Temperature Stress in Fruit Plants: Physiological Responses, Coping Mechanisms, and Management Strategies

Akriti Banyal
PhD scholar, Department of fruit science, YSP UHF Neri, Hamirpur, Himachal Pradesh
Corresponding Author: Banyalakriti1777@gmail.com

1. Introduction

Temperature is a critical environmental factor affecting the growth, productivity, and survival of fruit plants. Extreme temperature fluctuations, including both high and low temperatures, can lead to severe physiological and biochemical alterations, ultimately reducing yield and quality (Luo et al., 2022). Climate change has exacerbated temperature stress conditions, making it essential to understand plant responses and develop adaptive strategies for sustainable fruit production.

2. Classification of Temperature Stress in Fruit Plants

Temperature stress can be broadly classified into:

2.1 High-Temperature Stress

High-temperature stress, also known as heat stress, occurs when temperatures exceed the optimal range for plant growth, typically above 30-35°C. It can be further classified into:

- **Moderate Heat Stress (30-35°C):** Causes a decline in photosynthetic efficiency and mild cellular damage.
- **Severe Heat Stress (Above 35°C):** Leads to membrane destabilization, protein denaturation, and reduced pollen viability.
- **Heat Shock (>40°C):** Triggers irreversible cell damage, necrosis, and even plant death if prolonged.

2.2 Low-Temperature Stress

Low-temperature stress includes both chilling and freezing stress:

- **Chilling Stress (0-10°C):** Affects membrane fluidity, metabolic processes, and enzyme activity in sensitive plants.
- **Freezing Stress (<0°C):** Causes ice crystal formation, cellular dehydration, and tissue damage, often leading to mortality in non-hardy plants.

3. Impact of Temperature Stress on Fruit Plants

3.1 Effects of Heat Stress

Heat stress can disrupt cellular homeostasis, causing oxidative stress, membrane damage, and enzyme inactivation. It significantly reduces photosynthetic efficiency by impairing photosystem II, leading to chlorophyll degradation and reduced carbon assimilation (Zhang et al., 2021). Moreover, elevated temperatures affect fruit set, pollen viability, and hormonal balance, reducing fruit yield and quality (Raja et al., 2023).

3.2 Effects of Cold Stress

Cold stress, including chilling and freezing, induces cellular dehydration, membrane lipid peroxidation, and ice crystallization, leading to tissue damage (Wisniewski et al., 2018). Fruit crops like citrus and banana are highly susceptible to chilling injury, which manifests as browning, pitting, and impaired ripening due to disruptions in cellular metabolism and reactive oxygen species (ROS) accumulation (Liu et al., 2020).

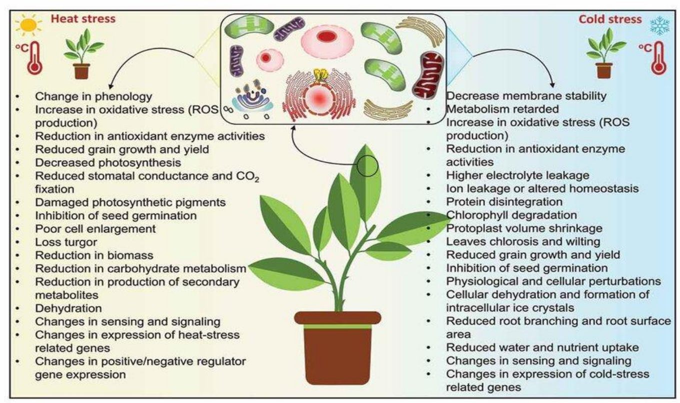

Fig 1. An overview of the impact of temperature stress on plant's morphological, physiological, biochemical, molecular and cellular

Source: Raza et. Al., (2022)

4. Coping Mechanisms and Defense Systems in Fruit Plants

Fruit plants have evolved several defense mechanisms to cope with temperature stress:

4.1 Morphological Adaptations

- **Leaf Morphology:** Smaller leaves and thicker cuticles reduce transpiration under heat stress.
- **Pubescence:** Hairy leaf surfaces reflect excess radiation and minimize water loss.

- **Root System Adjustments:** Deeper root penetration helps plants access cooler soil layers and water during high temperatures.

4.2 Physiological and Biochemical Responses

4.2.1 Antioxidant Defense Mechanisms

To mitigate oxidative stress induced by temperature extremes, fruit plants activate antioxidant defense mechanisms, including enzymatic antioxidants (superoxide dismutase, catalase, peroxidase) and non-enzymatic antioxidants (ascorbic acid, glutathione) (Hasanuzzaman et al., 2020). These compounds scavenge ROS and protect cellular integrity under thermal stress conditions.

4.2.2 Hormonal Regulation in Stress Response

Plant hormones play a crucial role in stress adaptation. Abscisic acid (ABA) accumulation under heat and cold stress regulates stomatal closure, osmotic balance, and stress-responsive gene expression (Sakata et al., 2021). Cytokinins and auxins also contribute to heat stress tolerance by modulating cell division and maintaining meristem activity (Ding et al., 2022).

4.2.3 Heat Shock Proteins (HSPs) and Cold Responsive Proteins (CRPs)

HSPs act as molecular chaperones, stabilizing proteins and preventing aggregation under heat stress (Wahid et al., 2018). Similarly, CRPs, including dehydrins and antifreeze proteins, protect cell membranes and enhance freezing tolerance in fruit plants (Thakur et al., 2020).

5. Management Strategies for Temperature Stress

5.1 Breeding for Temperature-Resilient Cultivars

Genetic improvement through conventional breeding and molecular approaches has led to the development of temperature-resilient fruit varieties. For instance, heat-tolerant tomato cultivars with improved fruit set under high temperatures have been developed through marker-assisted selection (Xu et al., 2023). Cold-hardy citrus varieties have also been identified using genomic approaches (Peng et al., 2021).

5.2 Agronomic Practices for Temperature Management:

- **Shade nets and Mulching:** Shade nets help reduce excessive heat, while mulching stabilizes soil temperature and improves moisture retention (Bai et al., 2019).
- **Foliar Sprays:** Application of protective compounds like kaolin and salicylic acid has been reported to improve heat and cold tolerance in fruit crops (Farooq et al., 2021).
- **Precision Irrigation:** Maintaining adequate soil moisture helps plants withstand temperature fluctuations.

5.3 Biotechnological Approaches for Stress Tolerance

- **Genetic Engineering:** Overexpression of heat shock factor genes has been found to improve thermotolerance in fruit crops (Chen et al., 2022).
- **CRISPR-Cas9 Technology:** Gene-editing tools have been used to introduce cold-responsive transcription factors in transgenic fruit plants, enhancing freezing tolerance (Zhou et al., 2023).

6. Conclusion

Temperature stress poses a significant threat to fruit production, affecting physiological, biochemical, and molecular processes in plants. Understanding the mechanisms underlying heat and cold stress responses can aid in developing effective mitigation strategies. Integrating advanced breeding techniques, agronomic practices, and biotechnological interventions can enhance the resilience of fruit crops against temperature extremes, ensuring sustainable fruit production in changing climatic conditions.

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