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Effects of Fruit Thinning on Yield and Quality of Loquat

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Abstract Fruit thinning is an important horticultural practice for regulating fruit load, improving resource allocation, and enhancing fruit yield stability and quality in loquat (*Eriobotrya japonica* Lindl.) production. Excessive fruit setting often leads to intense competition for assimilates, resulting in reduced fruit size, uneven development, and inferior commercial value. This review summarizes recent advances in the effects of fruit thinning on loquat yield formation, fruit quality improvement, and physiological regulation mechanisms. Fruit thinning can optimize the source-sink relationship by reducing fruit competition, increasing individual fruit weight, improving external appearance, and promoting the accumulation of soluble sugars, organic acids, vitamins, and bioactive compounds. Furthermore, thinning regulates photosynthetic performance, hormone metabolism, and carbon-nitrogen balance, thereby facilitating fruit expansion and quality formation. The effects of thinning intensity and timing vary among cultivars and cultivation environments, highlighting the need for precise management strategies. Case studies demonstrate that the integration of fruit thinning with fertilization, irrigation, canopy management, and digital orchard technologies can significantly enhance production efficiency and economic benefits. Future research should focus on developing cultivar-specific thinning models, exploring molecular mechanisms underlying fruit load regulation, and applying precision agriculture technologies to achieve sustainable and high-quality loquat production.
Keywords Fruit thinning; Loquat (*Eriobotrya japonica*); Yield regulation; Fruit quality; Source-sink relationship

1 Introduction

Loquat (*Eriobotrya japonica* Lindl.) is a subtropical evergreen fruit tree native to China and now cultivated commercially in more than 30 countries, including production regions in the Mediterranean, Australia, and Central Europe (Shafiq et al., 2025). Its fruit is valued for attractive flavor, juiciness, and a rich nutritional profile that includes carotenoids, phenolics, vitamins, minerals, and other bioactive compounds, which has increased both consumer interest and research attention. At the same time, the crop remains underexploited relative to its biological and commercial potential, with the fruit still consumed mainly fresh and lacking extensive industrial utilization (Shah et al., 2023). In several producing regions, growers have increasingly recognized the economic importance of loquat and expanded commercial orchards, yet productivity and fruit marketability remain constrained by cultivar characteristics, environmental adaptation, and postharvest fragility. Many traditional loquat cultivars bear relatively small fruit and produce lower yields than major rosaceous fruit crops such as apple, pear, and peach, which has slowed wider industry expansion and intensified demand for practical orchard management strategies that can improve fruit size and output without waiting for long breeding cycles. Market acceptance of loquat depends strongly on visual and eating quality, and fruit with suitable soluble solids, balanced acidity, low firmness, good flesh-to-seed ratio, and attractive size are more competitive in fresh markets. Cultivar evaluations under Mediterranean conditions further show that fruit size, soluble solids, seed traits, and ripening time vary substantially among genotypes, indicating that improving loquat production requires not only varietal selection but also crop-load regulation adapted to local production systems. This need is becoming more urgent because recent reviews note that loquat productivity is also being affected by climatic change and environmental stress, while the fruit's short shelf life and sensitivity to physiological disorders reduce the margin for error in orchard management and harvest quality.

Fruit thinning has long been used in horticultural production to regulate crop load by removing part of the developing reproductive structures so that the remaining fruits receive a greater share of assimilates and mineral nutrients (Wei et al., 2021). Across fruit crops, thinning is regarded as a core management practice because natural fruit drop alone rarely achieves the balance between yield quantity and market quality required in commercial orchards. Broad reviews of thinning research show that its principal effects arise through crop-load adjustment, with fruit size generally increasing as thinning intensity increases, although the response is modified by factors such as wood age, flower quality, within-cluster competition, canopy position, and the timing and method of thinning. Thinning can improve a first group of commercially decisive quality traits-including size, colour, firmness, and sugar-acid characteristics-but excessive reduction in crop load can create trade-offs with total yield and must therefore be optimized for local market goals rather than maximized indiscriminately. Experimental evidence from other fruit trees supports this general pattern. In peach, repeated fruit thinning during early development improved individual fruit weight, yield, internal and external quality, and leaf resource-use efficiency, while late thinning was less effective (Zhang et al., 2024). In pear, hand thinning increased fruit weight, diameter, height, and soluble solids, and although immediate yield could decline, thinning helped stabilize production over years and increased the proportion of marketable fruit. In loquat specifically, thinning has been studied at both flower and fruit stages. Earlier work showed that fruit thinning increased fruit growth and sugar accumulation, but also raised the incidence of purple spot, indicating that quality improvement can be accompanied by physiological risks. More recent studies confirm that loquat thinning is an essential management practice because the species tends toward heavy fruiting, and reducing competition among reproductive sinks can produce larger, sweeter, and more uniform fruit with better consumer appeal (Nordi et al., 2025). Flower-bud thinning at full bloom in the cultivar ‘Precoce de Itaquera’ improved overall fruit quality when four buds per cluster were retained, whereas keeping more buds increased cluster weight and total yield, clearly demonstrating the central agronomic trade-off between fruit quality and crop quantity in loquat production.

Against this background, studying the effects of fruit thinning on loquat yield and quality is important both scientifically and practically. From a physiological perspective, thinning provides a tractable way to modify source-sink relations, fruit set, and subsequent fruit enlargement, and loquat research increasingly links these orchard-level responses to developmental processes such as early cell division and shoot vigor. From a production perspective, growers urgently need management protocols that improve the performance of existing cultivars, because breeding alone has not solved the combined problems of small fruit, low yield, and inconsistent quality. Thinning is also relevant to orchard profitability because larger, higher-value fruit generally obtain better prices, even when hand thinning increases labor costs, and because proper crop-load regulation can support more regular cropping and better return bloom in subsequent seasons. Nevertheless, the benefits of thinning in loquat cannot be separated from important constraints. Responses vary with cultivar, site, climate, and thinning timing or intensity, and improvements in sugar accumulation or rapid fruit growth may increase susceptibility to disorders such as purple spot, while postharvest perishability remains a major bottleneck for market expansion. Future research should therefore move beyond asking whether thinning works and focus instead on how to optimize stage, intensity, and method for specific cultivars and environments; how thinning interacts with pruning, nutrition, and preharvest sprays; and how quality gains in the orchard translate into storability, disorder resistance, and supply-chain performance. Additional opportunities lie in improving the utilization of removed unripe fruit, since thinned fruits contain recoverable bioactive compounds and their revalorization could offset management costs while reducing orchard waste. Overall, fruit thinning appears to be a key tool for reconciling yield regulation with market-oriented quality improvement in loquat, and systematic evaluation of its effects is essential for developing more efficient, sustainable, and profitable loquat cultivation systems.

2 Fruit Development Characteristics of Loquat and Theoretical Basis of Fruit Thinning Regulation

2.1 Flowering, fruit set characteristics and yield components of loquat

Loquat has a distinctive reproductive calendar among rosaceous fruit trees, with flower bud formation beginning in summer, blooming occurring in autumn to early winter, and fruit ripening taking place in spring or early summer. This phenology exposes flowering and early fruit set to low temperature, rain, wind, and reduced pollinator activity, which makes the fruit-setting process especially sensitive to orchard environment and pollination conditions. Fruit set in loquat depends on the normal sequence of pollen deposition, pollen germination, pollen tube growth, and ovary viability, so any climatic disturbance during bloom can reduce the conversion of flowers into retained fruit. Field studies under Mediterranean conditions further show that minimum temperature significantly affects initial and final fruit set, while humidity and precipitation during bloom can suppress blossoming and reduce fruit retention.

Yield formation in loquat therefore depends not simply on flower abundance, but on the interaction among genotype, flowering traits, fruit set efficiency, and the proportion of fruit that remain to harvest. Considerable cultivar variation has been reported: in one multi-year trial, ‘Gold Nugget’ showed the highest mean initial fruit set, final fruit set, and productivity among four cultivars grown in the same environment. Rootstock effects also contribute to yield components, because the number of flower buds per cluster, flower number, and final fruit set differed significantly among quince rootstocks, with Quince-C producing higher values for these reproductive traits (Akkuş and Polat, 2021). At the developmental level, loquat fruit growth is not uniform across stages; pulp thickens steadily, whereas rapid early fruit enlargement before the Z02 stage is closely associated with strong seed expansion, indicating that final yield and fruit size are shaped early in fruit development (Lin et al., 2025).

2.2 Fruit load and nutrient allocation

In loquat, fruit load directly alters the internal distribution of assimilates because fruit acts as a dominant sink during development (Assefa and Debella, 2020). Experimental work with field-grown loquat trees showed that as fruit develops, photosynthate translocation to the roots declines markedly, especially from the period when fruit reaches about 50% of final size until the onset of color change. During this same period, carbohydrate concentrations in roots are reduced and root development is strongly inhibited, indicating that actively growing fruit competes effectively with belowground organs for available carbon. This pattern is especially important in loquat because fruit growth occurs in winter, when non-shoot growth is also active, so competition between reproductive and vegetative sinks becomes unusually direct (Reig et al., 2013).

The broader source-sink literature supports this interpretation and helps explain why excessive crop load often reduces both fruit quality and tree vigor. When sink demand is too low, leaves accumulate non-structural carbohydrates and photosynthesis becomes feedback-limited, as shown in low-crop-load apple trees (Yang et al., 2021). When sink demand is high, however, carbon export to fruit is favored at the expense of vegetative growth, and fruit-bearing citrus trees show reduced shoot growth because developing fruits accumulate carbon that would otherwise support new flushes. Loquat appears to follow the same general rule, but with an added hormonal component: heavy fruit load is associated with increased ABA, reduced IAA in roots, and depressed root respiration, showing that crop load regulates not only carbon partitioning but also growth through coordinated metabolic and hormonal signals (Figure 1).

2.3 Theoretical basis and technical principles

The theoretical basis of fruit thinning in loquat is the regulation of the source-sink balance so that the remaining fruits receive more assimilates, mineral nutrients, and growth-promoting capacity per fruit (Assefa and Debella, 2020). This principle is especially relevant in loquat because fruit size is a major production constraint, and both domestication studies and functional analyses indicate that sugar metabolism, hormone signaling, and fruit size-related genes are central to fruit development. At the cellular level, fruit weight in loquat is more strongly associated with cell size than with cell number, which means that reducing competition among fruit can theoretically favor enlargement through enhanced cell expansion rather than only through increased cell division. This framework is consistent with molecular evidence that brassinosteroid-related regulation, including EjBZR1-mediated repression of cell enlargement pathways, contributes to final fruit size formation.

Technically, fruit thinning is an exercise in crop-load optimization rather than simple fruit removal, because excessive retention depresses fruit size and quality while excessive thinning can sacrifice yield or destabilize postharvest performance (Sidhu et al., 2022). Studies across fruit crops show that earlier thinning generally produces better outcomes for fruit size, soluble solids, and return bloom than later thinning, supporting the principle that competition should be reduced before the most critical stages of sink establishment and fruit enlargement (Bound, 2023). Modeling work in apple likewise shows that fruit weight is jointly determined by thinning time, crop load, flower-bud formation, and shoot growth, reinforcing that thinning intensity must be matched to canopy vigor and production targets rather than applied uniformly. In loquat cultivation, this means that thinning should focus on adjusting panicle or fruit number early enough to improve assimilate availability to retained fruit while preserving a crop load that sustains total yield, return flowering, and stable orchard productivity over successive seasons (Su et al., 2021). In sum, loquat fruit thinning rests on a clear physiological logic: the crop's unusual flowering season, variable fruit set, and strong fruit sink demand make crop-load regulation central to both yield formation and fruit quality. Across the available evidence, the most defensible conclusion is that thinning works best when it is treated as targeted source-sink management rather than as a purely mechanical reduction in fruit number.

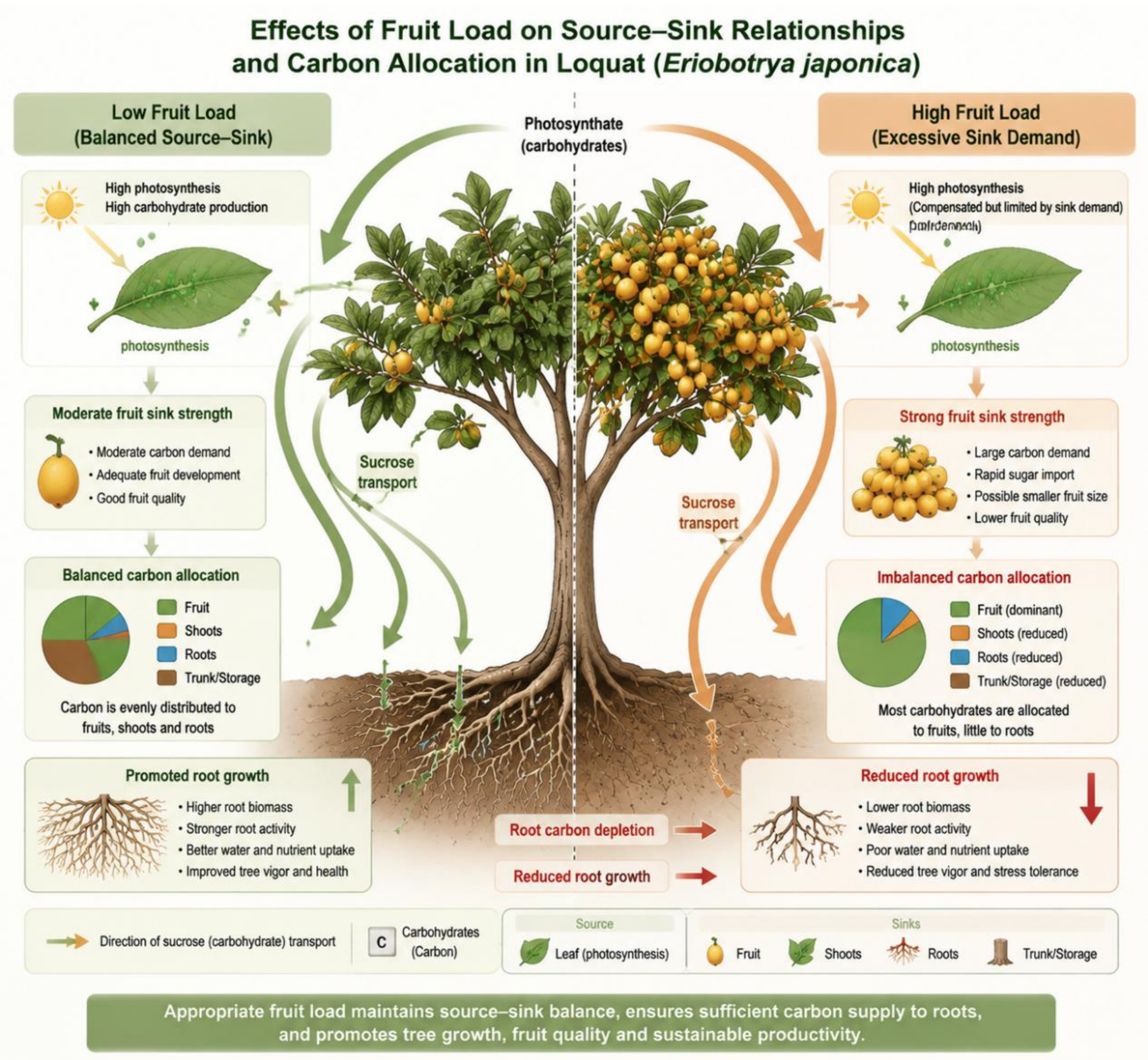

Figure 1 Source-sink regulation of carbon allocation under different fruit loads in loquat

3 Effects of Fruit Thinning on Yield Formation in Loquat

3.1 Effects of fruit thinning on individual fruit weight and fruit size

Fruit thinning clearly increases individual fruit weight and fruit size in loquat, because reducing the number of competing sinks allows more assimilates to be directed to the retained fruit. Early loquat studies directly showed that thinning increased fruit size, and later work confirmed that fruit size is a central determinant of commodity value and profitability in this crop. Recent field evidence in 'Precoce de Itaquera' further indicates that stronger flower-bud thinning can produce larger and sweeter fruit, with the best overall fruit-quality response obtained when only four buds per cluster were retained (Nordi et al., 2025).

The size response is also reflected in chemical thinning studies, which show that loquat fruit enlargement depends on both treatment efficacy and developmental timing. Application of naphthaleneacetic acid at 20 mg L^{-1} about 10-15 days after anthesis was reported as the most effective treatment for thinning and increasing average fruit size, while NAAm applied at the end of bloom increased fruit diameter by an average of 11% to 18% depending on dose. This response is biologically plausible because loquat fruit weight is tightly associated with fruit dimensions across genotypes, and larger fruits are consistently favored by the market (Kodad et al., 2022).

3.2 Effects of fruit thinning on yield per unit area and yield components

The effect of fruit thinning on yield per unit area is more complex than its effect on fruit size, because thinning usually reduces fruit number while improving the marketable proportion of the crop. In loquat, the highest cluster weight and total yield were obtained under the lightest thinning treatment, with 12 buds retained per cluster, even though fruit quality was better at lower bud numbers. Similarly, chemical thinning with high NAA doses produced the largest fruit but also the lowest yield per tree, showing that excessive crop reduction can shift the balance too far from yield formation toward fruit enlargement.

From the perspective of yield components, fruit thinning mainly acts by changing fruit set, fruit number per panicle or tree, and average fruit mass. In ‘Precoce de Itaquera’, fruit set was significantly influenced by thinning intensity, while in ‘Algerie’ loquat heavier thinning slightly improved packout but did not compensate for the substantial yield loss caused by reducing fruit number per panicle. More broadly, yield per unit area in fruit crops is the product of yield per plant and plant number, so in loquat orchards the contribution of thinning to area-based productivity depends on whether gains in fruit mass and market grade can offset the decline in fruit number per tree (Haque and Sakimin, 2022).

3.3 Effects of thinning timing and intensity on yield regulation

The regulatory effects of thinning depend strongly on when thinning is performed and how severe it is. Loquat is usually hand-thinned relatively late, but this has been described as expensive and of limited usefulness because late execution reduces the opportunity to redirect resources during early fruit development. By contrast, chemical thinning at the end of bloom or shortly after anthesis appears more effective for regulating crop load early enough to improve fruit growth, and treatment date was explicitly identified as a determinant of thinning efficacy in loquat. In practice, this means that timing is not a minor technical detail but a central variable controlling the final balance between fruit number and fruit size.

Thinning intensity also has to be optimized rather than maximized. In loquat under deficit irrigation, reducing crop load to one, two, or three fruits per panicle did not generate enough value to compensate for the associated yield loss, and four fruits per panicle gave the highest revenue. Comparable evidence from other fruit crops points in the same direction: low crop loads generally produce heavier fruit, but very high or very low thinning intensity can destabilize yield, whereas medium crop loads often provide the best compromise between size and production consistency (Sidhu et al., 2022). Overall, yield regulation in loquat should therefore target an optimal crop load, not the strongest possible thinning, with timing and severity adjusted to cultivar, orchard conditions, and market objectives. In summary, fruit thinning in loquat consistently improves individual fruit weight and fruit size, but its effect on total yield depends on the trade-off between reduced fruit number and improved fruit mass and grade. The most defensible conclusion is that early, moderate thinning is usually more effective for regulating yield formation than either late thinning or excessively severe fruit removal.

4 Effects of Fruit Thinning on Fruit Quality Formation in Loquat

4.1 Effects of fruit thinning on external fruit quality traits

Fruit thinning improves the external commercial quality of loquat mainly by increasing fruit size and fruit mass. In the recent ‘Precoce de Itaquera’ study, the strongest flower-bud thinning treatment produced an overall improvement in fruit quality, with four buds per cluster giving larger fruit (Nordi et al., 2025). Earlier work on loquat also showed that thinning was necessary because natural crop load produces many low-caliber fruits, and thinning to four fruits per panicle resulted in greater fruit length, width, and weight.

Chemical thinning studies support the same pattern and add information on appearance and maturity. Application of naphthaleneacetic acid 10-15 days after anthesis increased average fruit size and also improved coloration while advancing harvest time (Agustí et al., 2000). NAAm treatments likewise increased fruit diameter by 11% to 18%, improved grading, and promoted earlier harvest, showing that thinning affects not only size but also market presentation and earliness.

4.2 Sugar-acid composition and flavor quality

Fruit thinning generally improves sweetness-related traits in loquat, although the response is not uniform across studies. In 'Precoce de Itaquera', maintaining four buds per cluster produced larger and sweeter fruit, and a higher number of flower buds reduced soluble solids content. A separate thinning study also found that fruit thinning increased sugar contents, indicating that reduced sink competition favors sugar accumulation in the retained fruit.

The balance between sugars and acids, which is central to eating quality, also tends to improve after thinning or thinning-like crop regulation. In the same Brazilian study, pH and ripeness ratio were negatively associated with higher bud number, indicating that stronger thinning improved the sugar-acid balance important for consumer acceptance. Chemical thinning with naphthaleneacetic acid improved total soluble solids concentration (Agustí et al., 2000), although one cultivar trial reported that thinning intensity did not significantly affect pH, titratable acidity, or total soluble solids, so the compositional response appears cultivar- and condition-dependent rather than universal.

4.3 Nutritional quality and bioactive compounds

Evidence on nutritional quality shows that thinning changes fruit composition beyond sugars and acids, particularly through effects on mineral distribution. Fruit thinning significantly altered the mineral composition of loquat fruit (Gariglio and Agustí, 2005), and the most intense treatments increased potassium but reduced iron in flesh tissue at colour break. Thinning also reduced several mineral concentrations in the rind, especially K and Fe, which increased the concentration gradient between flesh and rind tissues.

These compositional changes are relevant because quality improvement can be accompanied by physiological costs. Fruit thinning has been linked to higher purple spot incidence, and the association appears to involve both increased sugar accumulation and altered solute gradients during rapid fruit development. Broader loquat quality studies also indicate that crop-regulating treatments can enhance bioactive substances such as phenolics, flavonoids, and carotenoids while improving the sugar-to-acid ratio and aroma compounds, which supports the view that sink regulation can reshape secondary metabolism as well as external and sensory quality (Zhang et al., 2025). Overall, fruit thinning improves external fruit quality most consistently, especially fruit size, mass, grading, and earliness. Its effects on flavor and nutritional composition are generally positive but less uniform, and excessive thinning can increase purple spot risk even as it enhances sweetness and some compositional traits.

5 Physiological and Metabolic Mechanisms Underlying Fruit Thinning-Mediated Improvement of Loquat Quality

5.1 Regulation of leaf photosynthetic characteristics by fruit thinning

Fruit thinning changes leaf photosynthetic behavior primarily by altering the source-sink ratio between leaves and developing fruits. Source-sink balance is a major determinant of carbon partitioning in fruit trees, and thinning directly modifies this balance by reducing sink demand. In orchard systems, this shift can improve canopy light distribution and gas exchange, and a meta-analysis in apple showed that thinning significantly increased leaf net photosynthetic rate, stomatal conductance, and transpiration while also improving fruit quality traits (Junna et al., 2021). For loquat, this framework is physiologically relevant because sugar translocation from leaves is essential for fruit development, and impaired translocation can compromise sink growth (Sotiras et al., 2019).

The photosynthetic response to thinning is not uniformly stimulatory, because excessive sink reduction can cause feedback inhibition in leaves. In nectarine, thinned trees showed lower net photosynthesis associated with stomatal limitation and transient sugar accumulation in leaves, indicating that an increased source-sink ratio can temporarily exceed drain capacity (Andrade et al., 2019). Peach experiments after fruit removal similarly found that low sink demand reduced net photosynthetic rate, closely linked to lower stomatal conductance and accompanied by damage to PSII-related components. Comparable work in olive showed that high leaf-to-fruit ratios increased leaf saccharide content and depressed photosynthesis through feedback inhibition, especially when assimilate export was constrained. These results suggest that in loquat, the quality benefit of thinning is more likely to come from optimizing, rather than maximizing, leaf carbon supply to fruit.

5.2 Effects of fruit thinning on hormonal regulation networks

Fruit thinning also acts through hormonal regulation networks because fruit set, early fruit growth, and later maturation are all under strong phytohormone control. Across fleshy fruits, auxin and gibberellin are the core signals promoting fruit set and early growth, while cytokinin supports early cell proliferation and final fruit size (Zhang et al., 2026). More broadly, fruit development proceeds through coordinated crosstalk among auxin, gibberellin, cytokinin, ABA, and ethylene, rather than through any single hormone acting alone. Since thinning changes sink number and developmental competition among fruit, it likely shifts this hormonal balance by altering which fruits maintain growth-promoting signals and which enter arrest or abscission.

The mechanistic basis for this view is supported by studies showing that hormone pathways directly regulate fruit enlargement through cell division and expansion. Auxin and GA act together to promote these processes after fertilization, and their interaction is mediated by ARF/IAA and DELLA signaling modules. Cytokinin is also mechanistically linked to fruit size, because lowering endogenous CK reduced pericarp thickness, cell division, and single-fruit weight while repressing auxin- and GA-related genes. In a broader fruit-size framework, thinning is recognized as a cultivation practice that interacts with hormonal and environmental regulation of final fruit phenotype. For loquat, this implies that thinning improves quality not only by reallocating assimilates, but also by favoring hormonal states that sustain retained fruit growth and maturation.

5.3 Effects of fruit thinning on carbon and nitrogen metabolism and resource allocation

The clearest metabolic effect of thinning is on carbon allocation. Fruit biomass accumulation and metabolite formation depend on photosynthesis and carbon export from source leaves, and thinning increases carbon supply per retained fruit by reducing competition among sinks (Paz Covarrubias et al., 2021). Early developmental stages appear especially sensitive: in nectarine, thinning mainly altered fruit metabolic composition early in development, and early sugar, organic acid, and phenylpropanoid intermediates could distinguish fruits exposed to different source-sink conditions. Peach studies reached a similar conclusion, showing that adequate thinning created early metabolic shifts that later translated into superior fruit quality, consistent with a metabolic priming effect.

Nitrogen metabolism and whole-tree resource allocation also respond to crop-load manipulation, but the response is more complex than for carbon alone. Source-sink manipulation can trigger redistribution of both photosynthate and nitrogen in perennial crops, and stored C and N reserves help buffer temporary imbalances between assimilate supply and sink demand. In pistachio, late-season declines in photosynthesis under high sink demand were associated with lower leaf N, suggesting N remobilization toward kernels (Marino et al., 2023), whereas in kiwifruit a low-crop-load “feast” treatment increased fruit nitrogen concentration relative to a high-crop-load “famine” treatment. However, carbon sufficiency does not automatically improve every metabolic trait: severe sink reduction in grape caused large plant-level losses of sugars, organic acids, and aroma precursors without improving their balance in ripe fruit. In loquat, the most plausible interpretation is therefore that thinning improves quality when it creates a balanced redistribution of carbon and nitrogen to retained fruit, rather than an extreme reduction in sink demand. Overall, the physiological basis of fruit thinning in loquat is a coordinated adjustment of photosynthetic supply, hormonal signaling, and carbon-nitrogen partitioning. The evidence supports moderate, developmentally timed thinning as a way to improve fruit quality by strengthening retained fruit without inducing the metabolic inefficiencies that can follow excessive sink removal.

6 Different Fruit Thinning Strategies and Their Integrated Effects on Loquat Cultivation

6.1 Characteristics and applications of manual fruit thinning techniques

Manual fruit thinning remains the most direct and controllable crop-load regulation method in loquat. Commercial loquat trees often set excessively, so thinning is required to obtain marketable fruit size rather than relying on natural adjustment alone. In practice, hand thinning is usually done during early fruit development or after fruit set, and traditional operations retain only a limited number of fruit per panicle to reduce sink competition and improve fruit growth. This method is valued because it allows precise selection of fruit number and position within each cluster, which is difficult to achieve with less selective approaches. The main constraint is labor demand, since hand thinning is slow, costly, and dependent on trained workers, which limits its efficiency at larger production scales (Figure 2).

Loquat experiments consistently show that manual thinning improves external fruit quality, but the optimal intensity depends on the balance between fruit size and retained yield. In ‘Precoce de Itaquera’, maintaining four flower buds per cluster produced the best overall fruit-quality response, whereas retaining more buds increased cluster weight and yield. Across multiple loquat cultivars, thinning to four fruit per panicle also resulted in superior fruit length, width, and weight, confirming that stronger hand thinning generally favors fruit enlargement. Even so, the practical target is not the most severe thinning possible, because loquat performance also varies with cultivar, climate, and timing of intervention. Evidence from other fruit crops points to the same compromise, with moderate hand thinning at an early stage often giving high fruit quality without the disproportionate yield loss caused by very severe crop reduction.

Figure 2 Manual fruit thinning process and crop-load adjustment in loquat production

6.2 Research progress in chemical and mechanical-assisted thinning

Chemical thinning in loquat has been studied mainly as an alternative to expensive hand thinning, with naphthaleneacetic acid-related compounds giving the most consistent results. NAAm applied at the end of bloom increased fruit diameter by about 11% to 18%, improved grading, and advanced harvest, while total yield declined only slightly. A separate study found that naphthaleneacetic acid at 20 mg L^{-1} applied 10-15 days after anthesis was the most effective treatment for thinning and increasing average fruit size (Agustí et al., 2000). Chemical thinning therefore appears useful when growers need earlier crop-load adjustment than hand thinning can provide, especially because late manual thinning has been described as both expensive and of limited usefulness in loquat.

Its main limitation is that chemical thinning is highly sensitive to dose, timing, and environmental conditions. In ‘Golden Nugget’, higher NAA doses caused stronger thinning and larger fruit, but they also produced the lowest yield per tree, whereas lower doses gave size and yield similar to hand-thinned trees. Response variability within the canopy is another concern, since NAAm treatment showed variable thinning rates within trees. Mechanical-assisted thinning has not yet been well developed for loquat, but results from other fruit crops suggest why it remains attractive: in plums, mechanical thinning reduced fruit set by about 20% and increased fruit size, especially when integrated with selected chemical programs (Pavanello et al., 2018). That broader evidence suggests a likely future direction for loquat, in which mechanical pre-thinning could lower labor costs while hand or chemical follow-up restores precision.

6.3 Synergistic effects with other practices

Fruit thinning in loquat is rarely an isolated decision, because its effects interact with pruning, bagging, irrigation, and fertilization. Loquat studies explicitly note that fruit enlargement is influenced not only by crop load but also by tree vigor, temperature, and fertilization. Under traditional systems in Fujian, about half of the panicles are thinned for larger fruit, while pruning after harvest promotes strong summer shoots that later bear flower buds. More intensive shoot management can amplify this effect: double-heading pruning produced more vigorous shoots, deeper green leaves, and larger fruit, indicating that thinning and pruning can work together by improving both sink regulation and source capacity. Mechanistic modeling in fruit trees supports this integrated view, showing that the pruning and thinning combinations already used by growers often provide the best compromise between current fruit production and next season's vegetative renewal (Bevacqua et al., 2021).

Bagging is another important complementary practice in loquat because it protects the fruit after crop load has been adjusted. In one loquat study, clusters were bagged immediately after thinning, reflecting the practical pairing of these two operations in orchard management. Independent bagging experiments show why this combination is attractive: bagging improved appearance and fruit health, prevented insect and bird damage, and reduced skin burn, rotting, and black spot. Broader orchard evidence also indicates that thinning responses are modified by water and nutrient supply, with intermediate irrigation and potassium inputs combined with moderate thinning producing better yield and fruit quality than either excessive crop load or excessive input use (Ghazzawy et al., 2023). Similar interaction studies in other perennial systems show that thinning, pruning, and fertilization do not act independently, so the best loquat strategy is likely an integrated program that coordinates crop load with canopy management and resource supply. Overall, manual thinning remains the most precise loquat strategy, chemical thinning offers a labor-saving but less predictable alternative, and mechanical-assisted thinning is a promising but still underexplored option for this crop. The strongest practical conclusion is that fruit thinning works best in loquat when it is integrated with pruning, bagging, and resource management rather than applied as a stand-alone technique.

7 Case Studies: Application Effects of Fruit Thinning Practices in Loquat Production

7.1 Effects of different thinning intensities on loquat yield and fruit quality: case studies

A recent two-season field case study in the Paraíba Valley of southeastern Brazil compared five hand flower-bud thinning intensities in 'Precoce de Itaquera' loquat and showed a clear trade-off between fruit quality and yield. Retaining four buds per cluster gave the best overall improvement in fruit quality, producing greater fruit set per cluster as well as larger and sweeter fruit, whereas retaining 12 buds per cluster produced the highest cluster weight and total yield. This case indicates that stronger thinning benefits market-oriented quality traits, but lighter thinning better preserves output per tree.

Comparable results were reported in another case study covering five loquat cultivars and one selection, in which four fruits per panicle produced superior fruit length, width, and weight. However, that same trial found no clear effect of thinning intensity on pH, titratable acidity, or soluble solids, showing that external size responses are more consistent than internal compositional changes. Work in 'Algerie' loquat under two irrigation regimes reached a similar practical conclusion: heavier thinning slightly improved packout, but the gain did not offset the yield loss caused by removing too many fruits, and four fruits per panicle generated the highest revenue (Stellfeldt et al., 2013).

7.2 Effects of different thinning periods on fruit development and quality formation: case studies

Case studies on thinning period show that timing strongly influences both fruit growth and harvest quality in loquat. A three-year study of chemical thinning with NAAm found that application at the end of bloom increased fruit diameter by 11% to 18%, improved grading, and advanced harvest, while total yield declined only slightly. Another chemical-thinning trial showed that treatment efficacy depended on both date and concentration, and that the most effective schedule for increasing average fruit size was 20 mg L^{-1} naphthaleneacetic acid applied 10-15 days after anthesis. Together, these cases show that earlier crop-load regulation can improve fruit enlargement more effectively than delayed manual thinning.

Developmental case studies also show why thinning period matters biologically. In ‘Algerie’ loquat, fruit growth followed a sigmoid pattern in both thinned and unthinned trees, but thinning changed the slope of the growth curve, indicating faster fruit growth under reduced crop load (Cuevas et al., 2003). Initial fruitlet size was also highly predictive of final market class, because size differences present at hand thinning did not reverse later, which supports selective thinning based on early fruit size rather than random fruit removal. These findings suggest that the most effective thinning window is the early stage when fruit growth trajectories and competition among fruit are still being established (Figure 3).

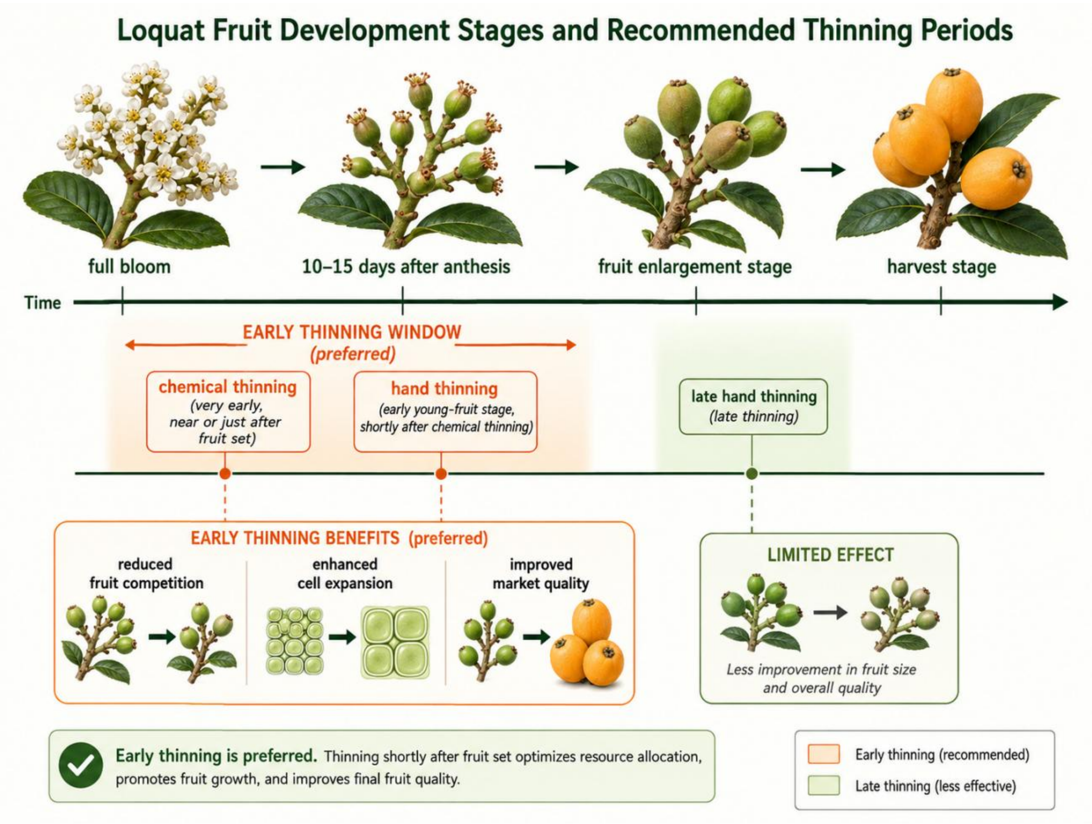

Figure 3 Optimal thinning windows during loquat fruit development and their effects on fruit growth and harvest quality

7.3 Improving loquat production efficiency through fruit thinning combined with modern management practices: case studies

Several case studies show that fruit thinning becomes more effective when combined with other orchard practices rather than used alone. In the Brazilian flower-bud thinning experiment, all clusters were bagged immediately after thinning, and the four-bud treatment produced the best overall fruit-quality response, illustrating a practical thinning-plus-bagging system for fresh-market production. Independent bagging work in Fujian was conducted in orchards that had already been systematically pruned, thinned, and fertilized, and aluminum-polyethylene bags increased fruit weight, length, and width while markedly reducing skin burn, rotting, and black spot (Zhi et al., 2021). This evidence suggests that thinning can be integrated with post-thinning fruit protection to raise the proportion of marketable fruit.

Other production-efficiency case studies combine thinning with pruning or irrigation management. Under the traditional Fujian pruning system, about half of the panicles are thinned, but double-heading pruning was developed to conserve nutrients in the remaining shoots and produced larger fruit together with higher yield. In water-limited orchards, preharvest deficit irrigation interacted with crop-load management in a different way: heavier thinning was not required under the mild stress conditions tested, and four fruits per panicle still provided the highest revenue while saving irrigation water. A related irrigation case study further showed that a short preharvest deficit-irrigation program could produce sweeter, earlier fruit with better handling performance, although excessive water restriction reduced fruit size (Hueso et al., 2021). Overall, the case-study evidence shows that loquat thinning works best as targeted crop-load regulation rather than simple fruit removal. Across different cultivars and management systems, moderate-to-strong thinning improves fruit size and market quality, but the best commercial outcome usually comes from combining appropriately timed thinning with bagging, pruning, or irrigation strategies suited to local production goals.

8 Challenges and Future Research Directions in Loquat Fruit Thinning Technology

8.1 Current limitations in the application of fruit thinning techniques

Manual thinning remains the most precise option in loquat, but its main weakness is that it is slow, labor-intensive, and expensive. In loquat, hand thinning is still valued because it can control the number of retained fruits more effectively than chemical or mechanical alternatives, yet this precision depends on trained labor and raises production costs. Earlier loquat studies reached the same practical conclusion, describing hand thinning as a slow and expensive operation that restricts wider commercial expansion. Manual thinning is also limited by its timing and biological variability. Late hand thinning in loquat has been described as of limited usefulness because it is commonly performed after a substantial part of the competitive phase among fruits has already occurred. Even when thinning is effective, results vary with cultivar, season, and orchard conditions, and recent loquat field work explicitly notes that climate, thinning timing, intensity, and other cultural practices all interfere with final fruit properties (Nordi et al., 2025).

Chemical thinning can reduce labor demand, but its commercial use in loquat is constrained by narrow margins between effective and excessive thinning. NAA responses in ‘Golden Nugget’ were closely dose-dependent, with the highest doses producing the largest fruits but also the lowest yield per tree. NAAm offers a partial alternative, since end-of-bloom applications increased fruit diameter and only slightly reduced total yield, but thinning rates remained variable within trees, which weakens predictability at orchard scale. Beyond efficacy, current thinning methods also create broader operational and biological constraints. Mechanized orchard thinning in other fruit crops still often relies on subjective operator judgment for speed, spindle rotation, and working distance, which results in low precision and uncertain damage to non-target tissues (Lei et al., 2023). In loquat specifically, stronger thinning can improve size and sweetness, but it has also been associated with higher purple spot incidence, showing that quality gains can be accompanied by physiological risk.

8.2 Development trends of precision fruit thinning technologies

A clear development trend is the shift from uniform thinning toward precision crop-load management based on sensing, detection, and tree-specific decisions. In apple systems, rapid and accurate fruitlet detection before thinning is already considered essential for early yield estimation and automatic thinning. The same logic is now extending to decision systems that support thinning timing and fruit-removal choices under natural orchard conditions, with recent models showing real-time detection performance suitable for automated management (Wang et al., 2025). The technical foundation of this trend is machine vision. Deep-learning systems can now segment fruitlets and canopy structures with high precision and low inference time, which is a prerequisite for selective thinning under complex orchard conditions (Sapkota et al., 2023). However, current vision systems still face persistent challenges from occlusion, clustered fruits, variable illumination, and incomplete spatial information, and 2D-only pipelines lose useful depth cues that could improve thinning decisions.

A second trend is the integration of perception with robotic or variable-rate actuation. Field-tested robotic blossom-thinning platforms have already shown targeted thinning of selected clusters, but commercial deployment is still early and depends on faster, more robust perception-control pipelines. Precision chemical thinning is moving in the same direction: computer-vision-guided variable-rate spraying achieved thinning effects comparable to conventional spraying while using about 18% less thinning agent (Kang et al., 2025). For loquat, these trends suggest that future thinning systems will likely be hybrid, not purely manual or purely automated. Traditional orchard operations already combine pruning, thinning, bagging, and crop-load adjustment, so loquat is well suited to integrated digital management rather than stand-alone hardware substitution. More broadly, PACMAN-type frameworks in apple show that precision crop-load management works best when pruning, chemical thinning, and hand thinning are treated as linked decisions rather than isolated interventions.

8.3 Future research priorities

The first research priority is to generate more loquat-specific thinning evidence across cultivars, environments, and management systems. Existing loquat studies already show that responses differ with cultivar, season, and thinning intensity, but the literature remains thin relative to apple and other major tree fruits. This gap is especially clear for chemical thinning, where additional work has long been identified as necessary before commercial-scale recommendations can be made. A second priority is to build loquat-adapted sensing and decision models rather than transferring tools directly from apple. Automated thinning depends on reliable datasets and detection models, yet even in apple, progress has required dedicated annotated datasets and optimized models to handle small fruit, occlusion, and natural-scene variability. For loquat, this means creating image datasets spanning panicle architectures, fruitlet sizes, lighting conditions, and canopy forms, then linking those inputs to crop-load thresholds that predict marketable yield and quality.

A third priority is to connect precision thinning with whole-orchard economics and sustainability. Variable-rate systems can reduce chemical inputs and potentially improve economic return by matching thinning intensity to local fruit set, but adoption barriers still include calibration demands, equipment compatibility, and grower familiarity with prescription-based systems (Kang et al., 2025). Robotic systems face parallel barriers in platform cost, sensor cost, and operational speed, so progress will depend as much on simplification and affordability as on accuracy alone. A final priority is to widen the concept of thinning from fruit removal alone to resource valorization and integrated orchard design. Loquat flower thinning generates large quantities of discarded biomass, yet recent work shows that these flowers contain recoverable flavonoids and antioxidant activity, creating a plausible by-product pathway for value-added use. In parallel, loquat management studies indicate that thinning interacts with pruning, vigor, and carbohydrate supply, so future work should optimize thinning within integrated canopy and source-sink management rather than treat it as an isolated operation.

9 Conclusions

Fruit thinning should be regarded as a core crop-load regulation practice in loquat because natural fruit set commonly exceeds the tree’s carrying capacity, resulting in many undersized fruits and unstable commercial output. Loquat orchards therefore need thinning not simply to reduce fruit number, but to balance marketable yield with fruit size, sweetness, and packout. The main conclusion across loquat studies is that heavier thinning improves individual fruit performance, whereas lighter thinning usually preserves higher total yield. In ‘Precoce de Itaquera’, maintaining four flower buds per cluster produced the best overall quality response, while twelve buds per cluster gave the highest cluster weight and yield. In ‘Algerie’, heavier thinning slightly improved packout, but four fruits per panicle generated the highest revenue under both irrigation regimes because severe fruit removal reduced output too strongly. This balance between quality and retained productivity is consistent with broader crop-load evidence from other fruit systems, where low to medium crop loads generally produce higher-quality fruit than overloaded trees. Taken together, the evidence indicates that the practical goal in loquat is optimized crop load, not maximum thinning intensity, and that moderate thinning usually offers the best economic compromise under commercial conditions.

The most consistent quality benefit of fruit thinning in loquat is the improvement of external fruit traits, especially fruit size, fruit weight, and uniformity. Across cultivars, thinning to four fruits per panicle produced superior fruit length, width, and weight. Growth studies also show that thinning increases fruit growth rate, which helps explain why retained fruits attain larger final size under reduced competition. Fruit thinning also improves important internal quality traits, although these responses are somewhat more variable than size responses. In the recent Brazilian study, a higher number of flower buds reduced soluble solids, whereas stronger thinning produced larger and sweeter fruit. Chemical thinning with NAAm similarly increased fruit diameter, improved grading, and advanced harvest, showing that thinning can enhance commercial quality as well as earliness. At the same time, thinning effects on acidity-related variables are not always uniform across studies or cultivars. One multi-cultivar loquat trial found no significant effect of thinning intensity on pH, titratable acidity, or total soluble solids. This agrees with the broader view that loquat fruit quality is determined not only by crop load, but also by cultivar, climate, mineral nutrition, and orchard management conditions. The overall effect of thinning on fruit quality is therefore best understood as part of a wider management system. Bagging improves fruit health, appearance, and protection from insect, bird, and abiotic damage. Likewise, pruning systems that increase shoot vigor and leaf quality can strengthen carbohydrate supply and support larger fruit, reinforcing the benefits achieved through thinning alone. The future of loquat thinning technology will depend on reducing labor cost while preserving the precision that makes thinning effective. Hand thinning remains highly efficient but is slow and expensive, and this continues to limit wider adoption in commercial orchards. Chemical thinning offers a partial solution, but current loquat studies still show variability in response within trees and a need for further development before routine large-scale use. A second major direction is the integration of thinning with other sustainable orchard practices. In semi-arid production systems, deficit irrigation can save substantial water and, when properly managed, maintain profitability without requiring stronger thinning intensity.

More broadly, sustainable loquat production will likely rely on combining thinning with pruning, bagging, rootstock choice, and mineral management rather than optimizing each practice in isolation. Future research should also move beyond fruit removal itself and consider whole-system efficiency and value creation. Loquat flowers removed during thinning represent a large discarded biomass, yet recent evidence shows they can be upcycled into value-added functional products rich in flavonoids and antioxidant activity. At the same time, predictive tools based on mineral nutrition and fruit quality modeling may help build more precise management frameworks for fruit weight, soluble solids, and acidity in loquat orchards. In conclusion, fruit thinning is not merely a corrective practice for excessive fruit set, but a strategic tool for balancing yield, fruit quality, and orchard profitability in loquat production. Its long-term value will be greatest when it is embedded in precision, resource-efficient, and integrated production systems designed for sustainable loquat cultivation.

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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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