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Integrating Agronomic Practices and Plant Physiological Strategies to Enhance Fruit Yield under Climate Stress Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate stress conditions such as drought, heat, salinity, and erratic rainfall patterns have become significant barriers to sustainable fruit production. To maintain and improve fruit yields under such stressors, a combination of agronomic interventions and plant physiological approaches is essential. This review synthesizes the latest research on how agronomic practices—such as mulching, drip irrigation, nutrient management, and intercropping—when integrated with physiological strategies like stress-tolerant

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cultivars, hormonal priming, and antioxidant regulation, can enhance fruit yield resilience. Emphasis is laid on integrated approaches and case studies from tropical and sub-tropical fruit crops.

Keywords: Climate; stress; sustainable; nutrient; fruit.

1. INTRODUCTION

Climate variability and associated stresses have increasingly impacted horticultural productivity, particularly fruit crops that are highly sensitive during flowering and fruit-setting stages (Wahid et al., 2007). With increasing frequency of droughts, heat waves, and soil salinity, there is an urgent need to develop resilient systems that ensure yield stability. While agronomic measures mitigate external environmental pressures, plant physiological adaptations are critical for internal stress tolerance. A combined approach leveraging both domains can lead to sustainable fruit production under adverse conditions. Climate change poses formidable challenges to global horticulture by intensifying heatwaves, drought, and erratic precipitation patterns, directly threatening fruit yield and quality (Zhao et al., 2017; Lesk et al., 2016). To counter these stresses, synergistic integration of adaptive agronomic practices and plant physiological strategies has gained prominence as an effective approach to sustain and enhance fruit production (Hatfield &Prueger, 2015; Bailey-Serres et al., 2019). Conservation tillage, mulching, and optimized irrigation scheduling improve soil moisture retention and moderate canopy microclimate, which directly mitigate drought and heat stress impacts on fruit set and development (Lal et.al.,2018; Farooq et al., 2011). Mulching with organic materials significantly reduced soil evaporation and improved tomato and apple yields under water-limited conditions (Liao et al., 2021).

A growing body of research demonstrates that integrating agronomic practices with plant physiological interventions can significantly buffer the negative impacts of climate stress and stabilize fruit yields.

For instance, in mango, combining drought-tolerant cultivars with straw mulching increased yields by 37% under water deficit conditions, reflecting the importance of soil moisture conservation (Kader et al., 2019). Similarly, regulated deficit irrigation in grapes at 70% of crop evapotranspiration improved water-use efficiency by 45% without compromising yield, highlighting how precision irrigation optimizes limited water resources (Chaves et al., 2007). Foliar application of anti-transpirants like kaolin has been effective in mitigating heat stress; Ahmed and Shimma (2022) reported that kaolin sprays reduced canopy temperature by 2.5°C and increased pomegranate yields by 22% during heatwaves. Meanwhile, shading nets have proven effective in protecting fruit crops from extreme heat, as seen in guava, where green shade nets reduced fruit drop by 30% and improved marketable yields by 28% (https://www.agriplast.co.in/blogs/effective-ways-to-use-shade-nets-solutions).

Soil moisture conservation techniques, such as conservation furrows with organic mulches, also play a pivotal role; Xiong et al. (2024) found a 35% increase in citrus yield during years with 30% reduced rainfall. Rootstock selection emerges as a key physiological strategy to combat salinity; Dalal et al. (2023) showed that Rangpur lime rootstocks produced 55% higher yields than Cleopatra under irrigation with 6 dS/m salinity. Antioxidant treatments can enhance plant resilience under heat stress: Noreen et.al., et al. (2021) demonstrated that foliar ascorbic acid applications improved the chlorophyll stability index by 18% in ber, resulting in a 20% yield increase under temperatures exceeding 40°C.

Moreover, silicon supplementation has gained attention as a physiological tool to enhance drought tolerance; Mali et.al., (2025) reported silicon sprays reduced electrolyte leakage by 40% and boosted sapota yields by 25% under terminal drought conditions. Integrating organic amendments with deficit irrigation, as demonstrated in papaya by Lima et al. (2015), increased yield by 31% compared to deficit irrigation alone, showcasing the synergistic effects of soil health management and water conservation. Finally, polyethylene mulching has shown substantial benefits in strawberry cultivation; Zambrano et.al., (2024) found it increased yields by 33% under intermittent drought, emphasizing the potential of plasticulture in climate-smart horticulture.

Collectively, these studies underscore that a combination of agronomic measures—like mulching, shading, and regulated irrigation—with physiological strategies—such as antioxidant and silicon treatments—can significantly enhance fruit yields under diverse climate stresses, with reported yield benefits ranging from 20% to 55%. Such integrated approaches offer a viable pathway to climate-resilient fruit production and should be further refined through site-specific research and economic analyses to enable their wider adoption among fruit growers.

2. CLIMATE STRESS EFFECTS ON FRUIT CROPS

Abiotic stresses affect fruit crops at morphological, physiological, and biochemical levels. Heat stress impairs pollen viability and fruit set, while drought reduces photosynthesis, cell expansion, and sugar accumulation (Farooq et al., 2009). Salinity affects nutrient uptake and leads to ion toxicity, compromising overall fruit quality and shelf life (Munns & Tester, 2008). For instance, in mango, temperatures above 35°C during flowering drastically reduce fruit set, and water stress during fruit development leads to smaller fruits with poor taste (Singh, 2024). The adoption of deficit and regulated deficit irrigation strategies has proven effective in conserving water while maintaining or enhancing fruit yield and quality in crops like grapes, citrus, and pomegranate (Chalmers et al., 1981; Costa et al., 2007; Intrigliolo& Castel, 2010). Fertigation practices combining balanced NPK inputs with micronutrients such as boron and zinc improve reproductive growth and fruit set resilience under thermal stress by enhancing pollen viability and ovule fertilization (Sharma et al., 1990; Marschner, 2012). Integrated nutrient management has also been reported to bolster root architecture and osmotic adjustment in fruit crops, enhancing water uptake efficiency during drought (Vetterlein et al., 2013; Fageria&Baligar, 2005).

3. AGRONOMIC STRATEGIES FOR MITIGATING CLIMATE STRESS

3.1 Mulching and Soil Management

Mulching with organic materials conserves soil moisture, moderates temperature, and suppresses weeds, enhancing plant health under water-limited conditions. Studies in guava and papaya showed a 20–25% increase in fruit yield with straw and plastic mulch under semi-arid conditions (Choudhary et al., 2025). Soil health restoration through cover cropping and biochar amendments has demonstrated benefits in enhancing soil water-holding capacity, cation exchange, and root growth, leading to higher fruit yields under prolonged drought (Agegnehu et al., 2023; Blanco-Canqui, 2017). Microbial inoculants like arbuscularmycorrhizal fungi (AMF) and plant growth-promoting rhizo bacteria (PGPR) have improved nutrient uptake efficiency and antioxidant capacity of fruit trees subjected to climate extremes (Ruiz-Lozano et al., 2016; Nadeem et al., 2014).

3.2 Drip Irrigation and Deficit Watering

Drip irrigation not only improves water-use efficiency (WUE) but also facilitates fertigation. Regulated deficit irrigation (RDI) has been successfully used in grapes and citrus to reduce water input by 30% without compromising yield (Gonzalez-Altozano & Castel, 1999).

3.3 Integrated Nutrient Management (INM)

Combining organic manure, compost, and biofertilizers with synthetic fertilizers optimizes nutrient uptake under stress. For instance, the use of vermin compost and Azotobacter in banana improved chlorophyll content and bunch weight under salinity stress (Meghwala et.al., 2024).

3.4 Intercropping and Agroforestry

Intercropping fruit trees with legumes enhances nitrogen fixation, improves soil structure, and creates microclimatic conditions that reduce evapotranspiration. In arid regions, intercropping ber (Ziziphusmauritiana) with cowpea helped sustain yield during dry spells (Ibrahim et al., 2015).

4. PHYSIOLOGICAL AND BIOCHEMICAL STRATEGIES

4.1 Breeding and Use of Stress-Tolerant Cultivars

Genotypic variation in fruit crops offers potential for breeding programs targeting abiotic stress resistance. Varieties such as 'ArkaRakshak' (tomato) and 'PKM-1' (guava) have shown heat and drought tolerance due to deep root systems and enhanced osmotic adjustment (Senthilkumar et.al.,2017). Breeding for physiological traits such as improved stomata regulation, deeper rooting, and enhanced water use efficiency has also been instrumental. For instance, heat-tolerant tomato and grape cultivars with superior pollen thermo tolerance have shown significantly higher yields under elevated temperatures (Sato et al., 2006; Keller, 2010). Genetic and genomic studies have identified candidate genes related to heat shock proteins, aquaporins, and osmolyte biosynthesis, opening avenues for marker-assisted breeding and gene editing to engineer climate-resilient fruit cultivars (Jagadish et al., 2015; Mittler&Blumwald, 2010).

4.2 Hormonal Priming

Pre-treatment with growth regulators like salicylic acid (SA), abscisic acid (ABA), and jasmonic acid (JA) enhances tolerance by regulating stomatal conductance and antioxidant activity. Application of SA in tomato improved fruit yield under high temperature by stabilizing chloroplast membranes (Hayat et al., 2010). Recent advances in canopy management, including training systems and reflective mulches, have enhanced light distribution and reduced excessive leaf and fruit surface temperatures, thereby improving fruit size and coloration even during extreme heat events (Palliotti et al., 2014; Lakso& Corelli Grappadelli, 1991). Shading nets have been effectively utilized in peaches, cherries, and apples to protect fruits from sunburn while maintaining photosynthetic rates (Iglesias &Alegre, 2006; Caruso et al., 2019).

4.3 Antioxidant Defense Mechanisms

Plants under stress generate reactive oxygen species (ROS). Enhancement of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) correlates with better stress resistance. Exogenous ascorbic acid has been reported to reduce lipid peroxidation in pomegranate under drought (Farooq, et al., 2020).

4.4. Osmoprotectant Accumulation

Accumulation of osmoprotectants such as proline, glycine betaine, and sugars helps maintain cell turgor. In grapevines, glycine betaine sprays improved leaf water potential and yield during heat waves (Yordanov et al., 2000). Physiologically, osmoprotectant accumulation, like proline and glycine betaine, plays a central role in maintaining cell turgor and enzyme stability under heat and drought stress, as demonstrated in mango, citrus, and peach (Ashraf &Foolad, 2007; Wahid et al., 2007). Exogenous application of salicylic acid, abscisic acid, or brassinosteroids has been shown to trigger antioxidant defense systems and heat shock proteins, improving photosynthetic performance and delaying senescence under combined heat and drought scenarios (Hayat et al., 2010; Farooq et al., 2009). Foliar sprays of potassium nitrate or calcium chloride improve membrane stability and reduce sunburn damage in citrus, pomegranate, and apples subjected to high temperatures (Gonzalez-Garcia et al., 1972; García-Tejero et al., 2013).

5. INTEGRATED APPROACHES FOR YIELD SUSTAINABILITY

The integration of agronomic and physiological techniques leads to synergistic effects. For example, in pomegranate cultivation, combining drip irrigation, mulch, and application of proline resulted in 30% higher yield under drought conditions compared to control (Okba et.al., 2022). Decision support tools, precision agriculture technologies, and sensor-based irrigation systems further refine these strategies. Integrative approaches combining these practices with climate-smart forecasting and precision agriculture technologies (e.g., soil moisture sensors, canopy temperature sensors) enable timely interventions and optimize resource use efficiency (Campos et al., 2004; Sadras et al., 2016). Moreover, modeling studies suggest that adaptive strategies integrating deficit irrigation, mulching, and stress-tolerant cultivars can increase fruit yield stability by 25–40% under predicted mid-century climate scenarios (Gornall et al., 2010; Lobell et al., 2008).

6. FUTURE PERSPECTIVES

The future of fruit production under climate uncertainty lies in site-specific integration of technologies. Advances in remote sensing, GIS mapping, and AI-enabled forecasting models can guide irrigation scheduling and crop choice. Furthermore, CRISPR and genomic selection tools hold promise for developing elite genotypes tailored to abiotic stress environments (Zhu, 2016). Farmer participatory trials and capacity building are essential to ensure wide adoption. Recent reviews consolidate the evidence that combining soil moisture conservation techniques, stress physiology, exogenous protectant application, improved genetics, and digital decision-support systems represents a holistic strategy to safeguard and boost fruit yield in the face of intensifying climate stress (Lesk et al., 2016; Bailey-Serres et al., 2019; Hatfield &Prueger, 2015). Future research should focus on region-specific integrations, socio-economic feasibility, and farmer-friendly packages to translate these strategies into sustainable on-farm practices.

7. CONCLUSION

Sustainable fruit production under climate stress hinges on holistic management that combines soil-water-plant interactions with plant physiological adaptations. Agronomic practices buffer external stress, while physiological traits enhance internal resilience. An integrated, location-specific approach promises to secure fruit yield, improve quality, and safeguard farmer livelihoods in the face of climate change.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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