microbial diversity, promotes tree growth, increases fruit sugar content and the sugar-to-acid ratio, and reduces organic acid levels (Guo et al., 2024).

3 Orchard Management and Peach Fruit Quality Development

3.1 Light regulation and fruit coloration

Light management plays a key role in peach appearance, especially peel redness and color uniformity. The main purpose of an ideal tree architecture is not simply to increase total light interception but also to improve light distribution within the canopy, producing fruit with more uniform and higher quality. In 'Xiahui 8' peach, the open-center canopy provided better light distribution and greater light interception than the Y-shaped canopy, resulting in higher fruit weight, soluble solids, dry matter, firmness, yield, and economic return. Fruits located in the upper canopy usually showed better coloration and higher soluble solids, and relative light intensity between 30% and 90% was positively correlated with fruit size, skin color, and the sugar-to-acid ratio (Zhen et al., 2025).

Under planar training systems, fruit color, soluble solids, and titratable acidity showed stronger metabolic relationships, suggesting that improved light conditions not only change fruit appearance but also reshape metabolic coordination during ripening. In rain-shelter orchards, light quality is also important. Long-term low light reduces tree growth, yield, and fruit quality. Neutral light-filtering films help maintain leaf photosynthesis and overall fruit quality, whereas yellow films increase fruit size but reduce skin coloration and internal quality (Zhang et al., 2018).

Anthocyanin accumulation in peach peel is highly dependent on light, and shading greatly reduces fruit coloration. Sunlight induces the expression of PpHYH, which, together with PpBBX4, activates the PpMYB10 gene cluster and promotes anthocyanin accumulation in the sun-exposed peel. Under dark conditions, PpCOP1 accumulates in the nucleus and suppresses this process (Zhao et al., 2022). Both UVA and UVB promote fruit coloration in 'Hujingmilu', and the combined treatment has a stronger effect than either alone. PpHY5 acts as a key regulator in this UV signaling pathway by upregulating anthocyanin biosynthesis genes such as PpCHS, PpDFR, and PpMYB10.1 (Zhao et al., 2021). Different cultivars respond differently to light quality. For example, 'Yulu' shows little response to UVA but responds well to UVB, indicating that the effect of light management on fruit coloration is genotype-dependent (Zhao et al., 2017). Blue light induces anthocyanin accumulation more effectively than red or green light, partly because it increases both PpHYH transcription and the proportion of its highly active splice variant PpHYH-X2 (Zhao et al., 2023) (Figure 1).

Laying reflective film on the orchard floor seven days before harvest significantly improved peel coloration in 'Taiko' peach and increased the expression of anthocyanin biosynthesis genes such as F3H and CHS, although it had no significant effect on soluble solids, acidity, or firmness (Lee et al., 2021). Bagging greatly reduces light exposure to the fruit surface. In a Florida study, peaches harvested without bagging contained about twice as much anthocyanin as fruits kept in white bags and about six times more than fruits in colored liner bags, while most internal quality traits were not significantly affected by bag color (Campbell et al., 2021). Peel color is also an important indicator of fruit maturity. The Color Development Index (CDI) is closely related to the Index of Absorbance Difference (IAD) and reaches a plateau around the climacteric stage. Therefore, standardized color monitoring can help determine harvest timing, although measurements should avoid direct sunlight to reduce errors (Scalisi et al., 2022).

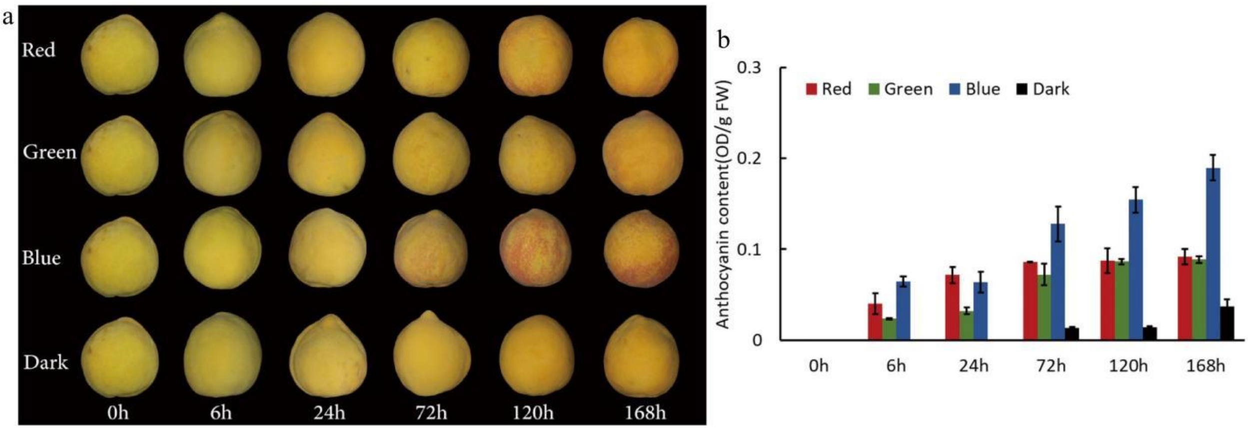

Figure 1 Effects of visible light with different wavelengths on anthocyanin accumulation in peach peel. (a) The peel coloration of 'Jinxiu' treated with red, green and blue light or under dark conditions. (b) Anthocyanin accumulation of peach peel treated with red, green and blue light or under dark conditions. Error bars in (b) show the standard error (SE) of three biological replicates (Adopted from Zhao et al., 2023)

3.2 Source-sink balance and sugar accumulation

Flower and fruit thinning improves the leaf-to-fruit ratio and reduces competition among fruits for photoassimilates, allowing the remaining fruits to receive more carbon throughout development. As a result, fruits achieve greater growth potential and better harvest quality. Excessive crop load reduces fruit quality, while fruits supplied with sufficient carbon show better appearance and internal quality even at the same maturity stage. In 'Cresthaven' peach, different thinning intensities caused clear metabolic differences during the early growth stage. At harvest, fruits grown under adequate carbon supply had higher dry matter and soluble solids, indicating that high-quality fruit is not produced simply by sugar accumulation during the final stage but is strongly influenced by early metabolic priming (Anthony et al., 2020).

Sugar accumulation is also regulated by canopy position and light conditions through their effects on the source-sink relationship. Fruit quality development involves carbohydrate metabolism, changes in sugar and organic acids, and dry matter accumulation. The composition of sugars and acids is one of the main factors determining fruit flavor. Under different training systems, improved light distribution not only enhances fruit coloration but also increases soluble solids and the sugar-to-acid ratio, indicating that better light conditions promote sugar accumulation by increasing leaf photosynthesis and strengthening local sink activity.

3.3 Water and nutrient regulation of fruit development

Water and nutrient management continuously influence peach fruit development and final quality by regulating cell expansion, ripening rate, sugar and acid metabolism, and mineral accumulation. Moderate deficit irrigation often improves fruit quality while saving water. In an early-ripening peach cultivar grown in Tunisia, sustained deficit irrigation at 50% ETc and partial root-zone drying both increased fruit dry matter and firmness. Fruits under sustained deficit irrigation reached 14.3 °Brix soluble solids and contained higher levels of phenolic compounds, anthocyanins, and mineral nutrients (Zhao et al., 2023). However, the response to water management depends on irrigation intensity and environmental conditions. High temperature accelerates fruit growth during stages S1 and S2 and advances fruit maturity by 12~18 days, but it also reduces fruit size, weight, and sweetness, indicating that faster development does not necessarily result in better fruit quality (Sikhandakasmita et al., 2022).

Soil mineral nutrients do not affect all quality traits equally. In a survey of 75 peach orchards in Jiangsu Province, available B, Ca, N, and K had the strongest effects on fruit weight. Available Fe, K, B, and Ca were the main factors affecting soluble solids, while available Ca, N, B, and K had the greatest influence on titratable acidity. These results indicate that fertilizer management should be adjusted according to the target quality traits (Sun et al., 2022). Ground cover management also affects fruit development by regulating soil nitrogen cycling. Grass cover improves nitrogen-related soil properties, increases fruit sugar content and the sugar-to-acid ratio, and reduces fruit acidity. Soil nitrogen was identified as the most important factor affecting peach fruit quality. Fruit weight and the sugar-to-acid ratio were positively correlated with total dissolved nitrogen, ammonium nitrogen, and nitrate nitrogen, whereas total acidity was negatively correlated with available nitrogen and available potassium. These findings suggest that nutrient management influences not only fruit growth but also flavor development.

Preharvest foliar application of potassium silicate (K-Si) increased fruit weight, peel color, soluble solids, titratable acidity, and several antioxidant compounds. It also increased anthocyanin and total phenolic contents after cold storage, indicating that functional nutrient supplementation can improve both harvest quality and postharvest performance (Abidi et al., 2023).

4 Applications of Fruit Quality Management in Commercial Peach Orchards

4.1 Quality-oriented orchard system

Quality management should begin at the orchard establishment stage. Orchard design should focus on small tree size, uniform light distribution within the canopy, maintenance of soil fertility, and compatibility with mechanized operations, because most fruit quality traits are determined before harvest. High-density or medium-density planting is not the goal by itself. Instead, growers should choose between two-dimensional fruiting walls and compact three-dimensional open-center systems according to local climate, labor availability, and frost risk. An ideal orchard system usually aims for 60%~70% light interception, a canopy thickness of 70~90 cm, and relatively low canopy density to achieve both high yield potential and uniform fruit quality (Anthony and Minas, 2021).

Two-dimensional planar training systems improve access for both workers and machinery, reduce the cost of pruning, thinning, and harvesting, and often produce larger fruits with higher soluble solids content. In Spain, the adoption of planar systems increased harvesting efficiency by 28%, reduced seasonal labor requirements from 651 h/ha to 398 h/ha, and lowered production costs by approximately 15% (Iglesias and Echeverría, 2022).

4.2 Key practices for improving fruit quality

Canopy management is one of the most effective ways to improve both orchard efficiency and fruit quality. Spring and summer pruning can increase work efficiency while enhancing fruit quality. Crop load management should aim to maintain an appropriate leaf-to-fruit ratio and achieve uniform fruit maturity, because fruits supplied with sufficient carbohydrates generally develop better quality at harvest. Moderate deficit irrigation can save water while improving fruit quality. For example, irrigation at 75% ETc produced larger fruits without reducing total yield and increased soluble solids content (SSC), vitamin C, fruit firmness, the sugar-to-acid ratio, and fruit coloration (Toumi et al., 2022; Losciale et al., 2020).

Fertilizer management should also be adjusted according to the fruit development stage. Higher nitrogen supply during Stage II favors yield formation, while higher nitrogen and potassium supply during Stages III and IV improves fruit weight, fruit diameter, SSC, and skin color. In contrast, excessive phosphorus supply is not favorable for total sugar accumulation (Maatallah et al., 2024).

4.3 Challenges and limitations

The main challenges in commercial orchards are labor shortages, environmental constraints, and production costs. Peach production still depends heavily on manual operations such as pruning, thinning, and harvesting. Rising labor costs reduce investment in careful orchard management and often result in less detailed pruning and fruit thinning, which can directly affect fruit quality (Yuan and Chen, 2019).

Sustainable practices such as mechanical weed control combined with ground cover can increase biodiversity without significantly reducing yield, and some fruit quality traits may even improve. However, these practices are more expensive per hectare than chemical weed control and often require government support or premium market prices to remain economically viable (Mia et al., 2020).

Moderate deficit irrigation is effective in water-limited regions, but its benefits depend on water quality. Under saline irrigation conditions, irrigation at 50% ETc can save water but may reduce yield by about 20% and increase salt accumulation around drip emitters (Toumi et al., 2024). In some peach-growing regions of China, fertilizer application has historically been excessive. Environmental impacts mainly come from fertilizer production, transportation, and field application. Therefore, improving fruit quality does not simply mean applying more fertilizer. Better results can be achieved by reducing fertilizer inputs, increasing the proportion of basal fertilizer, and optimizing fertilizer application frequency (Li et al., 2022).

Sensors, Vis-NIRS, and other non-destructive quality monitoring technologies have the potential to support fruit maturity assessment, nutrient management, and irrigation decisions in smart orchards. However, these technologies still need more affordable and practical solutions before they can be widely adopted in commercial orchards (Shin et al., 2023).

5 Case Studies of Orchard Management for Peach Fruit Quality

5.1 Zhejiang peach production region

Zhejiang is one of the major fresh peach production regions in China, with peach orchards mainly distributed in Huzhou, Jiaxing, Hangzhou, Ningbo, and Taizhou. Unlike northern peach-growing regions, where fruit quality mainly depends on high sugar accumulation, the peach industry in Zhejiang is strongly market-oriented toward fresh consumption. Therefore, fruit quality is evaluated not only by soluble solids and yield but also by fruit appearance, aroma, texture, food safety, and product uniformity.

Liu et al. (2023) evaluated pesticide residues and fruit quality in several specialty fruits from Zhejiang, including yellow peach. The study measured pesticide residue types and concentrations in fruit samples collected from different production areas and assessed consumer health risks using dietary exposure models. Overall, pesticide residue levels in Zhejiang peach samples were low, and long-term dietary exposure risks were also low. These results indicate that green pest management and standardized pesticide application have improved in Zhejiang peach orchards in recent years (Figure 2). However, fruit quality still varied among orchards. Even when fruit met food safety standards, differences remained in fruit appearance, sugar-to-acid ratio, and sensory quality.

The climate of Zhejiang is characterized by rainy springs and hot, humid summers. Under these conditions, peach trees are highly susceptible to brown rot, anthracnose, bacterial shot hole disease, aphids, fruit borers, and other pests and diseases. Luo et al. (2022) reviewed the global distribution and management of peach diseases and reported that disease outbreaks reduce not only yield but also fruit appearance, marketability, and storage performance. In the humid environment of Zhejiang, producing high-quality peaches cannot rely only on chemical pesticides. Effective orchard management should combine disease monitoring, proper spray timing, orchard sanitation, and cultural control practices.

Improving peach quality in Zhejiang increasingly depends on integrated preharvest orchard management. Minas et al. (2018) pointed out that most peach quality traits develop during fruit growth, and postharvest treatments cannot fully compensate for poor field management. Sugar accumulation, acid metabolism, flesh firmness, fruit coloration, and aroma formation are all influenced by orchard conditions and management practices. Among these factors, light exposure, water supply, nitrogen status, and crop load are the major drivers of fruit quality.

The fresh fruit market generally prefers large peaches with high sugar content and bright skin color. Excessive crop load often reduces nutrient supply to individual fruits, resulting in lower sugar content and uneven coloration. Therefore, flower thinning, fruit thinning, and proper leaf-to-fruit ratio management have become key practices for improving market quality. Li et al. (2022) reported that the evaluation of modern peach production has shifted from yield alone to a more comprehensive assessment that includes fruit nutritional quality, mechanical resistance, food safety, and market acceptance.

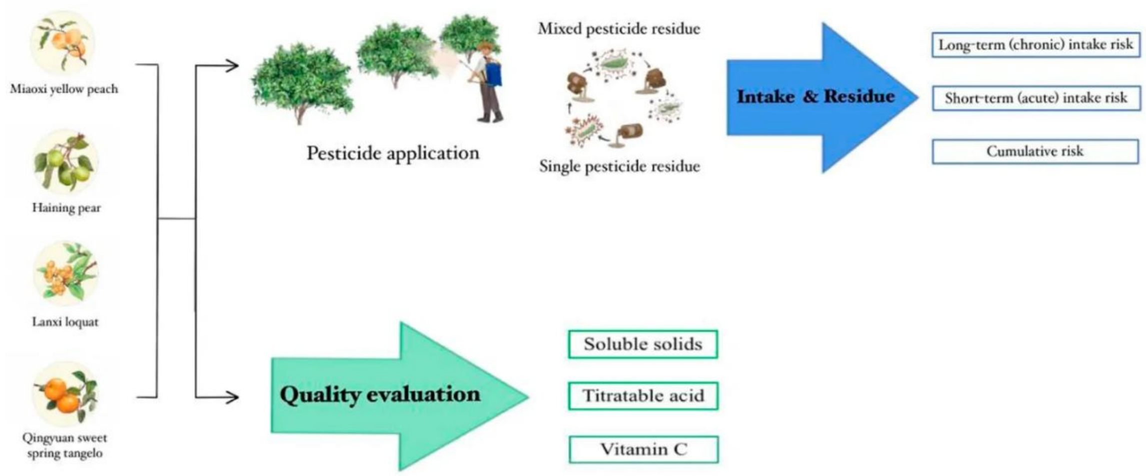

Figure 2 Levels of pesticide residues in four characteristic fruits from Zhejiang Province, China, and the associated dietary exposure risk for consumers (Adapted from Liu et al., 2023)

5.2 Shaanxi peach production region

Shaanxi is one of the major peach-producing regions in northwestern China, with orchards mainly located in the Guanzhong Plain and parts of northern Weibei. Compared with humid regions such as Zhejiang, Shaanxi has longer sunshine duration, larger day-night temperature differences, and lower annual rainfall. These conditions favor sugar accumulation and fruit coloration but also increase the challenges of water shortage and low fertilizer use efficiency.

Guo et al. (2018) conducted a life cycle assessment of peach production in the major peach-growing regions of China. Shaanxi and Gansu were selected as representative northwestern production areas. The study showed that chemical fertilizer input is one of the major contributors to greenhouse gas emissions and environmental impacts during peach production. Excessive nitrogen fertilizer not only increases production costs but also causes soil acidification and nutrient losses.

Fertilization affects not only environmental performance but also fruit quality. Cai et al. (2023) performed a meta-analysis to evaluate the effects of fertilization on peach yield and fruit quality in China. Appropriate fertilizer management increased fruit weight, soluble solids content, total sugar content, and the sugar-to-acid ratio. However, responses varied among production regions. Excessive nitrogen application promoted vegetative growth and increased early yield, but it also caused excessive canopy growth and reduced sugar accumulation and fruit flavor.

Because rainfall is limited in northwestern China, traditional irrigation often wastes water and reduces fruit quality stability. Toumi et al. (2022) studied deficit irrigation in peach orchards under arid conditions and found that moderate water stress improved several fruit quality traits compared with full irrigation, including soluble solids content, fruit firmness, and the concentration of some phenolic compounds.

5.3 Jiangsu peach production region

5.3.1 Flower and fruit thinning of 'Xiahui 5'

Peach trees have a high fruit-setting capacity. Without proper flower and fruit thinning, nutrients are distributed among too many fruits, resulting in lower fruit weight, reduced sugar accumulation, heavier branch load, and unstable production in the following season.

Zhang et al. (2024) carried out a field experiment using the major cultivar 'Xiahui 5' in Jiangsu under an open-center training system. Different flower and fruit thinning strategies were compared, including no flower thinning, conventional fruit thinning, and staged thinning during flowering and early fruit development. The study systematically evaluated their effects on yield, fruit quality, and leaf photosynthesis.

Compared with conventional fruit thinning alone, removing young fruits twice, at 20 and 40 days after full bloom, regulated nutrient distribution more effectively. This treatment maintained high yield while significantly increasing individual fruit weight, improving fruit appearance, enhancing soluble solids content, and producing more uniform fruit maturity. Reducing excessive fruit numbers did not reduce total yield because less competition among fruits allowed more photosynthetic products to be transported to the remaining fruits, increasing carbon supply to each fruit. The treatment also improved leaf photosynthetic performance, water use efficiency, and apparent carbon dioxide use efficiency.

5.3.2 Living mulch in 'Zijin Huangcui' peach orchards

Although clean cultivation reduces weed competition, long-term bare soil management often decreases soil organic matter, reduces microbial activity, and lowers nutrient use efficiency.

Guo et al. (2024) investigated the effects of different ground management practices on soil conditions and fruit quality in 'Zijin Huangcui' peach orchards in Jiangsu (Figure 3). The treatments included bare soil, different mulching materials, and living mulch with hairy vetch (Vicia villosa Roth). Compared with conventional clean cultivation, living mulch significantly improved the orchard soil environment. Hairy vetch increased soil organic matter, enhanced soil nitrogen supply, and promoted microbial communities involved in nutrient cycling. At the same time, the mulch reduced soil temperature fluctuations and improved soil water retention, providing a more stable environment for continuous nutrient uptake by peach roots.

Peaches grown under living mulch had higher soluble solids content and a higher sugar-to-acid ratio, while fruit acidity was reduced, resulting in better eating quality. These improvements were mainly associated with a healthier rhizosphere environment, gradual nutrient release, and a more stable nutrient supply for tree growth.

5.3.3 Canopy Microclimate Regulation

Peach fruit quality is highly dependent on the light environment within the tree canopy. Zhen et al. (2025) used the peach cultivar 'Xiahui No.8' to investigate the relationship between canopy microclimate and fruit quality under different canopy structures. Light intensity, temperature, and humidity were monitored at different canopy positions, and their relationships with fruit weight, soluble solids content, dry matter content, and fruit firmness were analyzed.

Clear microclimate differences existed within the canopy. Fruits located in the upper canopy received more solar radiation and showed better coloration and greater sugar accumulation. In contrast, fruits growing in shaded inner canopy positions had significantly lower soluble solids and dry matter contents because of limited light availability.

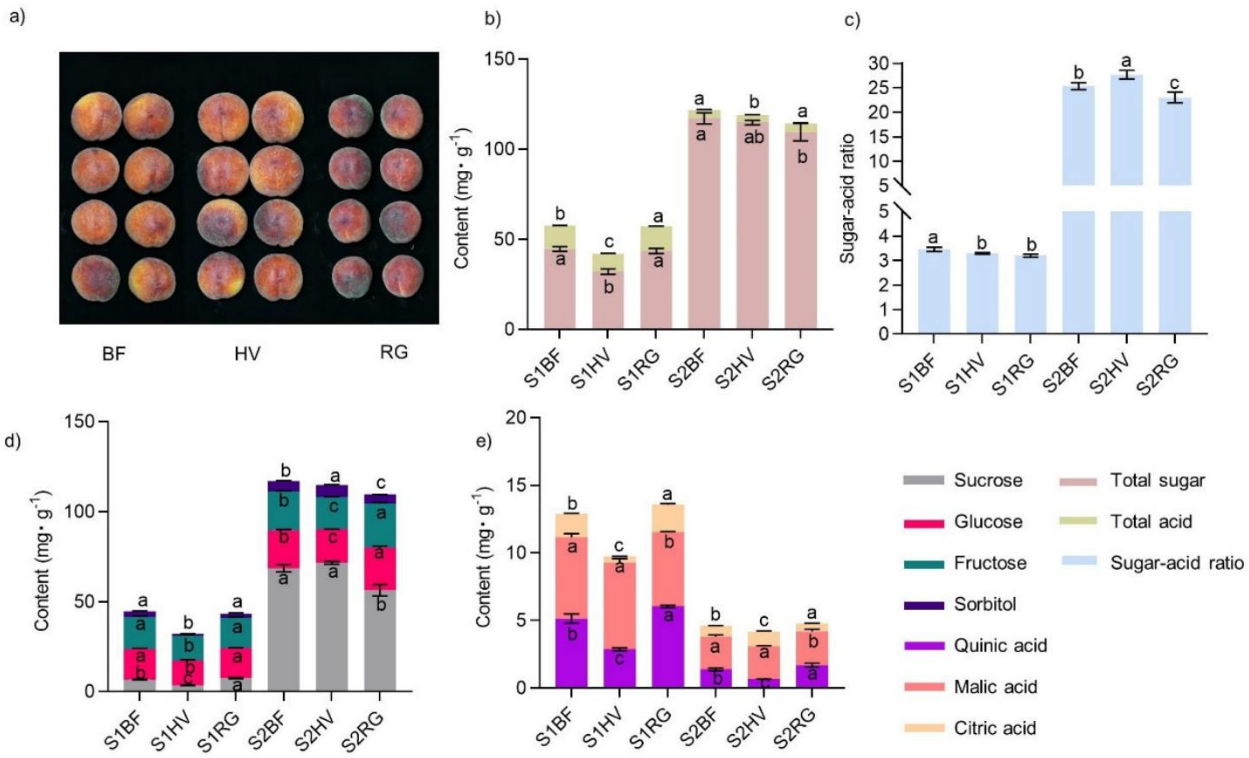

Figure 3 Fruit quality of peach under different mulch treatments. (a) pictures of fruit mature stages under different treatments; (b) total sugar and total acid content of fruits at the young fruit and mature stages under different treatments; (c) sugar-acid ratio of fruits at the young fruit and mature stages under different treatments; (d) content of each sugar component groups at the young fruit and mature stages under different treatments; (e) content of each acid component at young fruit and mature stages under different treatments. S1, the young fruit stage (30 April 2022); S2, the fruit mature stage (30 June 2022); BF, black ground fabric mulch; HV, living hairy vetch mulch; RG, living ryegrass mulch. Boxes with different lowercase letters indicate significant differences between different mulch treatments at the same stage based on the LSD test ($p < 0.05$) (Adopted from Guo et al., 2024)

5.4 North China peach production region

5.4.1 Ten-year monitoring of soil fertility in shandong peach orchards

Li et al. (2023) conducted a 10-year monitoring program on soil nutrient inputs and soil fertility in the major peach-producing areas of Shandong Province. The study systematically evaluated the long-term effects of fertilizer management on orchard soil quality. Production records from multiple representative orchards were collected to analyze changes in soil organic matter, nitrogen, phosphorus, potassium, and overall soil fertility.

After the adoption of scientific fertilization and increased organic fertilizer application, soil organic matter increased steadily, and overall soil fertility improved from a relatively low level to a medium-to-high level. Long-term dependence on chemical fertilizers often caused nutrient imbalance in traditional peach orchards, whereas increasing the proportion of organic fertilizer improved soil structure and enhanced soil water and nutrient retention.

5.4.2 Survey of 290 peach growers in Pinggu, Beijing

Li et al. (2022) conducted a large-scale survey of the peach industry in Pinggu District, Beijing. A total of 290 peach growers were investigated, and life cycle assessment was used to compare the environmental impacts of different orchard management practices.

The survey showed substantial differences in fertilizer management among growers. Some orchards applied excessive nitrogen fertilizer. Although high nitrogen input promoted vegetative growth in the short term, it did not increase fruit yield and instead raised the risk of nitrogen losses. By optimizing fertilizer management, including reducing nitrogen application, increasing the proportion of organic fertilizer, and adjusting the balance between basal and topdressing fertilizers, growers were able to maintain or even increase yield while improving partial factor productivity of nitrogen fertilizer. Environmental assessment further showed that the optimized fertilization strategy reduced several environmental impacts, including: (1) reactive nitrogen losses; (2) greenhouse gas emissions; (3) soil acidification risk; and (4) the risk of water eutrophication.

6 Future Directions for Orchard Management and Peach Quality Improvement

6.1 Precision orchard management

The main goal of precision orchard management is to replace experience-based decisions with real-time, non-destructive, and spatial monitoring. In-field fruit quality assessment can directly support irrigation, fertilization, thinning, and harvest decisions (Figure 4). This concept has now developed into a combination of different technologies, including portable devices, wearable sensors, non-contact sensing platforms, flexible robots, and multi-source data integration systems. However, field reliability and cost-effectiveness are still the main barriers to large-scale commercial use (Wang et al., 2026).

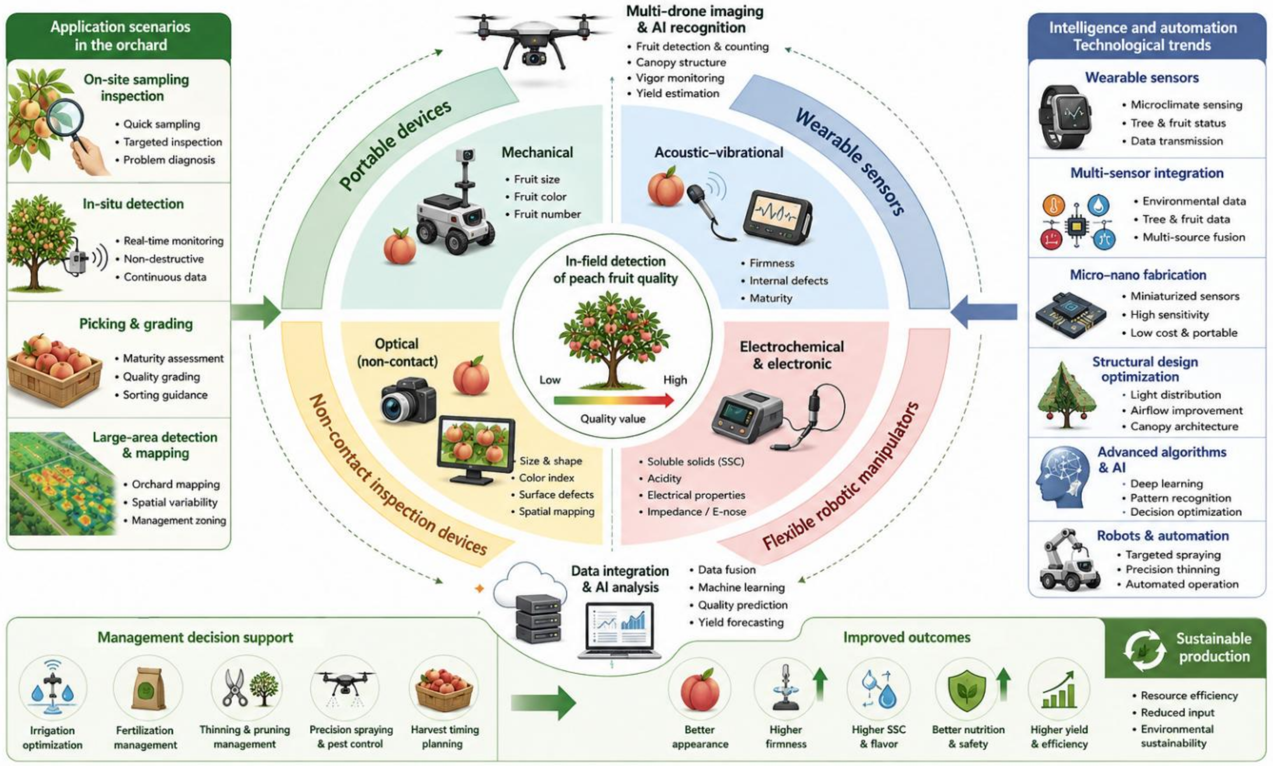

Figure 4 Conceptual framework for precision peach orchard management

In peach orchards and other stone fruit orchards, mobile sensing platforms can already estimate fruit number, fruit size, and fruit color with good accuracy and generate spatial distribution maps. These data can support thinning, pruning, spraying, and harvest planning (Islam et al., 2022). The same systems can also predict fruit size, quality, and yield at an early stage, helping connect orchard management with postharvest logistics, yield forecasting, and fruit grading. For harvest maturity, prototype electronic nose systems have been able to monitor changes in volatile organic compounds before harvest and identify fruit maturity with relatively low error. This suggests that future harvest decisions may shift from experience-based picking to sensor-based harvesting (Voss et al., 2020). Impedance sensors and multi-electrode array sensors have also shown strong relationships between the electrical properties of fruit tissues and internal quality traits. Correlation coefficients can exceed 0.85, and prediction R^2 values can be higher than 0.80, indicating that internal fruit quality may also be evaluated directly in the orchard (Huang et al., 2025).

Future precision management will increasingly focus on monitoring the entire orchard rather than individual trees. Multi-drone imaging combined with deep learning can already detect and count fruits in complex orchard environments in real time, improving both management efficiency and data accuracy. Sensors and data analysis can also improve water use efficiency and support sustainable production. However, different crops respond differently to environmental conditions, so monitoring only the environment is not enough. Future systems should combine tree, fruit, and microclimate data into integrated decision-making models.

6.2 Climate adaptation strategies

Climate change will continue to reshape peach orchard management because rising temperatures, drought, salinity, and extreme weather affect flowering, fruit set, fruit development, nutrient supply, and pest and disease pressure at the same time (Cosmulescu, 2026). Future adaptation strategies will go beyond irrigation alone and move toward integrated approaches that combine cultivar and rootstock selection, microclimate regulation, water and nutrient management, and protective production systems.

Growers need to actively adopt precision agriculture, artificial intelligence, shade nets, hail nets, and heat-tolerant, drought-tolerant, and low-chilling cultivars to reduce climate risks (Bacelar et al., 2024). Water management will remain one of the most practical adaptation strategies. Water deficit first reduces vegetative growth directly and then indirectly decreases photosynthesis, while fruit composition is generally less affected in the early stages. This means future research should better define the range of acceptable water stress and identify the threshold at which fruit quality begins to decline.

Microclimate protection will also become increasingly important. For peach orchards, future studies should systematically evaluate the combined effects of shading, evaporative cooling, reflective ground covers, and protective nets on fruit surface temperature, skin color, sugar accumulation, and acid metabolism.

6.3 Sustainable production and premium markets

The future development of the peach industry depends on whether sustainable production can be translated into quality attributes and market value that consumers are willing to pay for. A survey conducted in U.S. farmers' markets showed that consumers were willing to pay an additional US$2.10 per pound for organic peaches and US$1.41 per pound for environmentally friendly peaches, and the two products attracted different consumer groups (Curtis et al., 2020).

Evidence from South African peach and nectarine exports showed that better visual fruit quality was associated with higher export returns, whereas improvements in eco-efficiency were linked with lower export revenue (Tsvakirai and Mosikari, 2022). Production systems also do not always lead to better eating quality. A comparison of organic, transitional organic, and conventional peaches found that transitional organic fruit received the highest consumer preference, while organic peaches were the least preferred, even though they contained higher total phenolic compounds (Koneru, 2021).

For future industry development, a more practical approach is to improve sustainable production and maintain consistently high fruit quality at the same time. High-density orchards with compact tree architecture, precision sensing, smart irrigation, and sustainable fertilization are considered key technologies for reducing production costs, improving fruit uniformity, and meeting consumer expectations for health and environmental sustainability (Manganaris et al., 2022). At the same time, breeding programs should reduce the trade-off between yield and quality while placing greater emphasis on traits that consumers can easily recognize, such as aroma, nutritional value, and shelf life. Smart postharvest sensing systems, cold-chain logistics, and the Internet of Things will also become important parts of the premium peach market because they help preserve fruit quality established before harvest and reduce postharvest losses. However, their energy use and economic costs should also be carefully evaluated.

Author Contributions

The author would like to express sincere gratitude to Renxiang Cai for his valuable support and assistance.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Reference

Abidi W., Akrimi R., Hajlaoui H., Rejeb H., and Gogorcena Y., 2023, Foliar fertilization of potassium silicon improved postharvest fruit quality of peach and nectarine [*Prunus persica* (L.) Batsch] cultivars, Agriculture, 13(1): 195.
https://doi.org/10.3390/agriculture13010195

Anthony B., and Minas I. S., 2021, Optimizing peach tree canopy architecture for efficient light use, increased productivity and improved fruit quality, Agronomy, 11(10): 1961.
https://doi.org/10.3390/agronomy11101961

Anthony B., and Minas I. S., 2022, Redefining the impact of preharvest factors on peach fruit quality development and metabolism: A review, Scientia Horticulturae, 299: 110919.
https://doi.org/10.1016/j.scienta.2022.110919

Anthony B.M., Chaparro J.M., Prenni J.E., and Minas I.S., 2020, Early metabolic priming under differing carbon sufficiency conditions influences peach fruit quality development, Plant Physiology and Biochemistry, 157: 416-431.
https://doi.org/10.1016/j.plaphy.2020.11.004

Bacelar E., Pinto T., Anjos R., Morais M. C., Oliveira I., Vilela A., and Cosme F., 2024, Impacts of climate change and mitigation strategies for some abiotic and biotic constraints influencing fruit growth and quality, Plants, 13(14): 1942.
https://doi.org/10.3390/plants13141942

Cai T., You L., Yang X., Hao S., Shao Q., Wang H., Zhang Q., Cui Z., and Chen Y., 2023, Fertilization of peach for yield and quality, and optimization of nitrogen application rates in China: A meta-analysis, Scientia Horticulturae, 313: 111917.
https://doi.org/10.1016/j.scienta.2023.111917

Campbell D., Brecht J.K., Sarkhosh A., Liburd O., and Treadwell D., 2021, Photoselective-light impacts on fruit bagging microclimate, quality, and nutrients of peach, HortScience, 56(11): 1354-1362.
https://doi.org/10.21273/HORTSCI15954-21

Chatzieffraimidis I., Stouris D., Kyrou M.R., Papathanasiou F., and Karagiannis E., 2025, Canopy design drives photosynthetic performance, light environment, and fruit quality in peach (*Prunus persica* L. Batsch), Plants, 15(1): 29.
https://doi.org/10.3390/plants15010029

Cosmulescu S., 2026, Climate change and abiotic stress in fruit trees: Mechanisms and adaptive responses, Agronomy, 16(6): 665.
https://doi.org/10.3390/agronomy16060665

Curtis K.R., Drugova T., Knudsen T., Reeve J., and Ward R., 2020, Is organic certification important to farmers' market shoppers or is eco-friendly enough?, HortScience, 55(11): 1822-1831.
https://doi.org/10.21273/HORTSCI15291-20

Guo C., Wang X., Li Y., He X., Zhang W., Wang J., Zhang Y., et al., 2018, Carbon footprint analyses and potential carbon emission reduction in China's major peach orchards, Sustainability, 10(8): 2908.
https://doi.org/10.3390/su10082908

Guo L., Liu S., Zhang P., Hakeem A., Song H., Yu M., and Wang F., 2024, Effects of different mulching practices on soil environment and fruit quality in peach orchards, Plants, 13(6): 827.
https://doi.org/10.3390/plants13060827

Huang W., Yang H., Wang Y., Ding P., Nawi N.M., and Zhang X., 2025, In-situ precision sensing for smart agriculture using multi-electrode sensor array systems in orchards, Sensors and Actuators A: Physical, 382: 116134.
https://doi.org/10.1016/j.sna.2024.116134

Iglesias I. and Echeverria G., 2022, Current situation, trends and challenges for efficient and sustainable peach production, Scientia Horticulturae, 296: 110899.
https://doi.org/10.1016/j.scienta.2022.110899

Islam M.S., Scalisi A., O'Connell M.G., Morton P., Scheding S., Underwood J., and Goodwin I., 2022, A ground-based platform for reliable estimates of fruit number, size, and color in stone fruit orchards, HortTechnology, 32(6): 510-522.
https://doi.org/10.21273/HORTTECH05098-22

Lee D.B., Lee G.J., You Y.J., Ahn S.Y., and Yun H.K., 2021, Reflective film mulching before harvest promotes coloration and expression of ripening-related genes in peach fruits, Horticultural Science and Technology, 39(3): 324-331.
https://doi.org/10.7235/HORT.20210029

Li T., Zhang B., Du A., Yang S., Huang K., Peng F., and Xiao Y., 2023, Dynamic monitoring of nutrition inputs and fertility evaluation during a decade in the main peach-producing areas of Shandong Province, China, Plants, 12(8): 1725.
https://doi.org/10.3390/plants12081725

Li Z., Chen Y., Meng F., Shao Q., Heal M., Ren F., Tang A., Wu J., Liu X., Cui Z., and Xu W., 2022, Integrating life cycle assessment and a farmer survey of management practices to study environmental impacts of peach production in Beijing, China, Environmental Science and Pollution Research, 29(38): 57190-57203.
https://doi.org/10.1007/s11356-022-19780-0

Ligouri G., Farina V., Gullo G., and Inglese P., 2013, Tree and orchard variability of Silver King nectarine (*Prunus persica* (L.) Batsch) fruit quality components, Horticultural Science, 40(2): 72.
https://doi.org/10.17221/65/2012-HORTSCI

Liu Y., Bei K., Zheng W., Yu G., and Sun C., 2023, Pesticide residues risk assessment and quality evaluation of four characteristic fruits in Zhejiang Province, China, Frontiers in Environmental Science, 11: 1124094.
https://doi.org/10.3389/fenvs.2023.1124094

Losciale P., Gaeta L., Manfrini L., Tarricone L., and Campi P., 2020, Orchard floor management affects tree functionality, productivity and water consumption of a late-ripening peach orchard under semi-arid conditions, Applied Sciences, 10(22): 8135.
https://doi.org/10.3390/app10228135

Luo C.X., Schnabel G., Hu M., and De Cal A., 2022, Global distribution and management of peach diseases, Phytopathology Research, 4(1): 30.
https://doi.org/10.1186/s42483-022-00134-0

Maatallah S., Guizani M., Elloumi O., Montevecchi G., Antonelli A., Ghrab M., and Dabbou S., 2024, Yield and biochemical fruit quality of irrigated peach cultivars subjected to conventional farmer's fertilization practices in warm production area, Journal of Food Composition and Analysis, 129: 106121.
https://doi.org/10.1016/j.jfca.2024.106121

Manganaris G.A., Minas I., Cirilli M., Torres R., Bassi D., and Costa G., 2022, Peach for the future: A specialty crop revisited, Scientia Horticulturae, 305: 111390.
https://doi.org/10.1016/j.scienta.2022.111390

Mazzoni L., Medori I., Balducci F., Marcellini M., Acciarri P., Mezzetti B., and Capocasa F., 2022, Branch numbers and crop load combination effects on production and fruit quality of flat peach cultivars (*Prunus persica* (L.) Batsch) trained as Catalonian Vase, Plants, 11(3): 308.
https://doi.org/10.3390/plants11030308

Mia M.J., Massetani F., Murri G., Facchi J., Monaci E., Amadio L., and Neri D., 2020, Integrated weed management in high-density fruit orchards, Agronomy, 10(10): 1492.
https://doi.org/10.3390/agronomy10101492

Minas I.S., Tanou G., and Molassiotis A., 2018, Environmental and orchard bases of peach fruit quality, Scientia Horticulturae, 235: 307-322.
https://doi.org/10.1016/j.scienta.2018.01.028

Nava G., Reisser Júnior C., Parent L., Brunetto G., Moura-Bueno J.M., Navroski R., Atílio Benati J., and Barreto C.F., 2022, Esmeralda peach (*Prunus persica*) fruit yield and quality response to nitrogen fertilization, Plants, 11(3): 352.
https://doi.org/10.3390/plants11030352

Scalisi A., O'Connell M.G., Islam M.S., and Goodwin I., 2022, A fruit colour development index (CDI) to support harvest time decisions in peach and nectarine orchards, Horticulturae, 8(5): 459.
https://doi.org/10.3390/horticulturae8050459

Shin J.S., Park H.S., Lee K.W., Song J.S., Han H.Y., Kim H.W., and Cho T.J., 2023, Advances in the strategic approaches of pre- and post-harvest treatment technologies for peach fruits (*Prunus persica*), Horticulturae, 9(3): 315.
https://doi.org/10.3390/horticulturae9030315

Sikhandakasmita P., Kataoka I., Mochioka R., and Beppu K., 2022, Impact of temperatures during fruit development on fruit growth rate and qualities of 'KU-PP2' peach, The Horticulture Journal, 91(2): 152-156.
https://doi.org/10.2503/hortj.UTD-341

Sun H., Huang X., Chen T., Zhou P., Huang X., Jin W., Liu D., Zhang H., Zhou J., Wang Z., Hayat F., and Gao Z., 2022, Fruit quality prediction based on soil mineral element content in peach orchard, Food Science & Nutrition, 10(6): 1756-1767.
https://doi.org/10.1002/fsn3.2794

Sutton M., Doyle J., Chavez D., and Malladi A., 2020, Optimizing fruit-thinning strategies in peach (*Prunus persica*) production, Horticulturae, 6(3): 41.
https://doi.org/10.3390/horticulturae6030041

Toumi I., Ghrab M., Zarrouk O., and Nagaz K., 2024, Impact of deficit irrigation strategies using saline water on soil and peach tree yield in an arid region of Tunisia, Agriculture, 14(3): 377.
https://doi.org/10.3390/agriculture14030377

Toumi I., Zarrouk O., Ghrab M., and Nagaz K., 2022, Improving peach fruit quality traits using deficit irrigation strategies in southern Tunisia arid area, Plants, 11(13): 1656.
https://doi.org/10.3390/plants11131656

Tsvakirai C.Z. and Mosikari T.J., 2022, The influence of product quality on export performance: Eco-efficient value in South African peach and nectarine fresh exports, Journal of International Food & Agribusiness Marketing, 34(4): 389-409.
https://doi.org/10.1080/08974438.2021.1900017

Voss H.G.J., Ayub R.A., and Stevan S.L., 2020, E-nose prototype to monitor the growth and maturation of peaches in the orchard, IEEE Sensors Journal, 20(20): 11741-11750.
https://doi.org/10.1109/JSEN.2020.3000070

Wang D., Li L., Jiang X., Qu M., Jiang H., and Zhou H., 2026, Toward robust in-field fruit quality evaluation: A critical review of emerging nondestructive technologies and devices, Food Research International, 225: 118058.
https://doi.org/10.1016/j.foodres.2025.118058

Wang X., Yu M., Guo S., Ma R., and Zhang B., 2023, The relationship between different fruit load treatments and fruit quality in peaches, Horticulturae, 9(7): 817.
https://doi.org/10.3390/horticulturae9070817

Yuan B., and Chen C., 2019, Evolution of a development model for fruit industry against background of rising labor cost: Intensive or extensive adjustment ?, Sustainability, 11(14): 3864.
https://doi.org/10.3390/su11143864

Zhang B., Chen H., Zhang Y., Guo S., Wang X., Sun M., Yu M., and Ma R., 2024, Effects of blooming and fruit thinning on the yield, fruit quality, and leaf photosynthesis of peach cultivar 'Xiahui 5' in China, Food Quality and Safety, 8: fyae019.
https://doi.org/10.1093/fqsafe/fyae019

Zhang B.B., Xu J.L., Zhou M., Yan D.H., and Ma R.J., 2018, Effect of light quality on leaf photosynthetic characteristics and fruit quality of peach (*Prunus persica* L. Batsch), Photosynthetica, 56(4): 1113-1122.
https://doi.org/10.1007/s11099-018-0820-x

Zhao L., Liu Y., Chen X., Zhang X., Liao L., Wang L., An J.P., and Han Y., 2023, Visible light induces the PpHYH transcription to promote anthocyanin pigmentation in peach peel, Fruit Research, 3: 25.
https://doi.org/10.48130/FruRes-2023-0025

Zhao L., Sun J., Cai Y., Yang Q., Zhang Y., Ogutu C., Liu J., Zhao Y., Wang F., He H., Zheng B., and Han Y., 2022, PpHYH is responsible for light-induced anthocyanin accumulation in fruit peel of *Prunus persica*, Tree Physiology, 42(8): 1662-1677.
https://doi.org/10.1093/treephys/tpac025

Zhao Y., Dong W.Q., Wang K., Zhang B., Allan A., Lin-Wang K., Chen K.S., and Xu C., 2017, Differential sensitivity of fruit pigmentation to ultraviolet light between two peach cultivars, Frontiers in Plant Science, 8: 1552.
https://doi.org/10.3389/fpls.2017.01552

Zhao Y., Min T., Chen M., Wang H., Zhu C., Jin R., Allan A., Lin-Wang K., and Xu C., 2021, The photomorphogenic transcription factor PpHY5 regulates anthocyanin accumulation in response to UVA and UVB irradiation, Frontiers in Plant Science, 11: 603178.
https://doi.org/10.3389/fpls.2020.603178

Zhen J., Wang Y., Xia H., Li H., Wu H., Zhao C., and Wang D., 2025, The relationship between microclimate factors and fruit quality in different tree canopies of Xiahui No. 8 peach trees, Frontiers in Plant Science, 16: 1551110.
https://doi.org/10.3389/fpls.2025.1551110