



## Mini Review

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# Frost Injury in Papaya (*Carica papaya* L.): Physiological and Biochemical Mechanisms, Orchard Impacts and Management Strategies

Naveen Kumar\* Ravi Kondle, Somesh Sharma, Ankit and Shailesh Kumar Singh

Department of Horticulture, Lovely Professional University, Jalandhar Punjab-144411, India

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\*Corresponding author: Naveen Kumar, Shailesh Kumar Singh, Department of Horticulture, Lovely Professional University, Jalandhar Punjab-144411, India

## Abstract

Papaya is a tropical fruit crop that is very susceptible to low temperature and frost events in subtropical regions. Frost damages cause rapid canopy injury, leaf necrosis, stem cracks, fruit abnormalities and poor recovery due to ice crystal formation, excessive ROS formation, cellular dehydration and membrane rupture, that's directly impact on productivity and fruit quality of papaya. This mini review summarizes frost risk factors, common injury symptoms, and main physiological and biochemical mechanism during low temperature stress, and useful field management techniques before, during, and after frost events. It also highlights research gaps for developing cost-effective frost mitigation and finding tolerant papaya genotypes.

**Keywords:** Papaya; Frost injury; Low temperature stress; Orchard management; Mitigation

## Introduction

The current global demand for sustainable agriculture faced the dual challenge of increasing the crop productivity and improving the nutritional value, while also reducing the negative impact of climatic fluctuation [1] Papaya (*Carica papaya* L.) is valuable fruit crop in tropical and subtropical region due to its rapid growth, short life cycle, high productivity and high economic value [2]. Papaya grows well in warm and humid climate, with ideal temperature between 21 to 32°C [3]. However, papaya is vulnerable to frost and low-temperature stress because of its delicate tissues, high water content, and limited natural chilling tolerance [4]. In subtropical regions, especially during clear winter nights, frost disrupts the membrane fluidity and promotes excessive electrolyte ion leakage results stem cracks, stunted growth, premature leaf drops, delayed flowering, immature flowers and fruit drops, improper fruit development etc. results, lower fruit yield and reduces the fruit quality [5]. In this review highlights the different physiological and biochemical mechanism during frost and sustainable management plans to improve papaya production in areas that are prone to frost while preserving high yield and nutritional value.

## Frost versus chilling: basic concepts

Low-temperature stress in papaya can occur in two main forms. Freezing temperature (<4 °C) are more severe to plants because they lead to ice crystal formation in or near to plant tissue which can hamper the plant tissue physically and even cause cell death [6]. On other hand chilling temperature (0–10 °C) effects plant growth and development by disrupting their cellular function. Frost is a specific form of freezing stress, that's occurs when ice crystal develops on plant surface due to various climatic events, which severally hampers succulent plant tissues [7]. Chilling mitigation focuses on storage/handling and gradual acclimation, while frost protection focuses on preventing tissue freezing during cold nights.

## Frost incidence and risk factors in papaya orchards

Frost intensity in papaya depends on both weather conditions and microclimate of the orchard.

**a) Type of frost:** Radiation frost is common on calm or very light wind, clear nights when heat is lost from the soil/plant surface, while advective frost is associated with cold air masses

and strong wind; radiation frost is often more manageable through microclimate interventions [8].

**b) Duration and minimum temperature:** Longer exposure below critical temperatures increases injury.

**c) Topography and site:** Low-lying areas collect cold air (“frost pockets”), increasing risk compared with gentle slopes.

**d) Soil conditions:** Moist, well-packed soil stores and releases more heat at night than dry, loose soil, reducing near-surface temperature drop.

**e) Crop stage:** young plants, actively growing tissues, and plants with tender canopy due to late nitrogen application are generally more susceptible.

**f) Windbreaks and canopy structure:** Windbreaks can reduce advective cooling in windy conditions but can also trap cold air in some layouts; orchard design must consider local frost type [9].

### Symptoms of Frost Injury in Papaya

Frost injury can be recognized through specific field symptoms that often become clearer after sunrise.

### Plant symptoms

- I. Water-soaked appearance on leaves and petioles shortly after a frost night.
- II. Rapid leaf wilting followed by blackening/necrosis (burnt appearance).
- III. Petiole collapse and drooping of the canopy.
- IV. Stem lesions, cracking, and crown damage in severe events.
- V. Dieback of young shoots and, in extreme cases, whole-plant death, especially in young orchards.

### Fruit symptoms

- a. External skin discoloration, blotches, and scald-like patches.
- b. Surface roughness or pitting and poor cosmetic quality.
- c. Uneven ripening and increased postharvest breakdown.
- d. In some cases, internal tissue browning and watery flesh can develop after cold stress, reducing marketability (Figure 1).

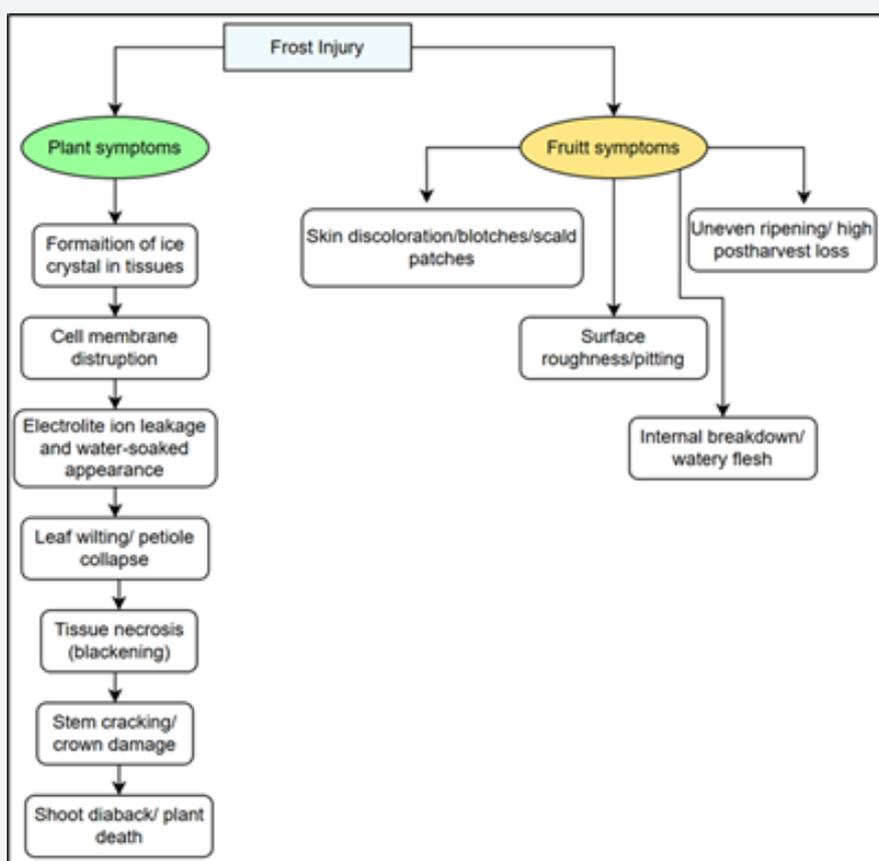


Figure 1: Frost injury in papaya.

### Physiological and biochemical basis of frost injury

Frost injury is fundamentally associated with ice formation and the resulting disruption of cell function [10]. When temperatures drop below freezing, ice tends to form first in extracellular spaces. This draws water out of cells, causing cell dehydration and mechanical stress. If freezing is severe or rapid, intracellular ice may form, which is usually lethal because it physically damages membranes and organelles [11,12]. Freezing and associated dehydration disturb membrane structure and

permeability, causing leakage of cellular contents and loss of compartmentalization [13]. Cold stress also promotes oxidative stress, increasing reactive oxygen species (ROS) that damage lipids, proteins, and chlorophyll, these effects visible as chlorosis followed by necrosis in leaves [14]. Plants can partially protect themselves through osmolyte accumulation (soluble sugars, proline), improved antioxidant enzyme activity (SOD, CAT, APX), and stress signalling pathways [15]. In papaya, these protective responses are limited compared with cold-hardy species, which explains the crop's high sensitivity to frost (Figure 2).

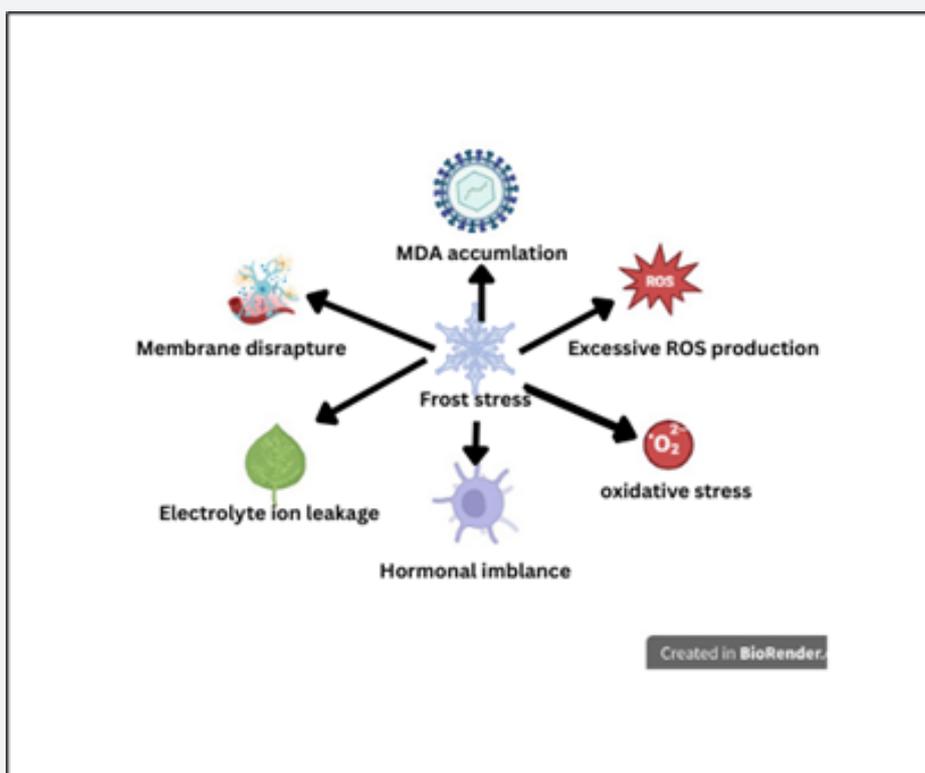


Figure 2: Physiological and biochemical mechanism under frost stress.

### Impacts on growth, yield, and economics

Frost can reduce papaya productivity through multiple pathways:

- a) **Stand loss:** death of young plants forces replanting and increases production cost.
- b) **Reduced canopy function:** leaf loss reduces photosynthesis, slowing recovery and delaying flowering.
- c) **Flower and fruit losses:** damaged inflorescences and young fruits lead to direct yield reduction.
- d) **Quality deterioration:** cosmetically damaged fruits

and those with internal breakdown fetch lower prices or become unmarketable.

- e) **Higher disease pressure:** frost-injured tissues can become entry points for pathogens, increasing post-frost rot and orchard sanitation costs.

### Management and mitigation strategies

Because frost injury can be sudden and severe, successful management typically combines preventive orchard planning with active protection on frost nights and good recovery practices afterward.

**Preventive strategies (before frost season)**

- I. Site selection and orchard layout:** Avoid frost pockets; prefer gentle slopes with good air drainage. Maintain pathways for cold air movement rather than blocking it.
- II. Planting time and crop scheduling:** Adjust planting to reduce exposure of very young plants during peak frost months where possible.
- III. Windbreak planning:** Use windbreaks carefully—helpful for advective frost but can increase risk if they trap cold air in radiation frost-prone sites.
- IV. Soil and irrigation management:** Keep soil adequately moist entering expected frost periods because moist soil stores more heat.
- V. Nutrient management:** Avoid heavy late nitrogen that produces tender tissues; maintain balanced nutrition, particularly adequate potassium and calcium for stronger tissues [16].

**Active protection (during frost nights)**

- a. Irrigation-based protection:** Overhead or micro-sprinkler irrigation can protect by releasing latent heat as water freezes, but it must be managed correctly (continuous application during freezing conditions and sufficient water supply). Improper use can worsen injury.
- b. Covers for young plants:** Use low-cost covers (plastic sheets, cloth, plant guards) for seedlings and young papaya, especially in small orchards or nurseries.
- c. Wind machines/fans:** Where feasible, these mix warmer upper air with colder surface air during radiation frost; effectiveness depends on local temperature inversion.
- d. Smoke/fogging:** Often used traditionally but generally

inconsistent and less efficient; it may provide limited benefit in calm radiation frost by reducing heat loss, but results are variable.

**Recovery and post-frost orchard care**

- I. Assess damage before pruning:** Wait until the extent of tissue death is clear; premature pruning can remove potentially recoverable tissues.
- II. Sanitation:** Remove dead, rotting tissues once clearly identified to reduce pathogen buildup.
- III. Irrigation and nutrition for recovery:** Provide supportive irrigation and balanced nutrition to promote regrowth, avoiding excessive nitrogen that encourages weak regrowth under continued cold risk.
- IV. Plant protection where needed:** If local recommendations exist, preventive disease management may be considered because damaged tissues are prone to infection; decisions should be region-specific and evidence-based.

**Research gaps and future needs**

- a) Critical threshold temperatures by growth stage:** Papaya needs stage-wise frost sensitivity benchmarks under field conditions for better advisories.
- b) Genotype screening:** Identification of relatively tolerant cultivars/lines and potential rootstock effects.
- c) Low-cost protection packages:** Field validation of combined methods (mulch + irrigation timing + covers + windbreak design) with cost-benefit analysis.
- d) Post-frost recovery protocols:** Standard recommendations for pruning time, nutrition, and disease management after frost (Table 1).

**Table 1:** Practical guide: frost injury symptoms and actions in papaya.

Symptom observed after frost	Likely issue	Practical action (field)
Water-soaked leaves/petioles early morning	Initial freezing injury and cell leakage	Monitor 24–72 h; avoid immediate heavy pruning
Leaf blackening/necrosis	Severe tissue damage, oxidative stress	Remove dead tissue after clear symptoms; maintain sanitation
Crown/upper stem injury	Potential plant death risk	Support recovery; remove severely damaged plants and replant if needed
Fruit skin discoloration/scald	Cold damage and disrupted ripening	Harvest selectively; grade fruits; reduce storage stress
Poor regrowth, dieback	Meristem/cambium damage	Prune back to healthy tissue once visible; provide balanced nutrition

**Conclusion**

Frost is a major abiotic constraint for papaya in subtropical production zones, causing direct tissue freezing injury, oxidative damage, yield reduction, and quality losses. Practical mitigation

relies on minimizing orchard frost risk through site and crop management, applying active protection during frost nights when feasible, and adopting careful post-frost recovery practices. Future research should prioritize defining stage-specific critical thresholds, developing tolerant genotypes, and validating low-

cost integrated frost protection strategies suitable for small and medium growers.

## References

1. Climate-Smart Agriculture (2021) Worldbank.org.
2. Parmar V, Kanzaria D, Varu D, Parsana J (2024) Economic impact of various farming systems on papaya (*Carica papaya L.*) cv. GJP 1. International Journal of Research in Agronomy 7(9): 820-823.
3. Cabrera JA, Ritter A, Raya V, Pérez E, Lobo MG (2021) Papaya (*Carica papaya L.*) phenology under different agronomic conditions in the subtropics. Agriculture 11(2): 173.
4. Pradhan S, Goswami AK, Singh SK, Prakash J, Goswami S, et al. (2019) Low temperature stress induced physiological and biochemical alterations in papaya genotypes. South African Journal of Botany 123: 133-141.
5. Goswami AK, Maurya NK, Goswami S, Bardhan K, Singh SK, et al. (2022) Physio-biochemical and molecular stress regulators and their crosstalk for low-temperature stress responses in fruit crops: A review. Frontiers in Plant Science 13: 1022167.
6. Xu CC, Liu DK, Guo CX, Wu YQ (2020) Effect of cooling rate and super-chilling temperature on ice crystal characteristic, cell structure, and physicochemical quality of super-chilled fresh-cut celery. International Journal of Refrigeration 113: 249-255.
7. Kumar N, Verma P, Singh SK, Bakshi M, Singh S, et al. (2025) Understanding plant resilience: Biochemical and physiological responses to low temperature stress in plants. CABI Reviews 20(1): 0073.
8. Hu Y, Asante EA, Lu Y, Mahmood A, Buttar NA, et al. (2018) Review of air disturbance technology for plant frost protection. International Journal of Agricultural and Biological Engineering 11(3): 21-28.
9. Brandle JR, Takle E, Zhou X (2021) Windbreak practices. North American agroforestry PP: 89-126.
10. Jahed KR, Saini AK, & Sherif SM (2023) Coping with the cold: unveiling cryoprotectants, molecular signaling pathways, and strategies for cold stress resilience. Frontiers in Plant Science 14: 1246093.
11. Palta JP, Weiss LS (2018) Ice formation and freezing injury: an overview on the survival mechanisms and molecular aspects of injury and cold acclimation in herbaceous plants. Advances in plant cold hardiness pp: 143-176.
12. Singh SK (2019) Freezing of proteins and cells. In Parenteral Medications, Fourth Edition pp: 947-973
13. Franzoni G, Spadafora ND, Sirangelo TM, Ferrante A, Rogers HJ (2023) Biochemical and molecular changes in peach fruit exposed to cold stress conditions. Molecular Horticulture 3(1): 24.
14. Manasa SL, Panigrahy M, Panigrahi KC, Rout GR (2022) Overview of cold stress regulation in plants. The Botanical Review 88(3): 359-387.
15. Ejaz S, Fahad S, Anjum MA, Nawaz A, Naz S, et al. (2020) Role of osmolytes in the mechanisms of antioxidant defense of plants. In Sustainable Agriculture Reviews pp: 95-117.
16. Bhattacharya A, (2022) Low-temperature stress and nitrogen metabolism in plants: A review. Physiological processes in plants under low temperature stress pp: 299-407.



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