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Safeguarding Fruit Production under Climate Change: Impacts and Adaptive Solutions

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INTRODUCTION

Fruit crops are important components of food and nutritional security, farm income and rural employment, providing vitamins, minerals, dietary fibre, antioxidants and other bioactive compounds. Mango, banana, citrus, grape, guava, pomegranate, papaya and custard apple are cultivated across diverse agro-climatic regions.

Fruit production, however, depends strongly on temperature, rainfall, humidity, solar radiation and seasonal conditions, and because many fruit crops are perennial, orchards remain exposed to changing climatic conditions for many years and cannot be relocated easily once their production environment changes.

Climate change is therefore recognised as a major production risk for horticulture. Malhotra (2017) highlighted shortened growing periods, terminal heat stress and reduced soil-water availability as important concerns for horticultural crops in India. More recent reviews confirm that climate change affects fruit-crop physiology, phenology, pest dynamics, quality and production, while adaptation research in this area is expanding rapidly (Bhattacharjee *et al*., 2022; Yadav *et al*., 2023; Raju *et al*., 2024; Sidharthan *et al*., 2026).

In a systematic review, Osorio-Marín *et al*. (2024) identified 403 relevant studies published between 2000 and 2023 on the climate impacts on temperate fruit and nut production, with major research areas including environmental responses, water management, sustainable agriculture, breeding and genetics, prediction models and production systems.

2. Major Climatic Drivers Affecting Fruit Crops

2.1 Rising Temperature

Temperature regulates growth, flowering, dormancy, fruit development and maturation. Higher temperatures can accelerate phenological events, shorten developmental periods and increase evaporative demand. During flowering, excessive heat may impair pollen viability and reproductive success, resulting in poor fruit set, while heat stress during fruit development can influence fruit size, colour, firmness and sugar acid balance (Yadav *et al*., 2023). In temperate crops, warmer winters may reduce chilling accumulation and disturb bud break and flowering.

2.2 Altered Rainfall and Water Availability

Climate change can produce irregular rainfall, longer dry spells and more intense rainfall events. Water deficit reduces photosynthesis, nutrient uptake, canopy growth, flowering and fruit retention, whereas excessive rainfall may cause waterlogging, nutrient losses, soil erosion and conditions favourable to certain diseases (Bhattacharjee *et al*., 2022).

2.3 Drought and Heat Waves

Drought combined with high temperature is particularly damaging, as it increases plant water demand while reducing soil-water availability. Young orchards and shallow-rooted plants are especially vulnerable, and heat waves during flowering or early fruit development can cause flower abortion, fruit drop and quality deterioration (Raju *et al*., 2024).

2.4 Extreme Weather Events

Hailstorms, cyclones, strong winds, frost, floods and unseasonal rainfall cause direct physical damage to flowers, shoots and fruits. Such events can reduce marketable yield even when total biological production is not entirely lost.

3. Effects on Phenology, Flowering and Fruit Set

Fruit crops require specific environmental conditions for flowering and fruit development, and climate-driven changes in temperature can shift both flowering and harvesting dates. In temperate fruits, inadequate chilling can result in delayed, uneven or prolonged bud break and flowering, whereas in warm-climate fruits, excessive heat during flowering may reduce pollen viability and fertilisation. Rainfall during the flowering period can further interfere with pollinator activity and pollen transfer (Malhotra, 2017; Yadav *et al*., 2023).

4. Effects on Yield and Fruit Quality

Climate change affects both the quantity and quality of fruit. Reduced fruit set, fruit drop, heat injury, drought and pest pressure can lower yield, while quality attributes such as total soluble solids, sugars, organic acids, colour, firmness, nutritional composition and shelf life may also be altered (Sidharthan *et al*., 2026). Concerns specifically related to fruit nutrition and fruit cracking under a changing climate have also been reported, along with the importance of breeding and protected-cultivation approaches for improving resilience (Bacelar *et al*., 2024).

The magnitude of these responses is crop- and cultivar-specific: the same change in temperature or rainfall may have different effects depending on developmental stage, rootstock, soil, irrigation and local climate. Adaptation recommendations should therefore be based on crop-specific and region-specific evidence rather than a single general prescription (Osorio-Marín *et al*., 2024).

5. Crop-wise Examples



Fig 1: Cultivating Resilience: Overcoming Climate – Driven Stress in Modern Fruit Production

5.1 Mango

High temperature and unseasonal rainfall can disturb flowering, pollination and fruit retention in mango. Heat and moisture stress may increase flower or young-fruit drop, while humid conditions during flowering can favour disease development (Raju *et al*., 2024).

5.2 Citrus

In citrus, temperature and water availability influence flowering, fruit retention, fruit size and quality. Drought can increase water stress and fruit drop, whereas excessive rainfall may increase disease pressure.

5.3 Grape

Temperature and rainfall affect berry development, sugar accumulation, acidity and disease risk in grape. Rain close to harvest can be particularly problematic where it promotes berry cracking or fungal infection.

5.4 Banana

Banana requires adequate water and a suitable temperature range. Heat, drought, strong winds and flooding can each reduce plant growth and bunch development.

5.5 Pomegranate

Pomegranate is relatively tolerant of dry conditions, but irregular water availability can contribute to fruit cracking and associated quality problems, making water management important under variable climates.

5.6 Guava and Custard Apple

Heat, drought and irregular rainfall can influence flowering, fruit set, fruit size and quality in guava and custard apple. Appropriate irrigation, mulching, canopy management and cultivar selection can help reduce climatic stress in both crops.

6. Pest and Disease Dynamics

Climate change can alter pest development rates, seasonal activity, geographical distribution and disease-favouring conditions. Warmer temperatures and changes in humidity may increase the suitability of some pests and pathogens, although responses differ among species and regions (Yadav *et al*., 2023). Integrated pest management should therefore be supported by regular monitoring, weather information, biological control, cultural practices and need-based chemical intervention.

7. Post-Harvest Effects

Climate conditions before and during harvest influence fruit physiology and subsequent storage performance. High temperature can accelerate respiration and ripening, while climate-related stress can affect firmness, nutritional composition and susceptibility to pathogens. Recent evidence emphasises that climate impacts extend beyond the orchard into storage and supply chains, making improved cooling, packaging, storage and transport important adaptation measures (Sidharthan *et al*., 2026).

8. Climate-Smart Adaptation Strategies

8.1 Climate-Resilient Cultivars and Rootstocks

Selection and breeding of cultivars tolerant to heat, drought, salinity, irregular water availability and other stresses is a key long-term strategy. Recent work by the Indian Council of Agricultural Research (ICAR) highlights the development and release of climate-resilient and nutri-smart subtropical fruit varieties, underlining the importance of breeding-based adaptation (Damodaran *et al*., 2026).

8.2 Efficient Irrigation and Water Harvesting

Drip irrigation, soil-moisture-based scheduling, mulching and rainwater harvesting can improve water-use efficiency. Irrigation scheduling should be matched to crop demand, soil condition and weather forecasts.

8.3 Mulching and Soil Management

Mulches reduce evaporation, moderate soil temperature, suppress weeds and improve soil-moisture conservation. Maintaining soil organic matter further supports water-holding capacity and overall soil health.

8.4 Canopy and Orchard Management

Appropriate pruning, training and canopy management can improve light distribution and air circulation and help moderate the orchard microclimate. Such practices should be adapted to the crop, cultivar and local weather conditions.

8.5 Protected Production

Shade nets, rain shelters, protected nurseries and related structures can reduce exposure to selected climatic hazards where economically and technically feasible.

8.6 Weather-Based Advisory and Digital Technology

Weather forecasts, remote sensing, soil-moisture sensors, automated irrigation, mobile advisories and decision-support tools can improve the timing of irrigation, plant protection and harvesting. Recent Indian horticulture literature likewise emphasises precision technologies for sustainable orchard management (Damodaran *et al*., 2026).

8.7 Integrated Pest Management

Integrated pest management combines monitoring, resistant cultivars, biological control, sanitation, cultural methods and need-based chemical control. Climate-informed pest forecasting can further improve decision-making under variable seasonal conditions.

8.8 Diversification and Value Addition

Diversification across crops and cultivars can reduce dependence on a single climatic risk. Processing surplus fruit into pulp, juice, nectar, jam, jelly, dried products and other value-added forms can reduce economic losses and improve farmer returns.

9. Research Gaps and Future Priorities

Although climate-change research on fruit crops is expanding, important gaps remain. More crop-specific field experiments are needed for tropical and subtropical fruits, particularly under combined stresses such as heat plus drought. Long-term orchard trials, cultivar-by-environment studies, improved phenology models, economic assessments and post-harvest research should receive greater attention; Osorio-Marín *et al*. (2024) similarly identified continuing needs in water management, breeding, prediction models and sustainable production systems.

Future research should integrate horticulture, plant physiology, genetics, soil and water management, meteorology, pest science, post-harvest technology and economics. Farmer-oriented technologies must also remain affordable, practical and region-specific.

CONCLUSION

Climate change is a major and growing challenge for sustainable fruit production. Rising temperature, altered rainfall, drought, extreme weather events and associated changes in pest and disease pressure can disrupt flowering, pollination, fruit set, yield, quality and post-harvest life. These impacts, however, are not uniform; they depend on crop, cultivar, developmental stage, production system and local climate.

A resilient fruit-production system should combine climate-resilient varieties and rootstocks with efficient irrigation, soil-moisture conservation, orchard management, weather-based advisories, integrated pest management, appropriate protected production and improved post-harvest handling. Recent Indian research on climate-resilient fruit varieties further demonstrates the value of breeding- and technology-led adaptation (Damodaran *et al*., 2026). Coordinated research, farmer training, extension services and supportive policy will be essential to sustain fruit productivity, quality, profitability and nutritional security under future climates.

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