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Meta-Analysis of Yield-Enhancing Cultivation Techniques for Cherry Tomatoes

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Abstract This study reviews various yield-enhancing cultivation techniques for cherry tomatoes, including regulated deficit irrigation (RDI), pruning, biostimulants, organic fertilizers, and modern greenhouse technologies. These techniques have shown significant effects in optimizing water and fertilizer management, as well as improving crop yield and quality. For example, a multi-level fuzzy comprehensive evaluation indicates that precise irrigation and nutrient management can significantly enhance tomato growth and yield. Additionally, using drip irrigation systems combined with bio-organic fertilizers, intercropping with leguminous green manures, and utilizing shading nets have proven effective in improving water use efficiency and fruit quality. Optimizing greenhouse environments also significantly boosts yield and fruit quality. Despite the notable yield benefits of these techniques, their promotion faces challenges such as insufficient public awareness, management complexity, and high implementation costs. This study suggests further research directions, including exploring the synergistic effects of combining optimal irrigation with organic fertilizers, developing resilient varieties capable of withstanding various environmental stressors, and utilizing sensors and automation in precision agriculture to enhance efficiency and reduce labor costs.
Keywords Cherry tomatoes; Yield enhancement techniques; Irrigation management; Biostimulants; Precision agriculture

1 Introduction

Cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme*) have seen a significant rise in market demand due to their unique flavor, nutritional benefits, and versatility in culinary applications. They are particularly valued in the South African retail market, where fruit size and quality play crucial roles in consumer preference (Maboko and Plooy, 2008). The economic value of cherry tomatoes is further underscored by their profitability compared to other staple crops, making them a lucrative option for farmers (Guo et al., 2021). This profitability is driven by their high market price and the increasing consumer demand for fresh, high-quality produce.

Enhancing the yield of cherry tomatoes is critical to meet the growing market demand and to ensure economic sustainability for producers. Various cultivation techniques have been explored to optimize yield and quality, including regulated deficit irrigation (RDI), pruning, and the use of biostimulants. For instance, RDI has been shown to significantly reduce water usage while improving the content of soluble sugars, carotenoids, and total phenols in cherry tomatoes, although the yield response can vary by season and cultivar (Coyago-Cruz et al., 2019). Pruning techniques have also been investigated, revealing that pruning to two or three stems can increase yield and produce fruit sizes more acceptable to the market (Maboko and Plooy, 2008; Wu and Zhang, 2024). Additionally, the use of sustainable agronomic strategies, such as the application of seaweed extracts, has demonstrated potential in enhancing both yield and nutritional quality (Chanthini et al., 2019). These techniques not only aim to increase yield but also to improve the environmental sustainability of cherry tomato production by reducing the reliance on fertilizers and pesticides (Guo et al., 2021).

The purpose of this review is to synthesize current research on various yield-enhancing cultivation techniques for cherry tomatoes. By conducting a meta-analysis of studies on RDI, pruning, biostimulants, and other agronomic strategies, this review aims to provide a comprehensive understanding of the most effective methods for increasing yield and improving fruit quality. This synthesis will help identify best practices and guide future research and agricultural practices to ensure sustainable and profitable cherry tomato production.

2 Soil and Environmental Conditions for Cherry Tomatoes

2.1 Suitable soil types and their physical and chemical properties for cherry tomatoes

Cherry tomatoes thrive in well-drained, fertile soils with a balanced texture that supports both water retention and aeration. Optimal soil types include loamy and sandy loam soils, which provide the necessary balance of drainage and nutrient availability. Studies have shown that soil texture significantly impacts root distribution and nutrient uptake, which in turn affects yield and fruit quality. For instance, optimizing root distribution through appropriate soil management can enhance water use efficiency and yield (Shabbir et al., 2020). Additionally, soil bulk density and texture play crucial roles in determining the effectiveness of deficit irrigation strategies, which can improve fruit quality by increasing soluble solids and vitamin content (Lu et al., 2021).

The chemical properties of the soil, such as organic matter content, cation exchange capacity (CEC), and nutrient levels, are also critical for the successful cultivation of cherry tomatoes. Organic fertilizers have been shown to improve soil properties significantly, including increasing soil organic matter, total nitrogen, phosphorus, and potassium levels, which are essential for plant growth and fruit development (Fan et al., 2023). Long-term organic soil management systems, such as the application of manure and green manure, have been found to enhance soil fertility and support sustainable tomato production (Moccia et al., 2006).

2.2 The importance of ph balance and nutrient levels

Maintaining an optimal pH balance in the soil is crucial for the growth and productivity of cherry tomatoes. The ideal soil pH for cherry tomatoes ranges from 6.0 to 6.8, which ensures the availability of essential nutrients and promotes healthy root development. Studies have demonstrated that organic fertilizers can help maintain a favorable pH balance, thereby enhancing nutrient uptake and improving yield and fruit quality (Fan et al., 2023). Soil pH also influences the effectiveness of nitrogen application, which is vital for tomato growth. Optimal nitrogen levels, typically between 236 and 354 $kg \cdot ha^{-1}$, can significantly increase yield and improve fruit quality indicators such as vitamin C, soluble sugars, and total soluble solids (Cheng et al., 2021).

Nutrient management is another critical aspect of cherry tomato cultivation. Balanced fertilization, including the appropriate application of nitrogen, phosphorus, and potassium, is essential for maximizing yield and fruit quality. Research has shown that specific combinations of irrigation and fertilizer levels can optimize the integrated growth of cherry tomatoes, particularly in arid regions (He et al., 2021). Additionally, the use of organic fertilizers has been found to improve soil nutrient levels and enhance tomato yield and quality compared to chemical fertilizers alone (Figure 1) (Fan et al., 2023).

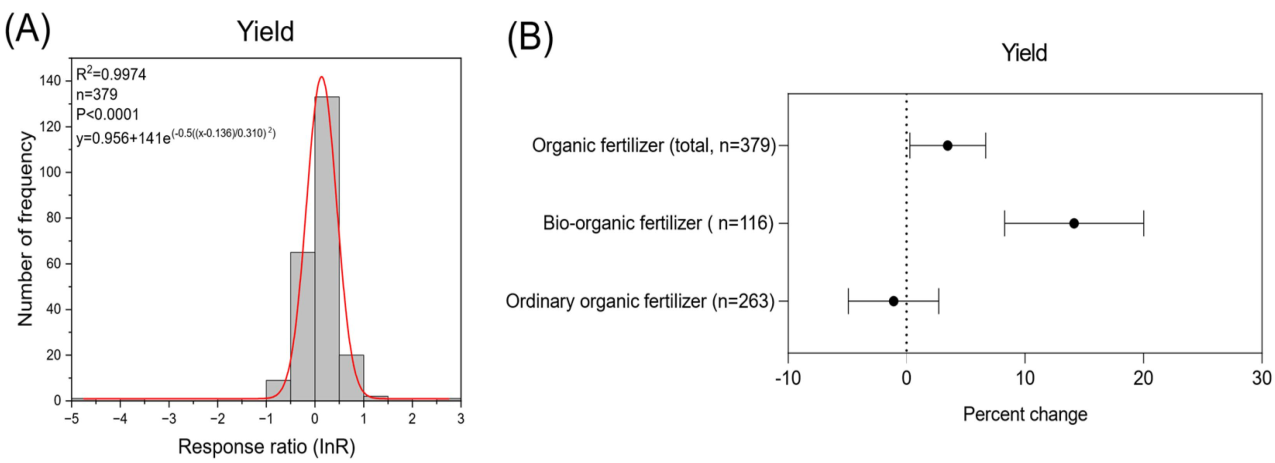

Figure 1 The number of tomato yield samples and global effects of organic fertilizer application on tomato yield (Adopted from Fan et al., 2023)

2.3 Management of temperature and humidity and climate adaptability analysis

Temperature and humidity are key environmental factors that influence the growth, yield, and quality of cherry tomatoes. Optimal temperature ranges for cherry tomato cultivation are between 20°C and 25°C during the day and 15°C to 18°C at night. High temperatures can lead to reduced fruit set and quality, while low temperatures can slow down growth and development. Studies have shown that regulated deficit irrigation (RDI) can help manage water use efficiency and improve fruit quality under varying temperature conditions (Lu et al 2019). Additionally, substrate-based cultivation systems have been found to enhance plant growth and yield by providing a controlled environment that optimizes temperature and humidity levels (Guo et al., 2022; Guo, 2024).

Cherry tomatoes are adaptable to a range of climatic conditions, but they perform best in regions with moderate temperatures and low humidity. High humidity levels can increase the risk of fungal diseases, which can negatively impact yield and fruit quality. Effective climate adaptability strategies include the use of grafting techniques to improve disease resistance and the selection of appropriate rootstocks that can withstand varying environmental conditions (Naik et al., 2021). Furthermore, optimizing irrigation and fertilizer inputs can help mitigate the effects of climate variability and enhance the sustainability of cherry tomato production (Guo et al., 2021).Therefore, many places adopt facility greenhouses to regulate temperature and temperature, in order to advance the cherry tomato picking time and improve the quality of cherry tomatoes, thereby increasing planting efficiency (Figure 2).

Figure 2 Cherry tomatoes cultivated in facility greenhouses at Zhejiang Rural Development Group Shangyu Co., Ltd base

3 Seedling Techniques for Cherry Tomatoes

3.1 Selection and treatment of high-quality seeds

The selection of high-quality seeds is a critical first step in ensuring robust cherry tomato yields. High-quality seeds are typically characterized by their genetic purity, high germination rates, and resistance to common diseases. For instance, the use of biostimulants such as seaweed extracts has been shown to enhance seed germination rates and early seedling vigor. The application of *Ulva flexuosa* extract, for example, significantly improved seed germination and early growth parameters, leading to higher biomass and better overall plant health (Chanthini et al., 2019). This suggests that integrating biostimulants into seed treatment protocols can be a valuable strategy for improving seed quality and subsequent plant performance.

Moreover, seed priming techniques, which involve pre-soaking seeds in solutions containing nutrients or growth stimulants, have been found to enhance seedling vigor and stress tolerance. Studies have demonstrated that priming seeds with specific biostimulants can lead to improved root development and early growth, which are crucial for the establishment of healthy plants (Polo and Mata, 2018). These techniques not only improve the initial growth stages but also contribute to higher yields and better fruit quality in the long term.

3.2 Preparation of seedbeds and optimal planting density

The preparation of seedbeds and the determination of optimal planting density are essential for maximizing cherry tomato yields. Proper seedbed preparation involves ensuring that the soil is well-drained, fertile, and free from pests and diseases. The use of organic amendments, such as compost or green manures, can improve soil structure and fertility, providing a conducive environment for seedling growth. For example, intercropping cherry tomatoes with leguminous green manures has been shown to enhance soil fertility and improve plant growth, leading to higher yields (Salgado et al., 2021).

Optimal planting density is another critical factor that influences yield. Research has shown that planting density affects root distribution, nutrient uptake, and overall plant health. For instance, studies have indicated that a balanced planting density allows for adequate root expansion and efficient nutrient uptake, which are essential for high yields (Shabbir et al., 2020a). Additionally, maintaining an appropriate distance between plants can reduce competition for resources and minimize the risk of disease spread, further contributing to better plant health and productivity.

3.3 Early management strategies and pest prevention

Early management strategies, including proper irrigation, fertilization, and pest prevention, are crucial for the successful cultivation of cherry tomatoes. Effective irrigation management, such as the use of deficit irrigation techniques, can optimize water use efficiency and improve fruit quality. For example, deficit irrigation has been shown to enhance the concentration of beneficial compounds in tomatoes, such as lycopene and vitamin C, while also conserving water resources (Lu et al., 2020). Implementing precise irrigation schedules based on plant needs can thus lead to better growth and higher yields.

Pest prevention is another vital aspect of early management. Integrated pest management (IPM) strategies, which combine biological, cultural, and chemical controls, can effectively reduce pest populations and minimize crop damage. The use of biostimulants and organic amendments can also enhance plant resistance to pests and diseases. For instance, the application of optimized fertilizer and pesticide inputs has been shown to reduce environmental impacts while maintaining high yields (Guo et al., 2021). By adopting these early management strategies, growers can ensure healthy plant development and achieve higher productivity in cherry tomato cultivation.

4 Water and Fertilization Management for Cherry Tomatoes

4.1 Implementation of efficient irrigation systems (e.g., drip irrigation)

Efficient irrigation systems, such as drip irrigation, have been shown to significantly enhance the yield and water use efficiency (WUE) of cherry tomatoes. Drip irrigation allows for precise water application directly to the root zone, minimizing water loss due to evaporation and runoff. Studies have demonstrated that drip irrigation can lead to a substantial increase in crop yield and WUE compared to traditional irrigation methods. For instance, a meta-analysis revealed that drip fertigation increased yield by 12.0%, WUE by 26.4%, and nitrogen use efficiency (NUE) by 34.3% while reducing crop evapotranspiration by 11.3% (Li et al., 2021). Additionally, the use of multiple emitters per plant under drip irrigation has been found to optimize root distribution and improve water and nutrient uptake, further enhancing yield and WUE (Shabbir et al., 2020a; 2020b).

Moreover, the strategic implementation of drip irrigation can mitigate the effects of water scarcity, particularly in arid regions. Research conducted in northwestern China indicated that drip irrigation, combined with appropriate nitrogen levels, significantly improved tomato yield, fruit quality, and WUE (Du et al., 2017). The study highlighted that moderate irrigation levels (75% of crop evapotranspiration) coupled with optimal nitrogen application (250 kg N ha^{-1}) provided the best results in terms of yield and resource use efficiency. Specially using drip irrigation tape to achieve precise and efficient utilization of water (Figure 3).These findings underscore the importance of adopting efficient irrigation systems to achieve sustainable and high-yielding cherry tomato cultivation.

Figure 3 Cherry tomatoes grown vigorously using drip irrigation tape

4.2 Application methods for organic and inorganic fertilizers

The application of fertilizers, both organic and inorganic, plays a crucial role in enhancing the yield and quality of cherry tomatoes. Drip fertigation, which involves the application of fertilizers through the drip irrigation system, has been shown to synchronize water and nutrient supply with crop demand, leading to improved productivity. A study comparing different fertigation strategies found that the combination of alternate partial root-zone drip irrigation with a specific ratio of basal to topdressing nitrogen (N30-70) resulted in the highest tomato yield, lycopene, and vitamin C content, as well as an optimal sugar/acid ratio in fruits (Luo and Li, 2018). This method not only improved yield but also enhanced the nutritional quality of the tomatoes.

In addition to inorganic fertilizers, the incorporation of organic fertilizers, such as chicken manure, has been found to further improve tomato yield and quality. Research comparing different organic fertilizer treatments under drip irrigation showed that a 50% substitution of urea with chicken manure significantly increased tomato yield and quality while reducing ammonia volatilization and soil nitrate nitrogen content (Li et al., 2023). The study concluded that the combination of drip irrigation and organic fertilizers, particularly chicken manure, resulted in the highest yield and quality of tomatoes, highlighting the benefits of integrating organic amendments into fertigation practices.

4.3 Impact of water-fertilizer ratios and application timing on yield

The ratio of water to fertilizer and the timing of their application are critical factors influencing the yield and quality of cherry tomatoes. Studies have shown that the interaction between irrigation and fertilization significantly affects fruit yield, WUE, and fertilizer partial factor productivity (PFP). For example, a study conducted in a solar greenhouse found that moderate irrigation (75% ET0) combined with high fertilizer levels (240N-120P_2O_5-150K_2O kg·ha^{-1}) provided the best compromise for maximizing fruit yield, quality, WUE, and PFP (Wang and Xing, 2017). This combination was ranked highest in a comprehensive evaluation, indicating the importance of optimizing both water and fertilizer inputs.

Furthermore, the timing of fertilizer application, particularly the split application of nitrogen, has been shown to influence tomato yield and quality. Research comparing different nitrogen application schedules under drip irrigation revealed that applying 30% of nitrogen as basal fertilizer and 70% as topdressing (N30-70) resulted in the highest yield and quality of tomatoes (Luo and Li, 2018). This approach ensures a steady supply of nutrients throughout the growing season, aligning with the crop's developmental stages and nutrient requirements.

Additionally, the study highlighted that alternate partial root-zone drip irrigation (ADI) combined with the N30-70 strategy provided the optimal water and nitrogen supply mode, further emphasizing the importance of precise water-fertilizer management.

5 Cultivation Techniques for Cherry Tomatoes

5.1 Comparison of different cultivation methods

Greenhouse cultivation of cherry tomatoes has been shown to significantly enhance yield And quality compared to open field methods（Figure 4). The controlled environment of greenhouses allows for optimized conditions such as temperature, humidity, and CO_2 levels, which are crucial for the growth and productivity of cherry tomatoes. For instance, the use of crop residues and animal manure composting (CRAM) in greenhouses can double the CO_2 concentration, leading to a 38% increase in yield and improved fruit quality, including higher concentrations of soluble sugars and ascorbic acid (Figure 5) (Karim et al., 2020). Additionally, greenhouse conditions facilitate the precise management of irrigation and fertilization, which are critical for maximizing yield and fruit quality (He et al., 2021).

Figure 4 Cherry tomato fruits cultivated in greenhouse at Zhejiang Rural Development Group Shangyu Co., Ltd. base

In contrast, open field cultivation is more susceptible to environmental fluctuations, which can adversely affect yield and fruit quality. However, open field methods can be more cost-effective and accessible for small-scale farmers. The use of organic mulches in open field systems has been shown to improve growth indicators such as leaf area, plant height, and fruit weight, thereby enhancing productivity (Cipriani et al., 2020). Despite these benefits, the lack of controlled conditions in open fields often results in lower overall yields compared to greenhouse cultivation.

5.2 Use of support structures and pruning techniques

Support structures and pruning techniques are essential for optimizing the growth and yield of cherry tomatoes. Sucker pruning and old leaf removal have been found to significantly improve plant height, fruit size, and overall yield. For example, sucker pruning resulted in the highest plant height and fruit size, while old leaf pruning led to the highest number of fruits per plant and yield per hectare (Ahmad et al., 2017). These techniques help in managing the plant's energy distribution, ensuring that more resources are directed towards fruit production rather than vegetative growth.

Moreover, the use of support structures such as trellises can prevent the plants from sprawling on the ground, reducing the risk of disease and pest infestations. This is particularly important in greenhouse settings where space is limited, and maximizing vertical growth can lead to higher yields. The integration of these techniques can be a viable way to increase the production of cherry tomatoes, as they help in maintaining plant health and improving fruit quality (Ahmad et al., 2017).

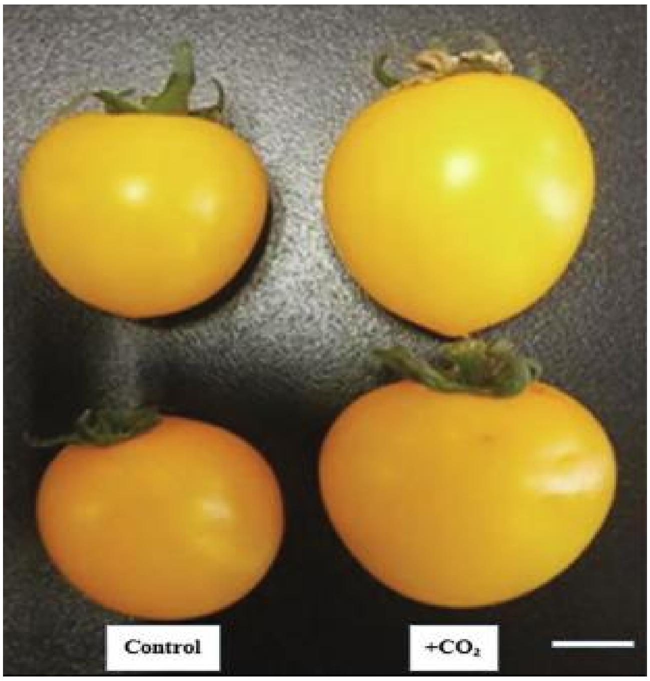

Figure 5 Difference of mature cherry tomato fruit in control greenhouse and CRAM-CO_2 treatment greenhouse. (Scale bar is 1 cm) (Adopted from Karim et al., 2010)

5.3 Regulation of the growth environment using mulching and ground cover

Mulching and ground cover are effective techniques for regulating the growth environment of cherry tomatoes. Mulching helps in conserving soil moisture, reducing weed growth, and maintaining a stable soil temperature, all of which contribute to improved plant growth and yield. Studies have shown that the use of organic mulches, such as crop residues, can significantly enhance the productive indexes of cherry tomatoes by improving growth indicators like leaf area, plant height, and fruit weight (Cipriani et al., 2020).

Ground cover techniques, such as the use of leguminous green manures in intercropping systems, can also improve soil fertility and structure, leading to better nutrient uptake and higher yields. For instance, intercropping cherry tomatoes with legumes like cowpea bean and dwarf velvet bean has been shown to increase the number and weight of marketable fruits (Salgado et al., 2021). These techniques not only improve the growth environment but also contribute to sustainable agricultural practices by enhancing soil health and reducing the need for chemical fertilizers.

6 Pest and Disease Control for Cherry Tomatoes

6.1 Diagnosis and management of common diseases

Cherry tomatoes are susceptible to various diseases, with gray mold (*Botrytis cinerea*) and leaf spot being among the most prevalent. Gray mold is particularly notorious for causing significant postharvest losses. Effective diagnosis involves identifying symptoms such as grayish mold on the fruit surface and lesions on leaves and stems. Management strategies for gray mold include maintaining proper ventilation and humidity control in greenhouses to reduce the favorable conditions for fungal growth (Ji et al., 2020; Brito et al., 2021). Leaf spot, caused by various fungal pathogens, manifests as small, dark lesions on leaves, which can coalesce and cause defoliation. Regular monitoring and early detection are crucial for managing these diseases effectively.

In addition to cultural practices, chemical and biological treatments play a vital role in disease management. Sodium pheophorbide A (SPA) has shown promising results in controlling gray mold by inhibiting spore germination and mycelial growth. SPA disrupts the cell wall integrity and membrane permeability of *B. cinerea*, leading to abnormal mycelial morphology and enhanced activities of defense-related enzymes in cherry tomatoes (Ji et al., 2020). Similarly, the use of antagonistic yeasts like *Wickerhamomyces anomalus* and *Cryptococcus laurentii* has been effective in reducing disease incidence by competing for nutrients and space, and by modulating the host's immune responses (Tang et al., 2019; Raynaldo et al., 2021).

6.2 Effectiveness of organic and chemical control methods

Organic control methods, such as the application of biocontrol agents, have gained attention due to their environmental friendliness and safety. *Wickerhamomyces anomalus* has demonstrated significant efficacy in controlling postharvest gray mold decay in cherry tomatoes. This yeast competes with *B. cinerea* for nutrients and space, and enhances the activities of defense-related enzymes like polyphenoloxidase (PPO), peroxidase (POD), and catalase (CAT), thereby inducing disease resistance in the fruit (Raynaldo et al., 2021). Another biocontrol agent, *Cryptococcus laurentii*, has been shown to modulate ethylene-associated immune responses, further reducing the incidence of gray mold (Tang et al., 2019).

Chemical control methods, while effective, often raise concerns about residue and environmental impact. Sodium pheophorbide a (SPA) is a natural photosensitizer that has been found to control gray mold by destroying the fungal cell structure and enhancing disease resistance-related enzyme activities in cherry tomatoes. SPA's mode of action includes affecting cell wall integrity and membrane permeability, leading to the collapse and dissolution of mycelial walls (Ji et al., 2020). These findings suggest that SPA could be a viable alternative to traditional chemical fungicides, offering a balance between efficacy and safety.

6.3 Application and potential of biological control techniques

Biological control techniques offer a sustainable approach to managing diseases in cherry tomatoes. The use of antagonistic yeasts such as *Wickerhamomyces anomalus* and *Cryptococcus laurentii* has shown considerable promise. *W. anomalus* not only reduces gray mold decay but also enhances the activities of defense-related enzymes, thereby boosting the fruit's natural resistance to pathogens (Raynaldo et al., 2021). Similarly, *C. laurentii* has been found to decrease disease incidence by modulating ethylene-associated immune responses, which are crucial for the fruit's defense mechanisms (Tang et al., 2019).

The potential of these biological control agents extends beyond their immediate antifungal effects. For instance, W. anomalus adapts well to the environment of cherry tomatoes, rapidly colonizing wounds and surfaces, which helps in outcompeting pathogens (Raynaldo et al., 2021). On the other hand, *C. laurentii's* ability to stimulate ethylene production and upregulate defense-related genes highlights its role in enhancing the overall immune response of the fruit (Tang et al., 2019). These attributes make biological control techniques a promising component of integrated disease management strategies for cherry tomatoes.

7 Growth Regulation Techniques

7.1 Use of hormones and growth regulators

The application of plant growth regulators (PGRs) such as gibberellic acid (GA3), auxins, and kinetin has been shown to significantly enhance the growth and yield of cherry tomatoes. For instance, a study conducted at the Sam Higginbottom University of Agriculture Technology and Sciences demonstrated that GA3 at 75 ppm resulted in the highest plant height, number of primary branches, early flowering, and fruit yield per plant among the treatments tested (Kavitha et al., 2023). Similarly, the use of 4-chlorophenoxyacetic acid (4-CPA) in high-temperature conditions in Botswana significantly increased fruit set and yield, with the highest concentration (75 ppm) yielding the best results (Table 1) (Baliyan et al., 2013).

Table 1 Effect of different concentrations of 4-CPA application on tomato fruit set

Source	SS	df	MS	F	Sig
Replications	7980.188	3	2660.063	2.253	.151
Treatments	29215.687	3	9738.562	8.248	006
Error	10626.563	9	1180.729		
Total	2814223.000	15			

These findings suggest that PGRs can be effectively used to manipulate plant growth and improve yield outcomes. The positive effects of PGRs are attributed to their role in enhancing cell division, elongation, and differentiation, which collectively contribute to better plant vigor and productivity. However, the concentration and type of PGR used are critical factors that need to be optimized for different environmental conditions and tomato varieties to achieve the desired outcomes (Baliyan et al., 2013; Kavitha et al., 2023).

7.2 Yield effects of intercropping and crop rotation

Intercropping and crop rotation are sustainable agricultural practices that can significantly impact the yield and quality of cherry tomatoes. A study evaluating the productivity of organic cherry tomatoes intercropped with various leguminous green manures found that intercropping with dwarf velvet bean and cowpea bean resulted in higher yields compared to monocropping (Salgado et al., 2021). Another study confirmed that intercropping with green manures like jack bean and velvet bean-dwarf improved the yield and quality of cherry tomatoes over two successive years (Ambrosano et al., 2018).

These practices not only enhance yield but also improve soil health by increasing nutrient availability and reducing pest and disease incidence. The incorporation of green manures into the cropping system adds organic matter to the soil, which enhances its structure and fertility. Additionally, the diverse root systems of intercrops can help in better nutrient uptake and water utilization, leading to improved overall plant health and productivity (Ambrosano et al., 2018; Salgado et al., 2021).

7.3 Control of fruiting periods through photoperiod and temperature adjustments

The manipulation of photoperiod and temperature is a crucial technique for controlling the fruiting periods of cherry tomatoes. Adjusting these environmental factors can synchronize flowering and fruit set, thereby optimizing yield. For instance, regulated deficit irrigation (RDI) has been shown to influence the development and fruit quality of cherry tomatoes by imposing controlled water stress during specific growth stages (Coyago-Cruz et al., 2019; Lu et al., 2019). This technique not only conserves water but also enhances the concentration of soluble sugars, carotenoids, and total phenols in the fruit, thereby improving its quality (Coyago-Cruz et al., 2019).

Moreover, the strategic use of photoperiod adjustments can help in extending the growing season and ensuring a continuous supply of marketable fruits. By manipulating light exposure and temperature, growers can induce flowering at desired times, which is particularly useful in regions with extreme climatic conditions. This approach allows for better planning and management of harvests, leading to more efficient production cycles and potentially higher economic returns (Coyago-Cruz et al., 2019; Lu et al., 2019).

8 Harvesting and Post-Harvest Handling

8.1 Selection of appropriate harvesting time and methods

Selecting the optimal harvesting time is crucial for ensuring the highest quality and yield of cherry tomatoes. The harvesting period significantly affects the quality characteristics of cherry tomato fruits, including external color, firmness, and nutritional components such as antioxidant capacity and soluble solids (Tsouvaltzis et al., 2023). Harvesting at the red ripe stage is recommended to maximize these quality traits. Additionally, the position of the fruit on the truss can influence its quality, with fruits at the base of the truss generally exhibiting better quality parameters than those at the top (Tsouvaltzis et al., 2023).

The method of harvesting also plays a vital role in maintaining fruit quality. Manual harvesting is often preferred for cherry tomatoes to minimize damage and ensure careful handling. This method allows for selective picking, ensuring that only fully ripe fruits are harvested, which is essential for maintaining the desired quality and extending shelf life (Wang, 2015). Proper training of laborers in gentle handling techniques can further reduce mechanical damage and post-harvest losses.

8.2 Post-harvest preservation techniques and treatment

Post-harvest preservation techniques are essential to extend the shelf life and maintain the quality of cherry tomatoes. One effective method is the use of controlled atmosphere storage, which can significantly reduce the rate of respiration and delay ripening, thereby extending the shelf life of the fruits (Glion et al., 2019). Additionally, maintaining an optimal storage temperature of around 12℃ can help preserve firmness, color, and nutritional quality (Tsouvaltzis et al., 2023).

Another important post-harvest treatment is the use of biostimulants, which have been shown to improve the post-harvest quality of cherry tomatoes. For instance, the application of enzyme hydrolyzed animal protein biostimulants has been found to enhance vegetative growth and yield, which can indirectly improve post-harvest quality by producing more robust and resilient fruits (Polo and Mata, 2018). These biostimulants can be applied through foliar sprays or irrigation, starting from the early stages of plant growth and continuing through the fruiting period.

8.3 Quality maintenance strategies during storage and transportation

Maintaining the quality of cherry tomatoes during storage and transportation is critical for ensuring that consumers receive fresh and high-quality produce. One effective strategy is the use of modified atmosphere packaging (MAP), which can help maintain the desired levels of oxygen and carbon dioxide around the fruits, thereby reducing respiration rates and delaying spoilage (Glion et al., 2019). This technique is particularly useful for long-distance transportation, where maintaining optimal conditions can be challenging.

Another important strategy is the careful management of temperature and humidity during storage and transportation. Studies have shown that storing cherry tomatoes at a consistent temperature of 12℃ and maintaining high humidity levels can help preserve firmness, color, and nutritional quality (Tsouvaltzis et al., 2023). Additionally, the use of grafted plants has been found to improve the post-harvest quality of cherry tomatoes by enhancing their resilience and reducing the incidence of post-harvest diseases (Lee et al., 2021). Grafted plants tend to maintain growth balance and photosynthesis efficiency for longer periods, resulting in higher fruit yield and better post-harvest quality.

9 Concluding Remarks

The meta-analysis of various cultivation techniques reveals significant impacts on the yield and quality of cherry tomatoes. Optimal irrigation and fertilizer management, as demonstrated by the multi-level fuzzy comprehensive evaluation, significantly enhance cherry tomato growth and yield. The study identified specific irrigation and nutrient levels that maximize growth across different seasons, highlighting the importance of precise water and nutrient management. Similarly, optimizing root distribution patterns through emitter density and deficit irrigation has shown to improve water use efficiency and yield, with two emitters per plant being the most effective. The use of organic fertilizers also positively impacts soil properties and tomato yield, with bio-organic fertilizers showing superior results in yield improvement and soil health. Additionally, intercropping systems with legumes and the use of shading screens under different irrigation levels have been found to enhance yield and fruit quality.

Despite the proven benefits of advanced cultivation techniques, their dissemination faces several challenges. One major issue is the limited public knowledge and adoption of these techniques, particularly in regions like Indonesia where cherry tomato cultivation is still emerging. The complexity of managing precise irrigation and nutrient levels, as well as the initial costs associated with implementing advanced systems like soilless substrate-based cultivation, can be barriers for small-scale farmers. To address these challenges, it is essential to provide comprehensive training programs and extension services that educate farmers on the benefits and implementation of these techniques. Additionally, developing cost-effective and user-friendly technologies can facilitate wider adoption. Government subsidies and support programs can also play a crucial role in encouraging farmers to adopt sustainable and high-yield cultivation practices.

Future research should focus on further refining and integrating these cultivation techniques to enhance their efficiency and applicability. Studies could explore the synergistic effects of combining optimal irrigation, nutrient management, and organic fertilizers to maximize yield and quality. Additionally, investigating the long-term impacts of these techniques on soil health and sustainability will be crucial. There is also a need to develop more resilient cherry tomato cultivars that can thrive under varying environmental conditions and stressors, such as drought and high temperatures. Innovations in precision agriculture, such as the use of sensors and automation for real-time monitoring and management of irrigation and nutrient levels, offer promising avenues for improving efficiency and reducing labor costs. Finally, expanding research on the economic feasibility and scalability of these techniques will be vital to ensure their adoption by a broader range of farmers, thereby contributing to global food security and sustainable agriculture.

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Conflict of Interest Disclosure

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

Reference

Ahmad H., Yeasmin S., Rahul S., Mahbuba S., and Uddin A., 2017, Influence of sucker pruning and old leaves removal on growth and yield of cherry tomato, Journal of Bioscience and Agriculture Research, 12(02): 1048-1053.
https://doi.org/10.18801/jbar.120217.128

Ambrosano E., Salgado G., Otsuk I., Patri P., Henrique C., and Melo P., 2018, Organic cherry tomato yield and quality as affect by intercropping green manure, Acta Scientiarum. Agronomy, 40: e36530.
https://doi.org/10.4025/ACTASCIAGRON.V40I1.36530

Baliyan S., Rao K., Baliyan P., and Mahabile M., 2013, The effects of 4-chlorophenoxyacetic acid plant growth regulator on the fruit set, yield and economic benefit of growing tomatoes in high temperatures, International Journal of Agricultural Science and Research, 3(2): 29-36.

Chanthini K., Stanley-Raja V., Thanigaivel A., Karthi S., Palanikani R., Sundar N., Sivanesh H., Soranam R., and Senthil-Nathan S., 2019, Sustainable agronomic strategies for enhancing the yield and nutritional quality of wild tomato, *Solanum Lycopersicum* (l) var *Cerasiforme* Mill, Agronomy, 9(6): 311.
https://doi.org/10.3390/AGRONOMY9060311

Cheng M., Wang H., Fan J., Xiang Y., Tang Z., Pei S., Zeng H., Zhang C., Dai Y., Li Z., Zou Y., and Zhang F., 2021, Effects of nitrogen supply on tomato yield, water use efficiency and fruit quality: a global meta-analysis, Scientia Horticulturae, 290: 110553.
https://doi.org/10.1016/J.SCIENTA.2021.110553

Cipriani D., Nascimento S., and Melo G., 2020, Mulch as a technique to improve the production of cherry tomato in conventional planting system, Revista Sítio Novo, 4(3): 88-96.
https://doi.org/10.47236/2594-7036.2020.v4.i3.88-96p

Coyago-Cruz E., Meléndez-Martínez A., Moriana A., Girón I., Martín-Palomo M., Galindo A., Pérez-López D., Torrecillas A., Beltrán-Sinchiguano E., and Corell M., 2019, Yield response to regulated deficit irrigation of greenhouse cherry tomatoes, Agricultural Water Management, 213: 212-221.
https://doi.org/10.1016/J.AGWAT.2018.10.020

Du Y., Cao H., Liu S., Gu X., and Cao Y., 2017, Response of yield, quality, water and nitrogen use efficiency of tomato to different levels of water and nitrogen under drip irrigation in Northwestern China, Journal of Integrative Agriculture, 16(5): 1153-1161.
https://doi.org/10.1016/S2095-3119(16)61371-0

Fan H., Zhang Y., Li J., Jiang J., Waheed A., Wang S., Rasheed S., Zhang L., and Zhang R., 2023, Effects of organic fertilizer supply on soil properties, tomato yield, and fruit quality: a global meta-analysis, Sustainability, 15(3): 2556.
https://doi.org/10.3390/su15032556

Fink J., Sánchez-Rodríguez A., Souza C., Junior C., Lagos F., Frosi G., Eckert D., and Schwengber A., 2020, Adjusting *P*-K fertilization and liming strategies to enhance yield of cherry tomato plants grown on an Oxisol, Communications in Soil Science and Plant Analysis, 51(13): 1736-1746.
https://doi.org/10.1080/00103624.2020.1798992

Glion H., Alkalai-Tuvia S., Zaaroor-Presman M., Chalupowicz D., Zanbar M., Amichai M., Cohen S., Shemer T., Sarig S., and Fallik E., 2019, Effects of rootstock/scion combination and two irrigation water qualities on cherry tomato yield and postharvest fruit quality, Horticulturae, 5(2): 35.
https://doi.org/10.3390/HORTICULTURAE5020035

Guo T.X., 2024, Genetic improvement of chickpeas: traits, targets, and technology, Legume Genomics and Genetics, 15(5): 221-231.
https://doi.org/10.5376/lgg.2024.15.0022

Guo J., Dong L., Kandel S., Jiao Y., Shi L., Yang Y., Shi A., and Mou B., 2022, Transcriptomic and metabolomic analysis provides insights into the fruit quality and yield improvement in tomato under soilless substrate-based cultivation, Agronomy, 12(4): 923.
https://doi.org/10.3390/agronomy12040923

Guo X., Zhao D., Zhuang M., Wang C., and Zhang F., 2021, Fertilizer and pesticide reduction in cherry tomato production to achieve multiple environmental benefits in Guangxi, China, Science of the Total Environment, 793: 148527.
https://doi.org/10.1016/j.scitotenv.2021.148527

He Z., Li M., Cai Z., Zhao R., Hong T., Yang Z., and Zhang Z., 2021, Optimal irrigation and fertilizer amounts based on multi-level fuzzy comprehensive evaluation of yield, growth and fruit quality on cherry tomato, Agricultural Water Management, 243: 106360.
https://doi.org/10.1016/j.agwat.2020.106360

Ji J., Yang J., Zhang B., Wang S., Zhang G., and Lin L., 2020, Sodium pheophorbide a controls cherry tomato gray mold (Botrytis cinerea) by destroying fungal cell structure and enhancing disease resistance-related enzyme activities in fruit, Pesticide Biochemistry and Physiology, 166: 104581.
https://doi.org/10.1016/j.pestbp.2020.104581

Karim M., Hao P., Nordin N., Qiu C., Zeeshan M., Khan A., and Shamsi I., 2020, CO_2 enrichment using CRAM fermentation improves growth, physiological traits and yield of cherry tomato (*Solanum lycopersicum* L.), Saudi Journal of Biological Sciences, 27(4): 1041-1048.
https://doi.org/10.1016/J.SJBS.2020.02.020

Kavitha G., Kerketta A., Topno S., and Bahadur V., 2023, Effect of plant growth regulators on cherry tomato (*Solanum lycopersicum* var. cerasiforme), International Journal of Environment and Climate Change, 13(8): 581-586.
https://doi.org/10.9734/ijecc/2023/v13i81986

Lee H., Lee J., Hong K., Kwon D., Cho M., Hwang I., and Ahn Y., 2021, Improving growth and yield in cherry tomato by using rootstocks, Journal of Bio-Environment Control, 30(3): 196-205.
https://doi.org/10.12791/ksbec.2021.30.3.196

Li H., Mei X., Wang J., Huang F., Hao W., and Li B., 2021, Drip fertigation significantly increased crop yield, water productivity and nitrogen use efficiency with respect to traditional irrigation and fertilization practices: a meta-analysis in China, Agricultural Water Management, 244: 106534.
https://doi.org/10.1016/J.AGWAT.2020.106534

Li T., Cui J., Guo W., She Y., and Li P., 2023, The influence of organic and inorganic fertilizer applications on nitrogen transformation and yield in greenhouse tomato cultivation with surface and drip irrigation techniques, Water, 15(20): 3546.
https://doi.org/10.3390/w15203546

Lu J., Shao G., Cui J., Wang X., and Keabetswe L., 2019, Yield, fruit quality and water use efficiency of tomato for processing under regulated deficit irrigation: a meta-analysis, Agricultural Water Management, 222: 301-312.
https://doi.org/10.1016/J.AGWAT.2019.06.008

Lu J., Shao G., Yang G., Zhang K., Wei Q., and Cheng J., 2021, Effects of water deficit combined with soil texture, soil bulk density and tomato variety on tomato fruit quality: a meta-analysis, Agricultural Water Management, 243: 106427.
https://doi.org/10.1016/j.agwat.2020.106427

Luo H., and Li F., 2018, Tomato yield, quality and water use efficiency under different drip fertigation strategies, Scientia Horticulturae, 235: 181-188.
https://doi.org/10.1016/J.SCIENTA.2018.02.072

Maboko M., and Plooy C., 2008, Effect of pruning on yield and quality of hydroponically grown cherry tomato (*Lycopersicon esculentum*), South African Journal of Plant and Soil, 25(3): 178-181.
https://doi.org/10.1080/02571862.2008.10639914

Moccia S., Chiesa A., Oberti A., and Tittonell P., 2006, Yield and quality of sequentially grown cherry tomato and lettuce under long-term conventional, low-input and organic soil management systems, European Journal of Horticultural Science, 71(4): 183-191.

Naik S., Hongal S., Harshavardhan M., Chandan K., Kumar A., , A., Kyriacou M., Rouphael Y., and Kumar P., 2021, Productive characteristics and fruit quality traits of cherry tomato hybrids as modulated by grafting on different *Solanum* spp. rootstocks under *Ralstonia solanacearum* infested greenhouse soil, Agronomy, 11(7): 1311.
https://doi.org/10.3390/agronomy11071311

Polo J., and Mata P., 2018, Evaluation of a biostimulant (Pepton) based in enzymatic hydrolyzed animal protein in comparison to seaweed extracts on root development, vegetative growth, flowering, and yield of gold cherry tomatoes grown under low stress ambient field conditions, Frontiers in Plant Science, 8: 2261.
https://doi.org/10.3389/fpls.2017.02261

Raynaldo F., Dhanasekaran S., Ngea G., Yang Q., Zhang X., and Zhang H., 2021, Investigating the biocontrol potentiality of *Wickerhamomyces anomalus* against postharvest gray mold decay in cherry tomatoes, Scientia Horticulturae, 285: 110137.
https://doi.org/10.1016/J.SCIENTA.2021.110137

Salgado G., Ambrosano E., Rossi F., Otsuk I., Ambrosao G., Patri P., Henrique C., Santana C., Muraoka T., and Trivelin P., 2021, Yield and nutrient concentrations of organic cherry tomatoes and legumes grown in intercropping systems in rotation with maize, Biological Agriculture & Horticulture, 38(2): 94-112.
https://doi.org/10.1080/01448765.2021.1992796

Shabbir A., Mao H., Ullah I., Buttar N., Ajmal M., and Lakhiar I., 2020a, Effects of drip irrigation emitter density with various irrigation levels on physiological parameters, root, yield, and quality of cherry tomato, Agronomy, 10(11): 1685.
https://doi.org/10.3390/agronomy10111685

Shabbir A., Mao H., Ullah I., Buttar N., Ajmal M., and Solangi K., 2020b, Improving water use efficiency by optimizing the root distribution patterns under varying drip emitter density and drought stress for cherry tomato, Agronomy, 11(1): 3.
https://doi.org/10.3390/agronomy11010003

Silva V., Ceará B., Rabelo J., Costa R., Silva A., and Almeida A., 2019, Response of the cherry tomato to watering and ground cover under organic cultivation, Australian Journal of Crop Science, 13(2): 214-220.
https://doi.org/10.21475/AJCS.19.13.02.P1220

Souza E., Medici L., Gentile M., Hassanpouraghdam M., Carvalho D., and Silva L., 2021, Grass (*Paspalum notatum*) clippings, with and without cattle wastewater, supported production of organic cherry tomatoes in pots, Biological Agriculture & Horticulture, 38(1): 29-39.
https://doi.org/10.1080/01448765.2021.1966506

Tang Q., Zhu F., Cao X., Zheng X., Yu T., and Lu L., 2019, Cryptococcus laurentii controls gray mold of cherry tomato fruit via modulation of ethylene-associated immune responses, Food Chemistry, 278: 240-247.
https://doi.org/10.1016/j.foodchem.2018.11.051

Tsouvaltzis P., Gkountina S., and Siomos A., 2023, Quality Traits and nutritional components of cherry tomato in relation to the harvesting period, storage duration and fruit position in the truss, Plants, 12(2): 315.
https://doi.org/10.3390/plants12020315

Wang D.F., 2015, High yield cultivation techniques of cherry tomato in greenhouse, Fujian Agricultural Science and Technology, 3: 25-27.

Wang X., and Xing Y., 2017, Evaluation of the effects of irrigation and fertilization on tomato fruit yield and quality: a principal component analysis, Scientific Reports, 7(1): 350.
https://doi.org/10.1038/s41598-017-00373-8

Wu J.Y., and Zhang T.Z., 2024, Next-Generation sequencing technologies: a game changer in cotton genomics, Cotton Genomics and Genetics, 15(2): 112-126.
https://doi.org/10.5376/cgg.2024.15.0011