SUNSHINE AGRICULTURE
e-Newsletter

ISSN (E): 2583 – 0821

Sun. Agri.:e- Newsletter, (2026) *6*(11), 01-07

Article ID: 707

When Orchards Feel the Heat: How Climate Change Is Reshaping Our Fruits

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Open Access

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Available online at
www.sunshineagriculture.vitalbiotech.org

Article History
Received: 02.11.2026
Revised: 07.11.2026
Accepted: 12.11.2026

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INTRODUCTION

Rising temperatures, erratic rains and warmer winters are changing the way mangoes flower, apples colour and grapes ripen. Here is what is happening in our orchards, and what growers can do about it.

The taste of a ripe Alphonso, the crunch and red blush of a Himalayan apple, the sweetness of a bunch of grapes: we take such pleasures for granted. But behind every fruit lies a delicate chain of events, from bud break and flowering to pollination, fruit set and ripening, each tuned to a particular range of temperature and moisture. Climate change is now disturbing that tuning. Fruits are far more than a treat. They supply vitamins, minerals, fibre and antioxidants, and they support millions of livelihoods. Yet erratic monsoons, heat waves, unseasonal rain and unexpected frost are already influencing how fruit crops grow, flower, yield and taste. Reviews of recent research suggest that global surface temperatures could rise by roughly 2.5-4°C by 2100 under the scenarios assessed, and tropical fruits such as mango, banana, papaya, passion fruit and custard apple are especially vulnerable to shifting monsoons and heat (Raju *et al.,* 2024).

1. Why fruit trees are especially exposed

An annual crop such as wheat lasts one season, and a farmer can change variety or sowing date the next year. A fruit tree is different. Planted once, it stands in the same spot for decades, facing whatever weather arrives. Developing a new fruit variety also takes about 15–20 years, so adaptation through conventional breeding is slow (Bhattacharjee *et al*., 2022). The orchard we plant today must cope with the climate of tomorrow.

2. Four climate pressures on the orchard

A. Rising temperature. High temperatures during flowering can reduce pollen viability, impair stigma receptivity and increase flower and young fruit drop. Heat stress during fruit development may cause sunburn, uneven ripening, reduced fruit size and shorter shelf life. Warm nights can further affect reproductive development and fruit quality.

B. Erratic rainfall. Irregular rainfall, prolonged dry spells and intense precipitation disturb orchard water balance. Water stress reduces photosynthesis and increases fruit drop, while excessive rainfall can cause waterlogging, root damage, soil erosion and greater incidence of fungal and bacterial diseases.

C. Rising atmospheric CO_2. Elevated CO_2 may enhance photosynthesis, biomass accumulation and water-use efficiency in fruit crops. For example, increasing CO_2 from 350 to 650 ppm enhanced root, leaf, branch and fruit biomass in sour orange in one experiment. However, these benefits may be restricted by high temperature, water scarcity and nutrient limitations.

D. Extreme weather events. Heat waves, frost, hailstorms, strong winds and floods can damage flowers, fruits and branches, resulting in substantial yield losses. Their impact is particularly severe when they occur during flowering, fruit set and early fruit development.

3. Fruit by fruit: what is changing

Climate change affects fruit crops differently depending on their temperature requirements, chilling needs and sensitivity to water stress. Its effects can be observed at different stages of crop development, from flowering and fruit set to yield and fruit quality. The major crop-wise impacts are summarized in Table 1

Table 1. Crop-wise impact of climate change, particularly high temperature, on flowering, fruit set, yield and quality of major fruit crops

Fruit crop	Major climatic factors	Impact on flowering and fruit set	Impact on yield and productivity	Impact on fruit quality
Mango (Mangifera indica)	High temperature, altered humidity, irregular rainfall and heat waves	Cool temperatures around 11.5°C, relative humidity above 80% and cloudy conditions may delay panicle emergence. Temperature fluctuations during panicle development may influence hermaphrodite flower proportion, flowering behaviour and fruit retention. Increased	Reduced fruit retention, increased fruit drop and unstable fruit production. A temperature rise of approximately 0.7–1.0°C may substantially alter areas suitable for quality production of Dashehari and Alphonso.	Increased incidence of sunburn, spongy tissue and black tip; altered fruit development, ripening and marketable quality.

		flower and young fruit drop may occur.		
Apple (Malus domestica)	Warmer winters, insufficient winter chilling and higher spring temperatures	Inadequate winter chilling results in delayed or irregular bud break, uneven flowering and poor fruit set. Spring warming of 0.45°C per decade (1973–2009) advanced apple and pear blooming by approximately 1.6 days per decade.	Inadequate chilling may result in irregular flowering, poor fruit set and unstable production.	Higher temperatures may reduce anthocyanin accumulation, resulting in poor red skin colour and reduced market appeal. Heat may also accelerate ripening and softening.
Pear (Pyrus spp.)	Warmer winters and changing spring temperatures	Altered chilling fulfilment may cause irregular bud break, uneven flowering and changes in flowering time. Spring warming of 0.45°C per decade (1973–2009) was associated with an advancement of approximately 1.6 days per decade in apple and pear blooming.	Potential reduction or instability in fruit production due to inadequate chilling and irregular reproductive development.	Changes in fruit development, ripening and market quality; altered maturity may affect post-harvest performance.
Grapes (Vitis vinifera)	Rising growing-season temperature, heat waves and warm nights	Higher temperatures advance flowering and subsequent reproductive stages, including veraison. In Alsace, France, a 2–3°C rise in	Earlier maturity and possible yield losses under severe heat stress. Heat damage may reduce marketable berry production.	Reduced acidity, altered sugar–acid balance and colour development; heat shocks above 35°C may cause berry sunburn and negatively

		growing-season temperature during 1964–2009 advanced flowering, veraison and harvest by approximately 13–19 days.		affect flavour and wine quality.
Citrus (Citrus spp.)	High temperature, drought, irregular rainfall and moisture stress	Temperature and moisture fluctuations may affect flowering behaviour, fruit retention and early fruit development.	Increased fruit drop, reduced fruit size, juice yield and overall productivity under severe heat and water stress. Faster maturity may shorten the harvesting and marketing period.	Changes in juice content, acidity, sugar concentration and vitamin C; altered sugar–acid balance and reduced market quality.
Banana (Musa spp.)	High temperature, irregular rainfall, drought and high humidity	Water stress may interfere with leaf development, bunch emergence and fruit development. Moisture stress during critical growth stages can affect bunch development.	Reduced bunch development and productivity under drought and irregular rainfall. High humidity may increase disease pressure, particularly Sigatoka.	Changes in fruit development, ripening and quality under moisture stress; accelerated ripening may reduce shelf life.
Litchi (Litchi chinensis)	High temperature, heat waves and moisture fluctuations	Heat stress may adversely affect fruit development and retention, increasing the risk of fruit loss during development.	Potential reduction in marketable fruit production due to fruit drop and heat-related damage.	Sunburn, fruit cracking, poor pericarp colour and reduced marketability under high-temperature and moisture-stress conditions.
Guava (Psidium guajava)	Rising temperature, warm and	Temperature changes may influence reproductive	Reduction in areas suitable for quality production and	Poor red-colour development, altered fruit

ISSN (E): 2583 – 0821

	humid conditions	success, fruit development and retention.	potential decline in marketable yield. A temperature rise of approximately 0.2°C has been reported to affect areas suitable for good red-colour development.	appearance and reduced market appeal; changes in nutritional and biochemical quality may also occur.
Pomegranate (Punica granatum)	High temperature, irregular rainfall and fluctuations in soil moisture	Moisture stress and sudden changes in soil moisture may affect fruit development and retention.	Increased fruit losses due to cracking, resulting in reduced marketable yield.	Fruit cracking, sunburn, reduced marketability and deterioration in external and internal fruit quality.

Beyond its effects on individual fruit crops, climate change also influences the overall nutritional and post-harvest quality of fruits. Rising temperatures and moisture stress can alter the sugar–acid balance, colour development, texture and ripening behaviour. They may also influence important nutritional compounds such as vitamin C, phenolics, flavonoids and carotenoids, although the response varies among fruit species and cultivars. Faster ripening, softening, sunburn and post-harvest deterioration can further shorten shelf life and reduce market value. Thus, climate change threatens not only fruit production but also the quality and nutritional benefits that fruits provide to consumers.

4. New pest and disease pressures

Warmer weather lets many insects complete more generations each year and survive winters more easily. Examples from the research include:

- Apple: a 2°C rise could mean five extra generations of woolly aphid per year, and winter mortality of the stink bug *Halyomorpha halys* may fall by 15% for every 1°C increase.
- Banana: burrowing nematodes become more severe under drier conditions.
- Citrus: leafhopper vectors of disease may increase.
- Mango and guava: fruit flies are more active in warm, humid weather.
- Pome and stone fruits: frequent stormy rain favours bacterial gummosis.

5. Orchards on the move

As temperatures climb, the map of fruit growing is being redrawn. Some regions may become less suitable because of heat, reduced chilling and water scarcity, while new areas may open up for tropical and subtropical fruits. But a suitable temperature alone does not make a good

orchard. Soil, water, chilling needs, pest pressure and infrastructure all matter, which is why region-specific crop planning is essential.

6. What can growers do?

The good news is that a toolkit of practical measures already exists.

A. Choose resilient planting material. Tolerant varieties and rootstocks give long-term protection. Reported examples include Dogridge, 110R and SO-4 for drought and salinity in grape; Rangpur lime for drought and *Phytophthora* tolerance in citrus; Cleopatra mandarin for salinity in citrus; Khirni for drought in sapota; and *Ziziphus nummularia* for drought in ber (Deori *et al*., 2024). These should always be tested under local conditions first.

B. Save every drop of water. Drip and micro-irrigation, irrigation scheduled to crop stage and soil moisture, mulching, rainwater harvesting and farm ponds make orchards more drought-proof, while good drainage protects against waterlogging.

C. Manage the canopy. Timely pruning and training, suitable spacing and shade nets where needed regulate sunlight, temperature and airflow inside the orchard.

D. Bag and protect fruit. Fruit bagging shields fruit from sun, insects and disorders. In studies cited in the research, mango bagged at the marble stage showed better retention, with newspaper bags giving heavier fruit free from spongy tissue, and parchment bags reduced cracking and sunburn in pomegranate. Nets and frost blankets help against extreme weather.

E. Use protective sprays wisely. Antitranspirants such as kaolin and chitosan reduce water loss and sunscald. Growth regulators, including melatonin, are being studied for stress tolerance, but results depend on crop, cultivar, dose and timing, so locally validated recommendations are essential.

F. Watch the pests. Regular scouting, conservation of natural enemies, pheromone traps, resistant varieties, weather-based forecasting and need-based chemical control keep integrated pest management effective.

G. Go digital. Weather stations, soil-moisture sensors, drones, remote sensing and artificial intelligence can guide timely irrigation, spraying and harvest decisions.

H. Protect pollinators and diversity. Flowering vegetation, natural habitats and fewer unnecessary pesticide sprays support pollinators, while conserving fruit germplasm keeps the genetic raw material for future climate-ready varieties.

7. The road ahead

Adaptation is not equally easy for everyone. Small and marginal farmers may struggle to afford drip systems, protective structures or digital tools, and resilient varieties are not yet available for every crop and region. Researchers still need long-term studies, heat-, drought- and salinity-tolerant genotypes, crop-specific climate models, affordable precision technologies and region-specific strategies. Farmer awareness, extension support and sound policy must travel alongside the science.

8. A final thought

Climate change touches almost every stage of a fruit's life, from the first bud to the last day on the shelf. Yet orchards are not helpless. With resilient varieties, smart water use, careful canopy and pest management, and respect for pollinators and biodiversity, fruit growing can adapt

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and thrive. The future of fruit production will depend not only on how much we produce, but also on how intelligently we adapt our orchards to a changing climate.

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