

Impact of Climate Change on Fruit Crops- A Review

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Abstract

Climate change is becoming an observed reality. Several researchers around the world have been working for decades to model predicted climatic changes that will occur in the 21st century and forecast the potential impact on the global eco-system. Climate plays a major role in deciding perennial fruit crop's distribution, phenology, fruit quality, and disease and pest incidents. Physiological and yield attributes of fruits are sensitive to changing global climate as the climatic factors such as temperature rainfall etc. has direct co-relation with the regulatory physiological events of fruit trees. Despite increasing atmospheric CO₂, which is needed for plant photosynthetic activity, the future of food production remains uncertain due to global warming and abnormal precipitation. Furthermore, there is a scarcity of information on the practical effects of pests and diseases in a climate change, which may have an effect on food availability in future. Studies suggested not only productivity but also quality of fruits will be impaired under the variable growing climates year to year. Plant diversity loss and area suitability issues would lead to more problems. In the face of such challenges to world fruit production, a plan-based strategic scientific evaluation of such effects, as well as adaptation and mitigation strategies, should be quantified. This review article briefly discusses effect of climate change on various fruit crops as well as approaches to mitigate with these future challenges.



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Introduction

Climate change can be explained in simple words as a significant shift in the statistical properties of the earth's climate over an extended period of time with a lasting effect. Changes in the biosphere, hydrosphere, cryosphere and other interacting elements of the atmosphere have contributed to climate change. It is widely acknowledged that man-made emissions have had a significant influence on climate change. A change in the atmospheric composition brought on by human activity, whether direct or indirect, in addition to the natural climate change that has occurred over a comparable time span. Although the earth's climate has remain largely constant for at least 10,000 years, it has still changed at a natural rate, primarily as a result of natural events like volcanic eruptions and continental shifts. According to the best projections, a 1.8–4°C rise in world average mean temperatures by 2100 will cause unpredictable rainfall and a rise in severe droughts, heat waves, cold waves and floods.

Higher emission of greenhouse gases increase opacity of reflected infrared rays in the atmosphere, eventually compensated by an increment in the temperature of the surface-troposphere system. The CO₂ concentration in atmosphere had a sharp rise up to 400 ppm in 2014, with a recent record of 415 ppm as per the data of October 2020 from NASA (Source: <https://climate.nasa.gov/vital-signs/>). Between 1906 and 2005, air temperature rose by 0.74°C¹, and it is expected to rise by 0.5 to 1.2°C by 2020, 0.88 to 3.16°C by 2050, and 1.56 to 5.44°C by 2080² the latest annual average anomaly (2019) was 0.99°C. Global temperatures are expected to rise by up to 6°C by 2100, while CO₂ concentrations may rise by up to 550 to 850 ppm over the same time period.³

According to the IPCC, the average temperature in the Indian subcontinent would rise by 0.5 to 1.2°C by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on future progress.⁴ The primary factors of climate change are abnormal rainfall patterns and an unpredictable high or low temperature regime, both of which have comprehensive consequences for agriculture in general and horticulture in particular.

Climate Change Implications In Fruit Crops

Given that long generation species (perennial trees,

shrubs, and herbs) would be less able to respond to new selective pressures than short generation species, fruit crops need to get special attention in the case of climate change.⁵ In comparison to annuals, developing a new variety in fruit crops takes 15 to 20 years, making it more difficult for it to compete with obstacles brought on by climate change. Fruit crops are challenging to reestablish since they are high value crops that produce quality yield with increased productivity and necessitate the utmost caution in a changing climatic environment.

Production of fruit crops is significantly impacted by climate, an important environmental variable. Poor fruit quality and low fruit production were the results of changes to plant physical characteristics like vigour, canopy development, and reproductive traits like fruiting ability and reduction in fruit size, as well as quality characteristics like less colour development, low juice content, decreased shelf-life, and higher pest attack.⁶ The ability of temperate crops to adapt to sudden changes in the weather at a certain time of the growing season in any historically inhabited areas of temperate crops is at risk, and this could result in serious production issues in the near future.⁷

In terms of the models used to predict how crops will respond to a changing climate, currently there are more than two dozen crop models available. The majority of these models consider crop response to only one climatic variable, such as CO₂ concentrations, temperature, or water stress, and they all generally agree on the general direction of the altered response but disagree on the magnitude of the changes predicted for the future. However, as was already indicated, the majorities of these techniques were developed for annual crops or were only tested on a few crops.⁸

Due to anticipated changes in temperature and rainfall, changes in enterprise structure and location are likely to have an impact on tropical fruits and regions. In a changing climate, increased irrigation demand as well as altered irrigation scheme efficiency and water supply are likely to be important concerns for tropical fruit. The spread of current pests, illnesses, and weeds, as well as the increased threat of invasions into new crops, as well as the incidence of minor pests, diseases, and physiological conditions including sunburn, fruit cracking, and tip

burn.⁹ In temperate fruit species, adequate cooling hours are crucial for healthy vegetative growth and fruiting. In temperate fruit crops, insufficient chilling hours results in inconsistent bud break and fruiting.¹⁰

According to numerous recent modelling attempts that include long-term temperature measurements, a large portion of the recent trend of global warming can be linked to increasing minimum temperatures, which have augmented at a quicker rate than mean or maximum temperatures.¹¹ Since their production depends on consistently cold temperatures during the growing season, perennial fruit trees are particularly susceptible to climate change.

Impact of Climate Change on Phenology of Fruit Crops

The shift in the time of plant growth activity, or change in phenology, is one of the well-known impacts of climate change. Fruit trees' vegetative and reproductive stages were altered due to climate change. Flowering is a critical stage in fruit development that has an effect on production and productivity. The flower primordia in pome fruits may totally or partially abscise in mild winters,¹² producing smaller flower bud clusters that resemble leafy spurs. Climate change has resulted in alterations in flowering, fruiting, and eventually yield. The absence of early cold in December and January has a detrimental impact on the amount of chilling requirement.¹³ In apple, lack of chilling time led to incomplete blossoms and poor fruit set.¹⁴ The blossoming and subsequently fruit set were both qualitatively and quantitatively affected by chilling hours. An increase of 0.45°C/decade (1973–2009) in early spring temperature led to an advance in apple and pear blooming by 1.6 days/decade.¹⁵ At various locations around the world, the following crops also had similar outcomes. In Alsace, France, an increase in the average growing temperature of 2–3°C (1964–2009) accelerated flowering, veraison, and harvest by 13–19 days in grape.¹⁶ Veraison for the cultivars "Riesling" and "Gewurtztraminer" will be advanced by up to 23 days by 2100.¹⁷ The peak flowering date of the cherry tree has shifted to early by 5.5 days in the past 25 years due to temperature fluctuations in February and March. There has been a 1.8°C increase in temperature during the past 25 years.¹⁸ Insufficient chilling requirements during warm seasons cause some phenological

disturbances, including late flowering, prolonged flowering times, and a longer time between flowering and harvest in apple.¹⁹ A substantial correlation found between flowering progress and changes in maximum and minimum temperature over time in several sites throughout Iran (Kerman, Shiraz).²⁰ In citrus fruits, it was discovered that flowering advances at rates of 3.15–3.39 days/°C for Kerman and 4.3–4.47 days/°C for Shiraz. In Junagadh, India, flowering was delayed in the majority of mango varieties due to temperatures that were over the ideal day/night temperature range and in part because of cloudy weather. After flower initiation, hermaphrodite flowers were more closely associated with greater temperatures.²¹ Undeveloped pistils were a result of the warm (15.9°C) temperature, which is 3–5°C higher than typical.²²

Impact of Climate Change on Fruit Crop's Physiology

CO₂ Effect

Increased CO₂ concentration affects a plant's physiological state. It performs a key role in photosynthesis, which produces the biomass of the plant. However, a rise in temperature and a shift in rainfall pattern may cancel out the positive effects.

Increasing net photosynthetic rate in grapes while decreasing stomatal conductance in response to increasing CO₂ improves innate water use efficiency in Portugal.²³ In general, they discovered that raising the atmospheric CO₂ level enhances the yield regardless of any good or negative impacts on grape maturity. Sour orange trees were particularly sensitive to the higher CO₂ levels even though they were well into middle-age reproductive maturity (17 years). At the time of final harvest, the root biomass, leaf biomass, branch biomass, fruit biomass and total biomass was significantly higher in the trees with CO₂ enrichment (350–650 ppm of CO₂) than that of the trees grown in ambient conditions.²⁴ The heat produced by CO₂ linked global warming in open environments and soil water evaporation tend to supersede these benefits under enriched CO₂ for plant biomass production, leading to shorter growth periods, decreased yield, and higher yield variance.²⁵

Temperature Effect

Temperature regulates the physiological functions of the plants. Imbalanced temperatures

causes to following impacts. *Viz.*, 1. Heat stress, 2. Inadequate chilling for temperate crops and 3. Disruption in pollination activity.

Heat stress increases evaporation, which leads to stomatal closure and a reduced influx of CO₂, which ultimately drives respiration and reduces photosynthesis. According to National Climate Assessment 2014, chilling hours will decrease by 30 to 60 % by 2050 and by up to 80 % by 2100. The In peach cultivars, flowering, fruit set, yield and quality all were proved to be significantly influenced by warmer climatic conditions. Due to lack of chilling, peach tree develop irregular patterns of phenological stages including late flowering and prolonged flowering period. These traits are directly associated with chill accumulation in stone fruit species.²⁶ Flower abortion occurs in warm winter years, resulting in lower fruit yield.²⁶

Temperature stress seriously affects the disruption of pollination activity, which accounts for 35% of the world's food production.²⁷ Plant-pollinator interactions gets disturbed due to temporal (phenological) and spatial (distributional) mismatches. Temporal changes are already visible as *Apis mellifera* accelerated their activity period earlier than their preferred forage species flowering peaks and Spatial- Shifting of areas in developing countries.²⁸ Crop plants which are self-incompatible, pollinator limited, pollinator specific are more vulnerable to this threat. Rising temperatures can hasten panicle growth and reduce the number of days available for successful pollination during mango panicle development. Under warm night conditions, a flower bud can transform into a vegetative one.²⁹

Fruit crops are more susceptible to climate change due to longer flowering period. Temperature alters hormones that are essential for tree growth and development. Fruit crops such as mango and litchi have already shown early blooming and crop harvest. Under changing climate conditions, mango can exhibit both early and delayed flowering. Low temperatures (11.5 °C), high humidity (>80%), and overcast weather all postpone panicle emergence in January, while low temperatures throughout the panicle growth decrease hermaphrodite flowers.³⁰ Mango malformation is a prevalent in areas where

winters are severe thus may get benefitted under a warmer climate.

The production and productivity of mango, banana, papaya and sapota were found to be inversely correlated with temperature and rainfall over a ten-year period (2007–2017) in Navasari district, Gujarat, India.³¹ In Spain, Palencia *et al.*³² conducted research on yield efficiency of strawberry cv. Camrosa with relation to average temperature (T^a) and sun radiation. At 15°C<T^a<20°C, they noticed higher yield (80 g/plant). Due to the high temperatures, total yield decreases when T^a>20°C. Higher yield (80 g/plant) will be obtained with average radiation ranging between 20 and 25 mJ/m². Total yield start to decline as mean radiation exceeds 25 mJ/m².

Climate Change Impact on Quality of Fruits

Quality parameters are of essential concern in order to fetch a lucrative price in export market. Changing climatic scenarios are impacting the ideal situations of proper pigmentation and secondary metabolites production which are of integral necessity to produce quality fruits. Temperature variability might also synergist to ideal conditions based on growing areas. Higher antioxidant activity was reported in 'Kent' strawberries under warm days (25°C) & warm nights (18–22°C).³³ Changes in climate have also been recorded to have negative consequences such as earlier ripening by the end of this century in California which may result in lower quality grapes in the region.³⁴ Incidental heat shocks (over 35°C) caused the loss of 50 % of the berries due to browning and berry burn.³⁵ Regarding quality, technical (primary metabolism) rather than phenolic (secondary metabolism) maturity was more significantly impacted by simulated climate change scenarios.³⁵ Jones and Davis³⁶ reported 10-15 days earlier maturity of grapes per degree increase in average temperature of growing season, the level of acidity and anthocyanin decline toward warmer temperature in wine varieties of grape in France. By accelerating the maturation phase of the grapes and reducing acidity and pigmentation, rising temperatures have a detrimental impact on the quality of grape wine production. Increased temperature is expected to hasten the growth of fruitlets and maturity in citrus, grapes, and litchi. Fruit availability period may be shortened due

to faster maturity and ripening.³⁷ Mandarin fruits grown in direct sunlight (35 °C) were 2.5 times firmer than those grown in shade (20°C) because direct sunlight reduces the activity of cell wall enzymes (cellulase and polygalacturonase) during growth, which delays ripening.³⁸ Long term exposure of fruits to sunlight caused high temperatures on fruit surface which accelerate ripening and other related events. Grapes are one famous example, with bunches exposed to direct sunlight ripening earlier than those matured in shaded areas inside the canopy.³⁹ It has also been discovered that high temperatures hinder the colour development of the fruit. Damage caused by downy mildew also increases when temperature coupled with unseasonal rains increases.⁴⁰ There was a breakdown incidence when fruits produced at higher temperatures were stored at 3 °C, which is attributable to the lower calcium content in the fruits grown at elevated temperatures.⁴¹ Sunburn can occur when fruits, such as litchi, are subjected to extremely high temperatures for a prolonged period of time or even for a short period of time during their growth and development.⁴² Reduced fruit sizes and anthocyanin content in litchi are caused by increased watering needs as a result of higher evaporation along with faster tree development as a result of faster heat unit accumulation.⁴³

Red color of apple fruit is very important in marketing of apple fruits. One of the most important factors affecting the red colour development of apple fruits is temperature. Anatomical observations through cross section of fruit tissues indicated that anthocyanin pigments were restricted only to the cells of the upper layers of the flesh and skin if cultured at higher temperatures. The treated cells were larger than that of untreated cells and it continuously increase with time. Red colour density was higher in the discs treated at 20 and 25°C than at 30°C.⁴⁴ Sunburn and fruit cracking are becoming more common in apple as a result of excessive temperature and moisture stress, which has significantly reduced fruit quality.⁴⁵ High temperatures has tens water core incidence in pear.⁴⁶

Impact of Climate Change on Area Suitability of Fruit Crops

Variations in the productivity, flowering, and quality of tropical fruits from year to year are influenced by changes in the rainfall distribution pattern.⁴⁷ Over the last several decades, warming has

expanded the tropical region,⁴⁸ leading to the importance of newer area for tropical fruits. A temperature increase of 1°C can change a major area suitable for tropical fruits. Several fruit crop suitable areas could become marginally suitable, while new suitable areas may emerge. Temperature rises are predicted to have a greater impact on reproductive biology of these crops.

High temperatures have two major effects on crop production: they limit vegetative growth and reduce fruit set. Extreme transpiration combined with high temperatures limits fruit crops that are prone to high transpiration losses. A temperature rise of 0.7-1.0°C could change the area currently suitable for the quality production of Dashehari and Alphonso mango varieties.⁴⁹ The area best suited for a mango variety Dashehari decreases dramatically with a rise of 1°C in temperature and Alphonso (a mango cultivar) is probably limited to Ratnagiri area because of its suitability in changing climate.²⁹

In a study of global banana production and its suitability under climate change scenarios, certain conclusions were inferred; such as increase in suitable areas due to temperature rise, mainly areas with $\geq 24^\circ\text{C}$ average temperature.⁵⁰ According to research of 24 locations around the world, it can be concluded that all of the sites show a linear rise in temperature, which has made climate change an issue for civilization. Only three sites – two in India (i.e. Bagalkot and Uttar Pradesh) and one in Argentina – display trends towards extremely high temperatures, which may reduce banana growth. It was predicted there will be increase in area with tropical growing climate, whereas, current tropical zones will face the threats of extreme climate.⁵⁰

Impact of Climate Change on Pest and Disease Incidence in Fruit Crop

Climate change has altered the occurrence of pest and disease in fruit crops. Changes in flowering time and temperature fluctuation can result in the introduction of new pests, minor pests gaining major pest status, and breaking of resistance. According to National Research Center for Banana annual report 2012, Sigatoka disease has occurred in destructive proportion in Maharashtra, where it was never considered a problem before, owing to climate change. Frequent occurrence of stormy

rains leads to increased bacterial gummosis of pome and stone fruits.⁵¹ Climate change can alter pathogen development stages and rates, as well as host resistance and the physiology of host-pathogen interactions.⁵² Warming up is harmful for tropical insects (physiological optima) than insects at higher latitudes.⁵³ In tropical regions, a decline in the number of specific vector insects could lessen the prevalence of particular viruses, such as citrus leprosy (mealy bug), papaya ring spot (aphid), pineapple wilt (mealy bug), and others.⁵⁴

The lifecycle of various insect pests is directly impacted by seasonal variations, including changes in temperature and rainfall patterns. Climate change

could lead to changes in geographic distribution, population growth rates, generation numbers, over wintering, developmental seasons, crop-pest phenology synchrony, increased risk of invasion by migrating pests and interspecific interactions.⁵⁵ Fruit fly development increased as temperature rises from 20 to 35°C in mango cv. Chausa. Future climatic circumstances can affect the codling moth occurrence in apple and the period of life phases that are crucial for pest control.⁵⁶ The possible risk for 3rd generation was also considerably rising in Switzerland. With the possibility of a third generation of codling moth, it would be necessary to intensify and extend protection measures (e.g. insecticides) in order to control this additional generation, meaning

Table 1: Favourable chances of pest incidents under climate change scenario

Crop	Insect pests	References
Apple	2 °C rise in temperature will result extra 5 generations / year in woolly aphids.	Harrington <i>et al.</i> ⁵⁸
Apple	Every 1 °C rise will reduce winter mortality of stink bug (<i>Halyomorpha halys</i>) by 15 %	Kiritani ⁵⁹
Banana	Severity of burrowing nematode (<i>Radopholus similis</i>) will increase with drier climates.	Villanueva ⁶⁰
Citrus	In spring and summer, Increased shoots formation would raise the population of leafhoppers (<i>Oncometopia facialis</i> , <i>Acrogonia</i> sp. and <i>Dilobopterus costalimai</i>) the main vectors of citrus variegated chlorosis.	Milanez <i>et al.</i> ⁶¹

an increased risk of pesticide residual effects on fruits.⁵⁶ Climate change has prompted a rise in disease incidence, water use, and insect infestation, which has led to an increase in input costs in citrus orchards of Punjab plains, Pakistan.⁵⁷

Resilient Strategies for Future

Adaptation is necessary, but mitigation must also be included because even though all emissions are stopped, the temperature would keep rising for decades until stabilising. If the rate of rise is not controlled, it will reach several critical tipping points, hastening climate change to the point that adaptation will be insufficient.⁶² The best approach for achieving superior levels of both adaptation and mitigation is to combine adaptation and mitigation.³ Under a changing climate scenario, the systematic degradation of plant genetic diversity harmed the

capacity to breed new cultivars for potential habitats. Nowadays, horticulture crops are losing genetic diversity as monoculture spreads over the world. Because species are unable to adapt to climatic change, global warming has expedited the loss of variety. Plant diversity is critical to the potential ability of horticulture industry to withstand disease, pest, and environmental threats. The core of any crop improvement programme is a diverse germplasm collection. Germplasm may contain genes or features that should be combined to create new or improved qualities which are resistant against abiotic/biotic stresses. Fruit breeders, scientists, and other users can benefit from genetic diversity collected from various agro-climatic conditions and maintained ex situ and in situ to increase production in the face of climate change. Plant germplasm resources should be safeguarded, preserved,

managed, collected, maintained, characterized and used for the benefit of us and our future generation.⁶³

Rootstocks give farmers a range of alternatives for improving yield and fruit quality, achieving early harvests, minimizing the juvenile phase, controlling tree vigour, enabling high density planting (HDP), etc. The selection of a rootstock is critical, as climatic and soil factors have a considerable influence. Rootstock can adapt to a variety of soil types, as well as resistance to drought, salinity, iron chlorosis and flooding.⁶⁴ When Sharad Seedless was budded on Dogridge rootstock plants exhibited higher water usage efficiency (WUE) at 50% water stress.⁶⁵

The most straight forward strategy to sustaining tropical fruit is to employ adaptable cultivars and cultural techniques in a location-specific manner.⁶⁶ Drought tolerant cultivars of certain fruits can be selected for growing in areas with higher temperature stress viz., 'Deanna and Excel' (fig), 'Arka Sahan' (Annona), 'Ruby' (pomegranate).⁶⁷ Due to its origin of evolution mono embryonic mango cultivars are more cold tolerant than polyembryonic cultivars.⁶⁸ Litchi and longan thrive in warm subtropical to tropical climates. Longan is sensitive to temperatures below 0°C, and temperatures ranging from -2 to -3°C can harm or kill young trees. Rambutan thrives in warm tropical regions with temperatures ranging from 22 to 30°C, but it is susceptible to cold below 10°C.⁶⁹ Aonla is capable of withstanding a variety of climate situations.⁷⁰ However, it is severely damaged by frost, and the scion part of young budded plants or grafts are dried. It is one of the fruits that is thought to be more resilient to climate change because it can withstand drought. Varieties that mature before frost occur produce the highest yield.⁷¹

Implementing new farm practices and resource-saving technologies (e.g., fruit bagging, fertigation, mulching, etc.) can be beneficial. Mango fruits bagged at the marble stage with brown paper and a scurting bag had the highest fruit retention (%), while mango fruits bagged with a newspaper bag had the highest fruit weight and were free of spongy tissue.⁷² Pomegranate fruit bagging with prgmen bags reduced fruit cracking and sunburn physiological disorders.⁷³

Use of anti-transpirants such as chitosane, kaolin, and others to reflect solar radiation from plant parts, thereby reducing water losses through transpiration and lowering the temperature of fruit and leaf surfaces. When compared to the other treatments, the use of 2% anti-transpirant chitosane resulted in substantially higher average finger weight, average hand weight, and bunch weight in banana.⁷⁴ Premium quality pomegranate fruits found in the terra alba (pulverised gypsum) treatment because it lowers the average fruit and leaf temperature relative to the control,⁷⁵ and kaolin treatment significantly reduce sunburn in pomegranate fruit.⁷⁶

Adapting to climate change in a location-specific manner is the primary option for farmers, while shifting current production systems to a more suitable place is also an alternative on a global scale. Tropical fruit trees are considered being more resistant to climate change owing to their perennial character.³⁰ Annual crops can sequester between 0 and 450 kg of soil carbon per/ha, while perennial crops can sequester between 320 and 1,100 kg of soil carbon/ha and they are more likely to achieve higher yields at higher temperatures. Raising carbon sequestration in soil via soil moisture and temperature manipulation, restoring soil carbon on depleted lands and reserving excess agricultural land can all help to reduce CO² emissions from agriculture. Manuring, minimum tillage, residue incorporation, mulching, micro aggregation and improving soil biodiversity can all help to sequester carbon in soil. Farmers can easily implement certain strategies, like intermittent drying and site-specific nitrogen management, with little additional investment, while others require financial inducements and policy support.⁷⁷

Conclusion

In 21st century, Climate change is that the utmost concern of humankind. Global climate change is likely to put pressure on fruit production, limiting the ability to procure future fruit production targets. Changing climatic parameters have influenced growth and development, changed flowering behaviour, influenced fruit quality, and caused shifts in pest and disease incidence. Recent climate change appears to have influenced geographic distribution, local population of plants and pollinators and phenology. The key strategies for addressing this challenge will be the development of new

horticultural crop varieties that are resistant to high temperatures, resistant to pests and diseases, and produce high yields under stress conditions, as well as the use of high-tech horticulture and prudent natural resource management. Despite of rising atmospheric CO₂, future food production is unpredictable with concurrent events of global warming and altered precipitation. There is a scarcity of data on the practical effects of pests and diseases in a changing climate, which could have an effect on future food availability by reducing fruit productivity and fruit quality. Plant diversity loss and area suitability issues would lead to more problems. In the face of such challenges to world fruit production, a plan-based strategic scientific evaluation of such impacts, as well as adaptation and mitigation strategies, should be quantified.

Future Thrust

Need to study on physiology, phenology, growth, yield and quality of fruit crops to increased

temperature, CO₂ and excess and deficit water stress. Crop simulation models for horticultural crops are urgently needed to allow regional impact, followed by adaptation and vulnerability analysis.

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