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Application of Loquat Flower and Fruit Management and Tree Regulation in Commercial Fruit Production

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Abstract Loquat (*Eriobotrya japonica* Lindl.) is characterized by prolific flowering, autumn-winter blooming, a relatively long fruit development period, and delicate fruit skin. Commercial fruit production is therefore readily affected by excessive crop load, imbalanced tree vigor, low-temperature stress, and uncoordinated water and nutrient supply. This paper systematically analyzes the application of flower and fruit management and tree regulation in commercial loquat production, with emphasis on flower bud differentiation and flowering and fruiting characteristics, fruit growth and quality formation, tree nutrient allocation, and the effects of source-sink relationships on commercial fruit development. In production management, appropriate flower and fruit thinning, regulation of cluster load, and timely fruit bagging can effectively improve individual fruit weight, soluble solids content, sugar-acid balance, and external fruit quality. Canopy training, renewal of fruiting shoots, and shoot regulation help improve canopy ventilation and light penetration, maintain appropriate tree vigor, and promote flower bud formation. Meanwhile, regulated deficit irrigation, balanced nitrogen-potassium fertilization, and precision water and nutrient management according to different developmental stages can further improve water and fertilizer use efficiency and coordinate vegetative and reproductive growth. Overall, commercial loquat production should focus on the dynamic balance among flower load, fruit load, and tree vigor, integrating flower and fruit thinning, canopy pruning, water and nutrient regulation, pollination assurance, and fruit protection throughout the production cycle. Future research should strengthen the quantitative evaluation of key regulatory indicators under different cultivars and tree vigor conditions, while integrating precision irrigation, intelligent monitoring, and mechanized management to promote standardized, precise, and efficient commercial loquat production.

Keywords Loquat; Flower and fruit management; Tree regulation; Crop load; Commercial fruit quality

1 Introduction

Loquat (*Eriobotrya japonica* Lindl.) is an evergreen fruit tree of the family Rosaceae, native to southeastern China, with a cultivation history of more than 2 300 years (Hueso et al., 2021). At present, loquat is commercially cultivated in more than 30 countries across subtropical, temperate, and Mediterranean climatic regions, including Spain, Pakistan, Turkey, Australia, Brazil, and India (Ahmad et al., 2021; Su et al., 2024). Published global estimates place loquat cultivation at approximately 131 260 ha and annual production at about 549 220 t, with China a major producer (Nordi et al., 2025). Loquat has considerable economic value because its fruit is flavorful and nutrient-rich and generally ripens from late spring to early summer, when the supply of many other fresh stone and pome fruits is relatively limited, giving it a distinct off-season marketing advantage (Kızıl and Durgac, 2023). Because early-maturing fruit often commands higher market prices, commercial orchards increasingly emphasize the production of large, visually attractive, and uniform fruit, with appropriate soluble solids content, balanced acidity, and minimal external peel defects. In addition, growing consumer awareness of the bioactive compounds present in loquat tissues, including triterpenes, flavonoids, carotenoids, and phenolics with antioxidant, antidiabetic, and anti-inflammatory activities, has further increased commercial interest in loquat for both fresh consumption and pharmaceutical applications (Kumar et al., 2024; Shafiq et al., 2025).

Despite its favorable market prospects, modern loquat cultivation still faces a range of biological and environmental constraints that limit overall economic returns. Unlike temperate rosaceous fruit trees such as apple, peach, and pear, which enter winter bud dormancy, loquat generally initiates flower bud differentiation in summer

and flowers directly from late autumn to winter (Peng et al., 2022; Wu et al., 2025). This distinctive phenological pattern exposes open flowers and young fruitlets directly to unfavorable winter weather, increasing the risk of low-temperature injury while also restricting insect foraging activity and destabilizing pollination and fertilization processes. Although native pollinators such as honeybees and hoverflies can markedly improve yield and fruit quality under open-pollination conditions, unstable field weather often restricts their activity. In addition, fruit size varies among loquat cultivars, and improvement of individual fruit weight remains a major commercial objective (Su et al., 2024). Each loquat panicle may naturally bear 30~100 flower buds; if left unmanaged, excessive fruit set intensifies source-sink competition, restricts final fruit enlargement, and weakens subsequent tree recovery. Loquat fruit also has a thin peel and relatively short postharvest shelf life, making developing fruit susceptible to sunburn, russeting, cracking, purple spot, bird damage, and fungal decay (Zhi et al., 2021; Dhiman et al., 2022).

Systematic flower and fruit management is an important horticultural strategy for reducing excessive natural crop load and meeting strict commercial grading requirements. Manual flower thinning and young-fruit thinning can effectively coordinate the relationship between tree nutrient reserves and developing fruit, while promoting cell proliferation, increasing individual fruit weight and longitudinal and transverse diameters, and improving pulp sugar accumulation. For example, retaining four flower buds per inflorescence can result in greater individual fruit weight and a more favorable sugar-acid balance, whereas unthinned inflorescences are more likely to produce small fruit with poor commercial value (Nordi et al., 2025). Following flower and fruit thinning, preharvest bagging with kraft paper bags, microperforated polyethylene bags, or composite-material bags can create a physical microenvironmental barrier that reduces damage from solar radiation, wind abrasion, and pests. Field studies have shown that protective bagging can markedly reduce physiological peel disorders, reduce the incidence of sunburn and fruit rot in tested treatments and modify fruit sugars and peel characteristics. In addition, the duration for which mature fruit remains on the tree can influence return bloom in the following season through hormonal interactions among gibberellins, auxins, and cytokinins, indicating that harvest timing itself is an important factor regulating annual floral induction.

Integrated tree regulation can further improve orchard yield stability, optimize canopy architecture, and regulate harvest timing. Canopy training and targeted postharvest pruning can alter the pattern of vegetative shoot growth, improve light distribution, and promote the differentiation of vigorous flower buds. Innovative pruning methods, such as summer double back-cutting, can promote the formation of vigorous fruiting shoots with greater leaf area and thicker branch diameters, while downregulating the expression of cell-division-inhibitory genes such as EjFWL1 and EjFWL2 in early floral primordia, thereby promoting commercial fruit enlargement and increasing total yield. Flowering time can also be regulated. For example, removal of the main floral axis at full bloom can induce secondary flowering and delay bloom by 2-4 months, with key flowering integrator genes such as EjFT and EjAP1 participating in this process, thereby helping avoid midwinter cold injury. Meanwhile, transcriptional regulators including *EjCAL, EjERF12, EjCO1,* and *EjRAV1/2* participate in flower bud differentiation under the regulation of endogenous hormones and sorbitol, providing a molecular basis for advancing or otherwise regulating flower bud formation. Postharvest regulated deficit irrigation has advanced bloom and reduced irrigation demand in field trials, but its effects depend on cultivar and local growing conditions (Ballester et al., 2018). Therefore, establishing an integrated technical system that coordinates flower, fruit, and canopy regulation is of great significance for promoting commercial loquat production toward greater sustainability and higher added value.

2 Flowering and Fruiting Characteristics of Loquat and the Basis of Commercial Fruit Formation

2.1 Flower bud differentiation and flowering and fruiting characteristics

Loquat is an evergreen fruit tree that flowers in autumn and winter and ripens from the following spring to early summer, and its reproductive growth cycle differs markedly from that of most temperate deciduous fruit trees. Fruit trees such as apple, peach, and pear usually undergo winter dormancy after flower bud formation and bloom in the following spring, whereas loquat can complete flower bud differentiation and enter the flowering stage within the same calendar year without undergoing a typical winter dormancy period (Reig et al., 2017; Jing et al.,

2020). Previous studies have shown that morphological differentiation of loquat flower buds mainly occurs from late June to September, followed by inflorescence development, with flowering occurring successively from October to January of the following year (Jiang et al., 2019; Jiang et al., 2021). Therefore, summer shoot growth, tree nutrient accumulation, and environmental conditions already begin to determine subsequent flower bud quality and inflorescence development.

The transition of loquat flower buds from vegetative to reproductive growth is jointly regulated by temperature, photoperiod, hormones, and carbohydrate signals. When summer temperatures exceed 25 °C, the expression of the floral repressor *EjTFL1* decreases, while the activities of floral meristem-related genes such as *EjAP1* and *EjLFY* increase, thereby favoring flower bud differentiation. In contrast, lower temperatures maintain relatively high *EjTFL1* expression and prolong the vegetative growth period of shoots (Jiang et al., 2020; Reig et al., 2023). Single-nucleus and spatial transcriptomic studies further indicate that epidermal and meristematic cells of the shoot apex participate in the transition from vegetative to reproductive growth through photoperiod- and circadian rhythm-related pathways involving genes such as *EjCRY2* and *EjAGL79* (Zhao et al., 2025). Meanwhile, endogenous signals such as abscisic acid, zeatin, and sorbitol are also involved in flower bud induction, among which sorbitol can promote flower bud formation through the EjERF12-EjCAL regulatory pathway (Chi et al., 2020; An et al., 2021; Xu et al., 2023).

Loquat inflorescences are generally borne at the terminals of current-season shoots, with abundant flowers and a relatively long flowering period. Although a high natural flower load helps provide a sufficient basis for fruit set, excessive shoot growth, canopy shading, or nutrient imbalance during summer and autumn can reduce the maturity of bearing shoots and the quality of flower buds. On the other hand, excessive numbers of flower buds increase nutrient consumption by the tree and intensify subsequent source-sink competition among developing fruits. Therefore, flower bud management for commercial fruit production should begin during summer and autumn. Shoot growth should be controlled, light conditions improved, and appropriate tree vigor maintained to promote full maturation of bearing shoots. After flowering begins, selective flower thinning should be conducted according to branch vigor and inflorescence quality, thereby providing a foundation for the subsequent production of uniform and stable commercial fruit.

2.2 Fruit growth, development, and quality formation

Following natural pollination and fruit set, loquat enters the young-fruit development stage, and fruit growth continues from late winter through spring, proceeding through successive phases of cell division, tissue expansion, ripening and color change, and quality formation (Jiang et al., 2025). Anatomical and histological studies have shown that final loquat fruit size depends largely on the cell division capacity established before anthesis and during the early stages of fruitlet development. During approximately the first 90 d after flowering, rapid seed expansion contributes substantially to early increases in fruit volume, while pulp tissues continue to thicken. This stage is also accompanied by multiple metabolic and transcriptional regulatory processes involving auxin, gibberellin, brassinosteroids, and heat-shock responses (Lin et al., 2025). Among these, cell proliferation-related inhibitory genes such as EjFWL1 and EjFWL2 can affect cell proliferation in flower buds and young fruitlets, thereby limiting the potential final fruit size.

As the fruit enters the ripening stage, its external appearance and internal quality gradually develop. The peel changes from green to yellow or orange-yellow, while soluble sugars, organic acids, pigments, and other flavor-related compounds in the pulp continue to change, eventually forming the characteristic color and flavor of different cultivars. Individual fruit weight, fruit diameter, fruit shape uniformity, peel cleanliness, soluble solids content, and sugar-acid balance are important indicators for evaluating commercial fruit quality. Fruit size differs among commercial white- and yellow-fleshed cultivars, and crop load regulation can help improve individual fruit weight and fruit uniformity.

Fruit load directly affects the amount of photoassimilates and mineral nutrients available to each fruit. When too many fruits are retained per cluster, strong sink competition develops, resulting in smaller fruit, uneven ripening, and insufficient sugar accumulation. In contrast, appropriately reducing fruit load can improve the source-sink

ratio and increase both individual fruit weight and soluble solids content. Studies have shown that adjusting each inflorescence or fruit cluster to approximately four flower buds per inflorescence can markedly improve fruit weight and ripening index, whereas retaining about 10-12 flower buds, although increasing total cluster mass, tends to produce smaller and less sweet fruit. In addition, mature loquat fruit has a relatively thin peel and is sensitive to intense light, mechanical abrasion, and fluctuations in water availability, making it prone to sunburn and surface damage. Therefore, the production of high-quality commercial fruit also requires coordinated water management, appropriate canopy light conditions, and effective fruit protection measures.

2.3 Relationship between tree nutrient allocation and commercial fruit formation

Loquat trees characteristically display relatively limited lateral branching and prominent terminal inflorescences, which restricts bearing surface and unit-area productivity. Transcriptomic and metabolomic analyses show that this weak branching habit is governed by abscisic acid and strigolactone signaling via EjSAPK1 and EjRMS3 (Li et al., 2026). Tree architecture directly influences canopy carbon assimilation, as developing panicles and mature pomes operate as strong carbohydrate sinks (Lin et al., 2025). Extended retention of mature fruit may delay the subsequent reproductive transition through changes in resource allocation and hormonal balance; the size and generality of this effect require further loquat-specific confirmation.

Regulating vegetative flushes through postharvest summer pruning and balanced nutrient supply balances source-sink dynamics. Implementing summer double back-cutting eliminates excessive weak terminal shoots, encouraging robust bearing branches with greater leaf surface area, thicker stem diameters, and enhanced nutrient reserves. This architectural rejuvenation downregulates EjFWL1 and EjFWL2, accelerating early cell division in emerging floral primordia and improving final pome dimensions. Autumn pruning and balanced nitrogen-potassium nutrition have been proposed to coordinate shoot growth and fruit production; however, nutrient ratios should be determined from orchard conditions rather than treated as universal thresholds. Understanding these physiological mechanisms provides the operational foundation for targeted crop load thinning, canopy regulation, and yield optimization.

3 Flowering Management and Fruit Set Regulation

3.1 Inflorescence management and flower thinning

Loquat naturally forms compact terminal panicles, with each inflorescence typically bearing 30-100 flower buds. Although a large initial flower load provides a basis for fruit set, it also causes substantial nutrient competition and carbohydrate consumption. Particularly during autumn and winter flowering, the simultaneous development of numerous floral organs increases the consumption of stored nutrients. If a high crop load is maintained thereafter, fruit crowding, reduced individual fruit size, and lower commercial grade may result. Therefore, inflorescence management should be used as an early crop-load regulation measure in commercial fruit production. According to cultivar characteristics, tree vigor, fruiting shoot diameter, and inflorescence development, weak, excessively dense, or poorly positioned inflorescences should be preferentially removed to reduce ineffective nutrient consumption and provide a more adequate source supply for subsequent fruitlet development (Huang, 2025).

The key objective of flower thinning is not simply to reduce the number of inflorescences, but to match the retained flower load with the nutrient-supplying capacity of the tree. Previous studies have shown that different bud-retention intensities significantly affect subsequent fruit size and quality. When approximately four flower buds are retained per inflorescence, a favorable balance can be established between source reserves and sink demand, resulting in higher individual fruit weight, greater soluble solids content, and a more balanced sugar-acid ratio than in unthinned treatments. In contrast, retaining approximately 10-12 flower buds per inflorescence or maintaining a high crop load may increase total cluster mass, but individual fruits are markedly smaller and their commercial value is reduced (Figure 1) (Nordi et al., 2025). Therefore, more intensive flower thinning should be applied to trees with weak vigor or a heavy crop in the previous year, whereas trees with moderate vigor and well-developed fruiting shoots can retain an appropriate flower load to ensure adequate fruit set and subsequent commercial fruit development.

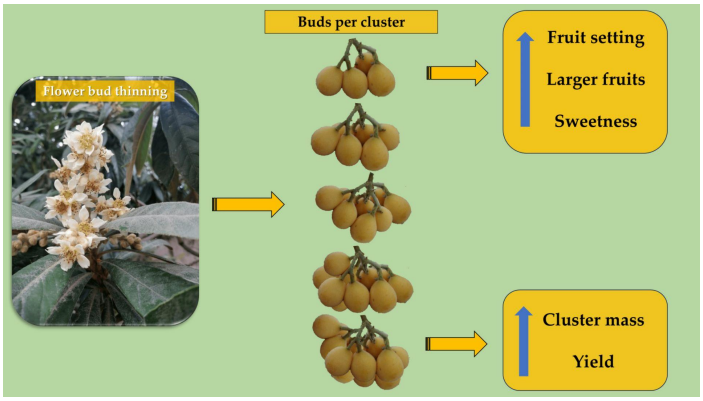


Figure 1 Flowers and fruits of loquat (Adopted from Nordi et al., 2025)

In addition to conventional flower thinning, manipulation of inflorescence structure can also be used to regulate flowering time. Removal of the upper portion of the main inflorescence axis at full bloom can induce secondary flowering from lateral buds, and the newly formed lateral inflorescences generally develop approximately 2-4 months later than the original terminal inflorescences, providing a potential means of adjusting flowering time and avoiding winter chilling injury. This process is accompanied by changes in the expression of flowering-related genes, including *EjFT1*, *EjFT2*, *EjAP1-1*, and *EjAP1-2* (Jiang et al., 2025; Wang et al., 2025). Therefore, beyond conventional crop-load regulation, manipulation of the inflorescence axis also has value for phenological regulation, although its application should be determined according to local winter temperature risks, cultivar characteristics, and production objectives.

3.2 Pollination management and fruit set assurance during flowering

Loquat generally flowers under the relatively low-temperature conditions of autumn and winter, and its prolonged flowering period is readily affected by rainfall, low temperatures, strong winds, and insufficient pollinator activity. Low temperatures not only reduce insect visitation frequency but may also impair pollen germination, pollen tube growth, and fertilization, thereby causing fluctuations in fruit set. Although self-compatibility occurs in many diploid loquat cultivars, pollen viability and successful fertilization remain important for normal seed development and fruit retention. Xia et al. (2022) found that abnormal embryo sac development and reduced female gametophyte fertility in the diploid line H30-6 markedly restricted seed formation and natural fruit set, indicating that normal fertilization is important for continued ovary growth.

Therefore, commercial loquat orchards should provide favorable conditions for natural pollination. In orchards with insufficient pollinator activity or unstable weather conditions, fertilization stability can be improved by conserving pollinating insects such as honeybees, appropriately arranging pollinizer cultivars, and applying supplemental artificial pollination when necessary. During flowering, pest and disease control should minimize the use of chemicals that may adversely affect floral organs and pollinators, and pesticide application should be avoided during peak insect activity. Water supply should also remain relatively stable, because drought during flowering can intensify floral abscission, whereas waterlogging and prolonged high humidity may reduce pollen viability and impair floral health. It should be emphasized that a higher fruit set rate is not necessarily better. The objective of flowering-stage management should be to obtain an appropriate number of uniformly developing fruitlets that allow sufficient scope for subsequent selection, rather than simply maximizing fruit set.

When natural pollination is limited, plant growth regulators can be used as supplementary regulatory tools. Jiang et al. (2016) reported that application of 500 mg/L GA_3 at full bloom induced fruit set in the experimental triploid loquat cultivar 'Danhe', which otherwise showed severe fertilization failure. Transcriptomic analyses indicated that this process is associated with the upregulation of auxin biosynthesis- and cell cycle-related genes such as *YUCCA, arr9,* and *CYCA3*, together with the downregulation of several ethylene biosynthesis-related genes and transcriptional repressors. However, GA_3 is a strong physiological regulator, and its effects vary with cultivar, application timing, and concentration. Therefore, this result should not be generalized to ordinary diploid orchard cultivars without additional field validation.

3.3 Environmental and nutritional regulation during flowering

Loquat flower bud formation and flowering are sensitive to temperature, light conditions, and tree nutritional status. Previous studies have shown that relatively high summer temperatures are an important environmental signal promoting the transition from vegetative to reproductive growth in loquat. When temperatures exceed 25 ℃, expression of the floral repressor gene *EjTFL1* decreases, while expression of floral meristem-related genes such as *EjAP1* and *EjLFY* increases, thereby favoring flower bud differentiation. In contrast, lower temperatures may maintain relatively high levels of *EjTFL1* expression and abscisic acid signaling, prolonging the period of vegetative growth. Once actual flowering begins, however, prolonged low temperatures, rainy conditions, and high humidity may damage floral organs and reduce pollen viability and insect activity. Thus, the temperature response of loquat varies markedly among phenological stages.

Light conditions and canopy position also influence flowering and fruit set. Polat (2015) showed that flowering time and fruit set differed among branches located at different canopy orientations, with better-illuminated branches on the southern side of the canopy generally exhibiting earlier flowering and higher fruit set. This indicates that flowering-stage management should address not only the floral organs themselves but also branch light conditions through appropriate pruning and canopy regulation. In production, excessive canopy shading should be reduced while maintaining good ventilation and light penetration. According to local climatic conditions, measures such as cold protection, drainage, and moderate irrigation should also be adopted to minimize the adverse effects of low temperatures, prolonged rainfall, and fluctuations in water availability on flowering and pollination.

Nutrient supply is an important basis for maintaining floral vigor and stable fruit set. Excessive nitrogen application before and during flowering should be avoided because it may stimulate excessive shoot growth, while balanced supplies of potassium, magnesium, zinc, boron, and calcium should be ensured. Ali et al. (2021) showed that two foliar applications of mineral nutrients at three-week intervals during full bloom improved the nutritional status of reproductive tissues and developing fruit in loquat. Specifically, treatments with 2% $MgSO_4 \cdot 7H_2O$ and 0.1% $ZnSO_4 \cdot 7H_2O$ increased potassium and calcium concentrations in developing pulp, while 0.2% $Na_2B_4O_7 \cdot 10H_2O$ improved the partitioning of boron and calcium among peel, pulp, and seed tissues. Because boron is closely associated with pollen germination and pollen tube growth, appropriate boron supplementation is of particular practical importance when trees are boron-deficient.

4 Fruit Thinning and Fruit Quality Regulation

4.1 Timing of fruit thinning and principles of fruit retention

Fruit thinning is an important practice for regulating crop load and improving individual fruit size and uniformity in commercial loquat production. Its primary purpose is to alleviate source-sink competition caused by excessive fruit set, thereby allowing limited photoassimilates and mineral nutrients to be preferentially allocated to retained fruits. If thinning is conducted too early, some fruitlets may not yet have fully expressed their final developmental potential, and subsequent natural fruit drop may result in insufficient fruit retention. In contrast, if thinning is delayed, a large number of fruitlets will already have consumed substantial tree reserves, reducing the resources available for later fruit enlargement and tree recovery. Therefore, manual fruit thinning is generally most appropriate after final fruit set has largely stabilized and fruitlet developmental status can be assessed more clearly. In some production regions, traditional manual thinning is commonly carried out in late winter, around February, when fruit developmental potential can be evaluated while crop load can still be reduced before the rapid fruit enlargement stage (Cuevas et al., 2004).

When selecting fruits for retention, priority should be given to fruitlets with regular shape, relatively uniform size, no disease, pest, or mechanical damage, and favorable positions within the cluster. Malformed, undersized, diseased, insect-damaged, mechanically injured, and overcrowded fruits should be removed promptly. Branch units with weak tree vigor, thin fruiting shoots, or insufficient effective leaf area should retain fewer fruits, whereas moderately vigorous branches with strong fruiting shoots and healthy functional leaves can sustain a relatively higher but still appropriate crop load. Timely removal of a portion of the fruitlets reduces unnecessary

depletion of stored reserves and enables retained fruits to receive greater supplies of photoassimilates and root-absorbed mineral nutrients during the cell expansion stage (Huang et al., 2021). Therefore, the essence of appropriate fruit retention is not to maximize fruit number, but to match crop load with the assimilate-supplying capacity of the canopy, fruiting shoots, and leaves.

In commercial orchards where labor costs are high, chemical thinning may serve as a supplementary approach to manual thinning. Cuevas et al. (2004) evaluated naphthaleneacetamide (NAAm) dosage, timing and wetting-agent effects for chemical thinning in loquat, reporting improved fruit size under the tested conditions. However, the effectiveness of chemical thinning is readily influenced by canopy position, chemical concentration, and environmental conditions. Therefore, manual inspection and supplemental thinning are still required in practical production. In addition, postharvest pruning and renewal of fruiting shoots can act synergistically with fruit thinning by improving light conditions and carbohydrate reserves, thereby establishing a more stable fruiting basis for the following production cycle.

4.2 Effects of fruit retention level on fruit size and quality

The number of retained fruits directly determines the amount of photoassimilates and mineral nutrients available to each individual fruit. When crop load is excessive, competition among fruits and between fruits and shoots intensifies, often resulting in reduced fruit weight, smaller fruit diameter, uneven ripening, and impaired sugar accumulation and fruit uniformity. Previous studies have shown that when approximately four flower buds are retained per inflorescence, loquat fruits exhibit clear advantages in transverse diameter, longitudinal diameter, and individual fruit weight. In contrast, retaining approximately 10-12 flower buds per inflorescence may increase total cluster mass but reduces individual fruit size and market value. These results indicate that commercial fruit production should seek a reasonable balance between individual fruit quality and total yield rather than simply maximizing the number of retained fruits.

Crop load also affects sugar and organic acid metabolism in the fruit flesh. The mature flavor of loquat is primarily determined by the balance between soluble sugars and organic acids. Fructose, glucose, and sucrose are the major soluble sugars, whereas malic acid is one of the predominant organic acids (Deng et al., 2023; Ali et al., 2024). Moderate fruit thinning increases assimilate availability to retained fruits, thereby promoting sugar accumulation and improving the sugar-acid balance. Measurements of sugar- and organic-acid-related enzymes during loquat fruit development indicate that flavor formation is developmentally regulated (An et al., 2026). Studies in mandarin (*Citrus reticulata*) have shown that manual fruit thinning can influence endogenous auxin and gibberellin levels and increase the expression of sugar transporter genes, including CrSUT1, CrSTP1, and CrTMT1 (Liu et al., 2022). However, whether similar mechanisms operate in loquat remains to be experimentally verified. These findings provide a useful reference for understanding the relationship between crop load regulation and sugar accumulation in loquat.

Appropriate nutrient management can further strengthen the quality improvements achieved through fruit thinning. Ali et al. (2024) showed that magnesium nutrition influences sugar and organic acid metabolism in loquat fruit, and foliar magnesium supplementation can improve leaf chlorophyll status and sugar metabolism capacity. Yang et al. (2026) further found that application of nano-MgO under magnesium-deficient conditions improved plant magnesium status and markedly enhanced fruit quality traits. Meanwhile, maintaining an appropriate nitrogen-to-potassium ratio can promote phloem sugar transport and fruit enlargement, thereby improving the uniformity of commercial fruit size and quality. Therefore, fruit retention regulation should not be managed separately from water and nutrient supply; rather, crop load, leaf area, and mineral nutrition should be jointly incorporated into a coordinated system for targeted commercial fruit production.

4.3 Fruit bagging and management of external fruit quality

External appearance is an important criterion in the commercial grading of loquat fruit. Because loquat fruit has a relatively thin peel, it is susceptible before and during ripening to sunburn, russeting, purple spot, disease lesions, mechanical abrasion, and damage caused by birds and insects. Therefore, preharvest bagging is an important measure for improving fruit surface quality and reducing external damage (Shah et al., 2023). Bagging creates a

physical barrier around the fruit cluster, reducing the direct effects of solar radiation, wind and rain, and friction with leaves and branches, while also limiting damage from certain pests and birds. Bagging is generally conducted when the fruit is still at the green-mature stage, approximately two months before harvest, so as to balance protective effects with continued fruit development.

Bagging materials and their light transmittance directly affect the microenvironment inside the bag and fruit quality. Zhi et al. (2021) reported that single-layer paper bags improved peel appearance, increased soluble sugar content, reduced titratable acidity, and increased the sugar-acid ratio relative to unbagged fruit. In contrast, excessively light-blocking materials such as double-layer black paper bags or aluminum foil, although providing strong protective effects, may reduce total phenolic and flavonoid contents and overall antioxidant capacity in the fruit flesh. Therefore, bagging material selection should not focus solely on achieving complete shading, but should instead balance protection against sunlight and pests with maintenance of internal fruit quality.

Different bagging materials also vary substantially in their protective effectiveness. Aluminum-polyethylene composite bags can significantly reduce the incidence of peel sunburn, fruit rot, and black spot, with reductions of approximately 66.7%, 55.6%, and 33.3%, respectively. Perforated plastic fruit bags have shown favorable fruit firmness and soluble-solids outcomes in a specific preharvest comparison. Before bagging, fruit thinning and removal of diseased or insect-damaged fruits should be completed, and the fruit surface should be dry and healthy to avoid enclosing infected or injured fruits within the bag. Improperly ventilated bags may increase humidity around developing fruit, so permeability should be considered alongside physical protection. Therefore, ventilation and moisture-release capacity are also important criteria when selecting bagging materials (Hussain et al., 2024).

Bagging cannot completely replace canopy and water management. Before and during ripening, appropriate pruning is still required to reduce friction between fruit and surrounding branches and leaves and to improve canopy ventilation and light penetration. At the same time, marked fluctuations in soil moisture during fruit enlargement should be avoided to reduce the risk of fruit cracking and physiological surface disorders. Thus, the development of high-quality commercial fruit appearance should be based on an integrated management framework of “appropriate crop load-rational bagging-stable water supply-favorable canopy environment.” Only through coordinated regulation of fruit load, fruit surface protection, and canopy microclimate can fruit size, surface cleanliness, and ripening uniformity be simultaneously improved, ultimately increasing the proportion of high-grade commercial fruit.

5 Tree Structure and Fruiting Shoot Regulation

5.1 Tree architecture and canopy ventilation and light penetration

A well-structured tree architecture provides an important foundation for high-quality and stable loquat production. Loquat naturally has a relatively weak branching capacity, often producing fewer but longer shoots with compact inflorescences at their terminals. Such architecture has implications for effective fruiting space and orchard access (Li et al., 2026). Branching characteristics also vary markedly among cultivars. For example, ‘Dawuxing’ and ‘Chunhua 1’ differ in the number of lateral branches and branch opening angles, and these differences are associated with regulatory factors such as the abscisic acid signaling-related kinase EjSAPK1 and the strigolactone receptor EjRMS3 (Li et al., 2026). Therefore, tree architecture regulation in commercial fruit production should not only control canopy size but also take into account cultivar-specific branching characteristics and tree vigor.

Canopy architecture directly determines internal light conditions, ventilation, and assimilate production capacity. When the canopy becomes excessively dense, interior and lower branches receive insufficient light, reducing leaf photosynthetic efficiency, causing the fruiting zone to shift gradually toward the canopy periphery, and limiting fruit enlargement and sugar accumulation. Improving branch arrangement can increase light penetration into crowded loquat canopies, although cultivar-specific effects on bud formation and fruit quality require direct measurements. In loquat production, open-center or cup-shaped training systems can improve internal light

distribution and assimilate transport between sources and sinks by appropriately arranging primary and lateral branches and increasing branch opening angles.

Tree architecture regulation should also consider the fruit-bearing environment and the convenience of orchard operations. Excessively tall, dense, or severely crossing canopies not only reduce light penetration but also increase the difficulty of flower thinning, fruit thinning, bagging, and harvesting. In production, overlapping, inward-growing, vigorous upright, and excessively dense branches should be removed in a timely manner according to tree age, planting density, and cultivar vigor, so that fruiting shoots are distributed relatively evenly throughout the inner and outer canopy. A well-structured canopy can improve the local temperature and humidity environment, reduce the risks of branch-fruit friction and disease, and increase effective leaf area and light-use efficiency, thereby providing a stable spatial basis for the formation of high-quality commercial fruit.

5.2 Pruning methods and renewal of fruiting shoots

Loquat fruiting shoots require continuous renewal. If weak, aging, or repeatedly overcropped branch units are retained for long periods, shoot vigor declines, inflorescence quality deteriorates, and subsequent fruiting capacity gradually decreases. Postharvest summer and autumn pruning are important practices for renewing fruiting shoots, regulating the leaf-to-fruit relationship, and restoring tree vigor. In traditional production, a single heading-back cut is often applied to previously fruited shoots after spring harvest; however, under some conditions, this practice can promote weak summer shoots and result in the formation of numerous but low-quality inflorescences in the following cycle. Therefore, pruning should not be aimed solely at controlling canopy size but should also promote fruiting shoot renewal and improve shoot quality for the next production cycle.

Different pruning methods should be selected flexibly according to tree vigor and branch condition. For overly vigorous trees with dense peripheral shoots, upright vigorous shoots and excessively dense strong branches can be selectively removed to reduce outer-canopy shading. For weak trees or those subjected to continuous heavy cropping, aging branch units should be headed back and ineffective fruiting shoots reduced to stimulate new shoot emergence and branch rejuvenation. Studies have shown that double heading-back pruning, in which approximately half of the newly emerged summer shoots are removed, can concentrate more nutritional resources in the remaining fruiting shoots, resulting in greater leaf area, thicker branch diameter, and higher chlorophyll levels. This renewal strategy favors the development of well-matured fruiting shoots for the following year and improves the resource supply for subsequent fruit growth.

The effects of double heading-back pruning on fruit size also have physiological and molecular bases. Su et al. (2024) found that double heading-back treatment downregulated the expression of the cell proliferation inhibitory genes *EjFWL1* and *EjFWL2* in early flower bud primordia, promoted receptacle cell division before anthesis, and increased the number of cell layers in the receptacle cortex, thereby providing a plausible developmental basis for the larger fruit observed after double-heading. After flowering, the EjCYP90A-EjBZR1-related brassinosteroid regulatory pathway also participates in fruit cell expansion (Su et al., 2021). These findings connect a specific pruning treatment to pre-anthesis fruit-cell development, rather than demonstrating that flower thinning alone changes EjFWL expression.

Combining postharvest pruning with flower and fruit load regulation can further enhance tree regulation. Double heading-back pruning and flower bud thinning may represent complementary approaches to regulating shoot growth and reproductive load. However, their combined effects on fruit quality, cumulative yield, and long-term tree vigor require validation in integrated field experiments. Therefore, renewal of fruiting shoots should be based on an assessment of tree vigor, with orderly replacement of old and new branch units to prevent excessive outward migration of the fruiting zone and to maintain long-term stable fruiting capacity throughout the canopy.

5.3 Regulation of shoot growth and flower bud formation

Shoot growth status is closely related to flower bud formation in loquat. Loquat generally enters floral induction and flower bud differentiation from late June to September and flowers successively from October to January of the following year (Wang et al., 2025). If shoots continue vigorous growth throughout summer and fail to stop

elongating and mature in a timely manner, more assimilates are allocated to vegetative growth, which is unfavorable for the transition to reproductive growth. Conversely, excessively weak shoots may also produce low-quality flower buds because of insufficient effective leaf area and limited carbohydrate accumulation. Therefore, production management should maintain moderate shoot growth and ensure that new shoots complete tissue maturation before flower bud differentiation.

Temperature and associated gene regulation represent important mechanisms linking shoot growth with flower bud formation. When summer temperatures exceed 25°C, expression of the floral repressor *EjTFL1* decreases, whereas floral meristem-related genes such as *EjAP1* and *EjLFY* are activated, promoting the transition from vegetative to reproductive growth. In contrast, under relatively low-temperature conditions, *EjTFL1* can remain highly expressed and form a transcriptional repressor complex with EjFD, thereby prolonging the vegetative state of the shoot apical meristem. In addition, single-nucleus transcriptomic studies have shown that photoperiod-related factors such as EjCRY2 and EjAGL79 participate in this reproductive transition, while EjFT1 and EjFT2 further contribute to the fine regulation of bud break and flowering time (Figure 2) (Jiang et al., 2025; Zhao et al., 2025).

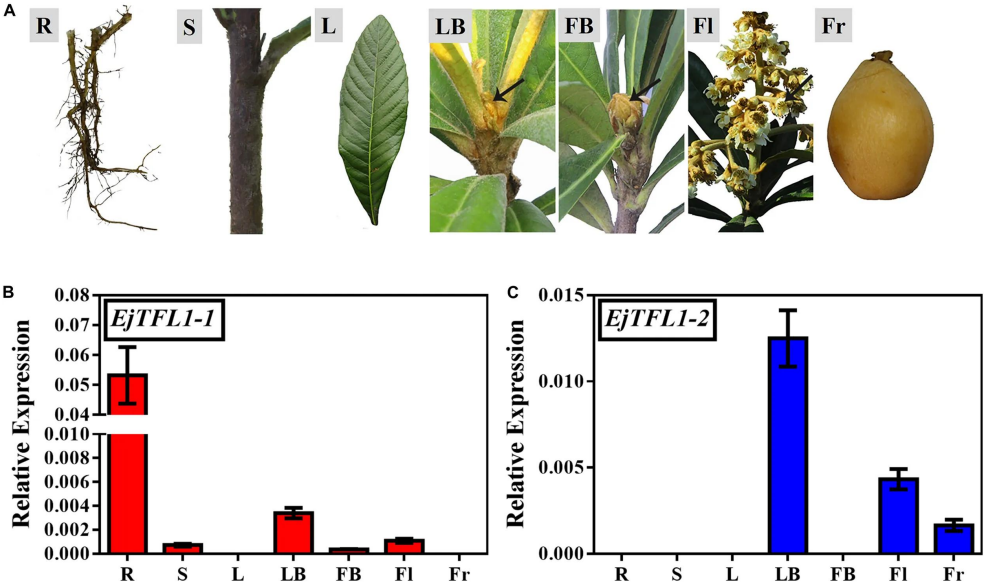


Figure 2 Tissue-specific expression of *EjTFL1-1* and *EjTFL1-2* (Adopted from Jiang et al., 2025)

Image caption: (A) Different tissues from loquat (*Eriobotrya japonica* Lindl) were analyzed. (B,C) Relative expression of *EjTFL1-1* and *EjTFL1-2* in different tissues shown in (A) (error bars indicate ± SE from three biological replicates). R, root (from rootstock); S, shoot; L, leaf (5.26); LB, leaf bud (5.26); FB, flower bud (8.18); Fl, flower (12.8); Fr, fruit (3.30). Leaf bud, flower bud and flower are phenotypes of the shoot apex at different developmental stages (Adopted from Jiang et al., 2025)

Carbohydrate and hormonal signals are also involved in shoot maturation and flower bud formation. Xu et al. (2023) found that sorbitol can promote flower bud formation through the EjERF12-EjCAL regulatory pathway. Gibberellin, however, exhibits clear stage-specific effects. Application of GA_3 during the early vegetative growth stage promotes shoot elongation and increases *EjTFL1* expression, thereby delaying flower bud differentiation. During the later stage of morphological flower bud differentiation, GA_3 can promote inflorescence development by regulating the DELLA protein EjRGL3a and downstream factors such as EjAGL24 and EjLFY (Wang et al., 2026). Therefore, shoot management should be closely aligned with phenological stage, and excessive nitrogen application or prolonged heavy irrigation before floral induction should be avoided to prevent renewed excessive vegetative growth.

In orchard management, shoot growth can be regulated through shoot thinning, pinching, branch bending, and adjustment of water and nutrient supply. Excessively dense new shoots should be removed promptly, while upright and overly vigorous branches can be bent to weaken apical dominance and gradually promote the transition from vegetative to reproductive growth. For weak shoots and branch units that have borne heavy crops

continuously, crop load should be appropriately reduced and nutrient supply improved. Under specific conditions, flowering phenology can also be modified through inflorescence manipulation. For example, in regions with a high risk of winter frost, removal of the main inflorescence axis at full bloom can induce lateral buds to reflower 2-4 months later, accompanied by changes in the expression of genes such as *EjFT* and *EjAP1-like1*, thereby helping to avoid low-temperature injury to some extent (Wang et al., 2025).

6 Water and Nutrient Management and Tree Vigor Regulation

6.1 Water management at different developmental stages

Regulating tree water status across distinct phenological stages serves as an effective horticultural tool to steer reproductive development and conserve water resources. Unlike temperate deciduous fruit crops, loquat differentiates flower buds during summer and blooms across late autumn and winter, developing fruit over late winter into early spring. In Mediterranean climates, this separation of shoot growth and fruit maturation allows trees to withstand summer water limitations without direct yield penalties (Gugliuzza et al., 2020). In the tested loquat cultivars, postharvest regulated deficit irrigation (RDI), involving the suspension of irrigation for six to nine weeks from June through August, advanced flowering by 10 to 27 days and achieved substantial irrigation-water savings without reducing yield (Ballester et al., 2018). However, earlier flowering did not consistently translate into an earlier harvest distribution, and potential economic benefits remain dependent on cultivar, treatment timing, and market conditions. The magnitude of economic return and water saving varies by irrigation strategy, cultivar, and season.

The physiological response to postharvest water stress involves cessation of terminal vegetative flushes, followed by accelerated floral bud differentiation in apical meristems upon re-watering. Studies of young loquat plants indicate that leaf metabolites, including sorbitol, respond to water deficit; such seedling responses should not be directly converted into irrigation thresholds for mature orchards (Gugliuzza et al., 2020). However, excessive pre-bloom moisture deficits can displace reproductive phenology into cooler months, requiring more calendar days and accumulated heat units to mature fruit (Cuevas et al., 2018). This relationship between bloom timing and accumulated growing degree days suggests that severe pre-bloom stress may alter the thermal conditions associated with fruit maturation. Water deficits during fruit expansion and maturation should be managed cautiously to avoid compromising fruit size, quality and postharvest handling.

6.2 Nutrient supply and fruit development

Adequate mineral nutrition provides the structural and metabolic foundation for loquat vegetative growth, blossom retention, and pulp quality. Soil and foliar nutrient diagnostics demonstrate that single fruit weight is heavily influenced by soil calcium, magnesium, and iron, as well as leaf potassium, zinc, and calcium concentrations (Huang et al., 2021). Foliar mineral diagnosis conducted on three- to four-month-old summer flush leaves between August and September accurately reflects canopy nutritional status and guides subsequent seasonal fertilizer programs. In orchard trials, adjusting the fertilizer formulation toward an increased potassium share-including increased potassium relative to nitrogen in certain tested orchard programs-fosters resilient canopies, enhances phloem sugar translocation, and accelerates pulp cell enlargement. In young trees, fertilizer and plant growth regulator combinations can influence seedling growth, although their performance cannot be used as a direct recommendation for mature bearing orchards (Surya et al., 2021).

Soluble solids and organic acid accumulation represent primary commercial indices that respond directly to mineral management. Artificial neural network analyses reveal that foliar nitrogen, phosphorus, calcium, and magnesium determine pulp titratable acidity, while soil manganese, iron, and magnesium together with leaf nitrogen are important predictors of soluble solids accumulation. Mineral nutrients also contribute to photosynthetic metabolism, although the statistical associations in the predictive model do not themselves demonstrate causal control of sugar transport. Furthermore, long-term soil health and rhizosphere arbuscular mycorrhizal fungal (AMF) communities require balanced chemical applications; excessive total nitrogen and potassium surplus negatively correlate with beneficial AMF spore colonization. These findings support avoiding

excessive nutrient enrichment and further evaluating soil organic matter and mycorrhizal management under local conditions (Zhang et al., 2025).

6.3 Coordination between water and fertilizer inputs and crop load

In loquat production, water and nutrient inputs should first be matched to the target crop load. Separate loquat studies have demonstrated benefits of flower-bud thinning and carefully timed irrigation for fruit quality and resource-use efficiency. However, their results do not yet establish a universally optimal combination of crop load, irrigation and fertilization. Controlled factorial experiments are needed to define joint management thresholds for specific cultivars and production regions.

In practice, soil and leaf nutrient diagnosis should be considered together with fruit load and orchard water status. Loquat-specific predictive studies provide a useful starting point, but fertilizer rates and irrigation thresholds need to be validated under local cultivar, soil and climatic conditions.

7 Integrated Regulation of Flowers, Fruits, and Tree Growth for Production Optimization

7.1 Dynamic balance among flower load, fruit load, and tree vigor

Loquat differentiates prolific terminal inflorescences containing 30 to 100 individual flower buds, resulting in intense carbohydrate competition that restricts vegetative shoot development and individual pome enlargement (Li et al., 2026). High reproductive load increases competition for assimilates and may limit the growth and renewal of fruiting shoots, but the hormonal contribution of prolonged fruit retention to return bloom requires direct loquat-specific validation.

Maintaining a dynamic physiological equilibrium requires early intervention through hand thinning of flower clusters and fruitlets. Thinning panicles to four flower buds per inflorescence at full bloom has increased individual fruit mass and sweetness in the tested loquat orchard relative to higher flower-bud retention treatments. Separately, double-heading pruning has been associated with lower *EjFWL1* and *EjFWL2* expression and enhanced pre-anthesis receptacle cell division. Crop-load adjustment and renewal pruning may therefore be complementary measures, although their combined effect on long-term yield stability remains to be tested.

7.2 Differential management strategies for trees with different vigor levels

Canopy vigor varies substantially across loquat plantings due to rootstock selection, scion genetics, and microclimatic exposure (Li et al., 2026). In a cultivar-specific trial, Quince-C and BA-29 promoted stronger shoot growth, flowering and yield than Quince-A, which produced smaller trees with sweeter fruit (Polat, 2025). Cultivars also display distinct intrinsic branching architecture; for instance, ‘Chunhua 1’ exhibits wider branch angles and fewer lateral branches than ‘Dawuxing’, a trait governed by abscisic acid signaling via *EjSAPK1* and strigolactone reception through EjRMS3. Consequently, management interventions should be adjusted according to vigor, rootstock and cultivar, and checked against field performance.

For overly vigorous trees with dense foliage and aggressive summer shoots, double-cut heading pruning applied after harvest removes approximately 50% of vegetative flushes, directing stored nutrients into thicker bearing wood while opening canopy pathways for improved light penetration. Controlling vegetative flushes through postharvest deficit irrigation also suppresses shoot overgrowth and accelerates floral bud formation without penalizing yield (Ballester et al., 2018). Conversely, low-vigor or highly dwarf trees should be subjected to more intensive flower and fruit thinning to maintain a lower crop load and prevent excessive allocation of limited assimilates to reproductive organs. Balanced water and nutrient management should then be strengthened according to tree nutritional status, including maintenance of an appropriate nitrogen-to-potassium ratio and targeted supplementation of zinc and calcium when necessary, in order to promote root activity, shoot growth, functional leaf recovery, and subsequent canopy restoration.

7.3 Integrated regulation strategies for commercial fruit production

Maximizing commercial returns requires synchronizing canopy pruning, phenological water management, pollination assurance, and fruit protection into an integrated annual workflow. Postharvest regulated deficit

irrigation (RDI) applied for 6 to 9 weeks during summer advances full bloom by 10 to 27 days, allowing growers to target high-value early-season spring markets while saving about 30% of irrigation water in the tested conditions (Ballester et al., 2018). In regions prone to winter cold or frost, removal of the main inflorescence axis has induced secondary flowering approximately 2-4 months later in specific experimental conditions; this approach may shift the period of cold exposure rather than consistently prevent winter injury. This phenological response also involves the regulation of flowering-related genes such as *EjFT1, EjFT2,* and *EjAP1-like1,* indicating that induced reflowering is controlled not only morphologically but also through flowering signaling networks (Jiang et al., 2025; Wang et al., 2025).

Once fruit set is secured, early crop load adjustment and fruit bagging ensure premium cosmetic and internal fruit quality. Retaining about four flower buds per panicle during thinning has improved individual fruit size and sweetness in field trials. Changes in sugar- and organic-acid-associated enzymes during fruit development are documented separately and should not be assumed to result from that thinning treatment (An et al., 2026). Preharvest paper and composite bagging can reduce peel damage, while magnesium nutrition can influence sugar-acid metabolism; both responses depend on treatment and cultivar. Integrating these management practices may help coordinate vegetative renewal and commercial fruit production. However, the long-term benefits for yield stability, economic returns, and orchard productivity require further validation through multi-year field trials.

8 Summary and Prospects

Flower and fruit management directly regulates sink-source dynamics, commercial pome sizing, and internal organoleptic composition. Under the conditions evaluated in the cited field experiment, thinning terminal panicles to four flower buds per inflorescence improved individual fruit size and sweetness compared with heavier retention levels. In a separate study, double-heading pruning enhanced pre-anthesis receptacle cell proliferation and altered EjFWL1 and EjFWL2 expression; these effects should not be attributed directly to flower thinning. In addition, appropriate application of plant growth regulators may promote fruit enlargement and improve the sugar-acid balance to some extent, although their effects depend on cultivar, concentration, application timing, and crop load. Fruit bagging can effectively reduce sunburn, disease lesions, mechanical damage, and bird or insect injury, thereby improving fruit surface integrity and the proportion of marketable fruit.

Tree architectural regulation and canopy pruning help maintain vegetative vigor, improve light interception, and support stable crop load management. In tested loquat conditions, postharvest double-heading pruning improved characteristics of renewal fruiting shoots, including shoot thickness and leaf development. Morphological comparisons between conventional single back-cutting and double back-cutting confirm the structural advantages of renewal pruning on branch caliber. Different clonal quince rootstocks can markedly regulate vegetative vigor, flowering, and fruiting performance in loquat, with the magnitude of these effects varying among rootstock types. Under high-density planting systems, suitable rootstocks can therefore be selected according to the target canopy size, cultivar growth habit, and orchard management objectives to optimize canopy architecture and improve space-use efficiency. Concurrently, imposing postharvest regulated deficit irrigation for 6 to 9 weeks during summer restricts excessive canopy growth and advances flowering by 10 to 27 days, capturing high early-market prices while saving over 30% of seasonal water allocations. Coordinated pruning and balanced nutrient management may support fruit quality and tree condition, although their long-term effects on annual yield stability require multi-year validation.

Future developments in commercial loquat cultivation depend on transitioning from empirical field interventions to standardized, precision-managed production systems. Decision-support approaches that combine orchard monitoring with crop-load and water-nutrient indicators could improve management, but these approaches require direct field validation in loquat. Deciphering genetic pathways regulating branch angle and bud outgrowth, such as the abscisic acid kinase EjSAPK1 and strigolactone receptor EjRMS3, provides molecular targets for breeding dwarfed, self-branching cultivars suitable for mechanized orchard systems. Furthermore, removal of the main inflorescence axis can delay flowering in experimental loquat conditions and could help adjust exposure to winter cold, but the net effect should be evaluated locally. Further integration of targeted fertigation, pollinator

conservation and scalable fruit-protection practices may improve the resilience and commercial value of loquat production.

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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.

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