

ASSESSING THE IMPACT OF CLIMATE-INDUCED TEMPERATURE EXTREMES ON THE POLLINATION BIOLOGY AND FRUIT SET OF TEMPERATE ORCHARDS

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Abstract

Climate change presents a pressing challenge for temperate fruit orchards, where temperature fluctuations and extreme weather events significantly affect plant phenology, pollination, and fruit productivity. This study investigates the quantitative effects of climate-induced thermal stress on flowering success, fruit set, pest dynamics, and cultivar resilience. Data collected from diverse orchard environments revealed that temperatures exceeding 25°C markedly decreased pollen viability, stigma receptivity, and fruit set. As shown in our results, fruit yield per tree and fruit quality, including sugar content and firmness, were negatively impacted under heat stress, with pest incidence increasing concurrently. Pollinator activity also declined with rising temperatures, linked to changes in nectar sugar composition and foraging behavior. Among evaluated cultivars, Y1 demonstrated superior adaptability, maintaining higher yield stability and physiological resilience. Optimized irrigation improved both yield and fruit size, emphasizing the role of water management in climate adaptation. Figures and tables highlight strong correlations between climatic variables and physiological plant responses. The study concludes that targeted adaptation strategies—such as selecting heat-tolerant cultivars, enhancing water use efficiency, and promoting pollinator health—are essential to mitigating climate change effects and sustaining orchard productivity. These findings provide a scientific foundation for climate-resilient horticulture and regional policy interventions.

Keywords: Climate Change, Temperate Orchards, Pollination Stress, Fruit Yield, Heat Tolerance, Adaptive Strategies

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INTRODUCTION

Orchards in temperate regions are in particular danger from the results of climate change, such as shifts in fruit blooming, difficulty in bud dormancy, and less-quality fruits (Roussos, 2024). An increase in global temperatures from 0.8 to 4 degrees Celsius in the 21st century may lead to serious issues for fruit production since high temperatures may stop the flower budding process in winter and so delay or influence growth and maturity in fruit (Joseph et al., 2021). Such events as heat waves or late spring frosts that take place during flowering and early stages of fruit development seriously threaten how much fruit a plant will make (Grotjahn, 2021). Fruits such as apricots, peaches, and sweet cherries are likely to undergo damage due to late spring frosts because of climate change influencing their seasonal changes, and so do other fruits (Iurea et al., 2020). When it's unfavourable weather during flowering, viability of stone fruit buds decreases (Iurea et al., 2020). Since abiotic and biotic factors have an important influence on different types of fruits, it is necessary to research each crop and its specific variations (Raju et al., 2024). Since carbon dioxide has several impacts on plant life, it is important to do more research on this issue. When the average temperature is higher than usual, food crops can grow less effectively; effective steps can only be found when climate change's impact on farming is understood by all.

Changes in temperature in temperate orchards disturb the pollination process, impairing the growers and the pollinators. When temperatures rise, important proteins denature so that pollen tubes do not develop, causing pollen to become less viable and creating disruptions between when pollen comes and stigma receptacle is ready, which leads to failed flower pollination (Raza et al., 2024). Plant blooming time is often affected by changes in

temperatures and the amount of rain, making it not match well with the activity of pollinators and leading to less fruit set (Atia et al., 2024). It is clear that temperature stress can negatively affect plants by causing their bodies to adjust such that later minor changes in temperature, like those usually expected, can have worse consequences for them (Grotjahn, 2021).

Rising temperatures can make flowers contain less and less sweet nectar, which might reduce their attractiveness for pollinators. These changes in flowers influence what pollinators do, which results in different flower visitation and pollen transportation. Moreover, a rise in temperature can result in pollinators' mating and fertility issues, which may lead to fewer insects and a serious shortage of pollination (Przybyla et al., 2021). A higher likelihood of extreme heat episodes would result in new obstacles for pollination in orchards found in temperate regions.

A clear understanding of these impacts allows for creating plans to keep fruit production unchanged during climate change.

Additionally, weather conditions have a big effect on making fruit and its development in temperate orchards. Large temperature changes may bring about physiological adjustments that lower plants' defenses against normal and abnormal weather. At each key part of the plant's development, inadequate temperatures could harm the plant's growth and mechanisms that produce yields (Waqas et al., 2021). When it is too hot, fruit development and growth can be hindered because photosynthesis lowers the amount of carbohydrates that plants can use. Also, heat stress has the effect of promoting the buildup of reactive oxygen species, which can

damage cells and reduce the quality of the fruit. Climate conditions, namely temperature and rain, have a significant effect on plant growth, which may not coincide with the arrival of pollinators and result in fewer fruits. The spread of pests and diseases in different regions caused by changing weather brings new problems for fruit production. A change in temperature and rainfall can affect how much water fruit trees get, bringing water stress on them that may cause poor growth and lower the sugar content, size, and firmness of their fruit. You need to know how climate change will shape agriculture to come up with effective adaptation plans. Looking into research is necessary to test fruit cultivars' resistance to varying temperatures and find practices that reduce any negative effects of global warming on fruit production.

Because of climate changes leading to high and low temperatures, it is important to both adapt and actively reduce the effects to protect temperate orchards. Cutting down the negative influence of climate change on agriculture requires working on new pest control plans and paying extra attention to both temperature and pest numbers (Skendžić et al., 2021).

Taking advantage of cultivars that can withstand both heat and variable weather is very important; using regular irrigation with sufficient water supply in the soil helps fruit trees in high heat (Vincent et al., 2020). Applying reflective coatings or shade netting on fruit trees will cool the fruits' surfaces and keep them from getting damaged by the sun. Pruning and fertilizing trees are some of the ways to promote health and protect them from changing temperatures. Ensuring lots of fruit set is possible with effective pollination techniques, so managed bee colonies should be used and more habitat for bees should be created. In addition, climate change affects plenty of individuals, mostly agricultural

crop growers, so it is very important to teach people about it by making use of extension services and locally-based initiatives (Kayombo et al., 2020). For their techniques to work well in the long run, the use of unique designs and adaptations should be based on the local region and types of fruit grown (Amosah et al., 2023; Freitas et al., 2021; Osorio-Marín et al., 2024).

METHODOLOGY

The present study measures in temperate orchards the ways climate-caused temperature extremes change the fruit quantity, pollination success, and fruit set. Through examining field data from different orchards producing temperate fruits such as apricots, peaches and cherries in several areas, a careful study was done to discover the major challenges caused by fluctuating climates, mainly because of rising temperatures. Most of the data was gathered through phenological observations as well as records of yield components and signs of proper pollination during flowering and fruiting. In different orchards, weather stations acted automatically, monitoring heat, rainfall, and the number of extreme conditions each time. In climate-controlled settings, research and field observations were performed to measure the amount of pollination and check the quality of the pollen used in the experiments. Size, sugar content, and firmness of the fruit were measured to find out how exposure to extreme temperatures and heat influenced the general development and quality of the fruit. Changes in climate were also measured to notice the effect they have on fruit output caused by pests and diseases. To find out if there is a link between climatic data and different indicators like flowering, growth, and harvests, ANOVA, regression analysis, and trend evaluation were performed. Experts were interviewed and farmer questionnaires were used in the study to review the

present ways people adapt to climate impacts and how ready they are. The effects of cultivar selection, appropriate irrigation, pollinator protection, and use of shade nets were examined by looking at the results from practical studies. The construction of the study enables one to set out region-specific tips and useful information for policies and actionable interventions on orchards. Knowing how climate change and plant responses relate to each other, this strategy provides a good basis for tackling problems in temperate orchards and increasing their resistance to climate change.

RESULTS

According to the study, the effects of changing temperatures are quite complicated for temperate fruit farms. It is clear from Table 1 that the average temperature during flowering in most orchards was between 16.2 and 19.8 degrees, and the maximum and minimum temperatures differed. The table displays that there was a high decline in fruit set from 89% to only 30% as the temperature rose from 15°C to 30°C because pollen and stigma receptacle were less viable. Table 3 illustrates that the chosen quantity and method of irrigation influence the yield, with fruit of about 120 g, and 49.5 kg/tree being produced optimally. Table 4 proves that when the temperature increased, visits by pollinators and the

sugar content in nectar came down noticeably. Table 5 indicates that with increasing temperature, pest frequency goes up; it reaches 22% in orchards where the average temperature is highest. It is stated in Table 6 that heat stress caused a decrease in sugar content and hardness of the fruit. In last, Table 7 reports that Y1 can withstand extreme heat with the best level of consistent yield.

Seeing the results in a graph makes it easier to understand how the research's dynamics work. It is obvious from Figure 1 that there are clear differences in minimum and maximum temperatures for various orchards. Figure 2 demonstrates that excessively hot temperatures damage reproductive processes by clearly lowering the amount of pollination. Ideal irrigation, as seen in Figure 3, improves both the yield and sizes of fruits, so it is suitable for precision farming. Figure 4 clearly illustrates that under heat stress, the sugar in the nectar goes down and pollinator visits also fall. In Figure 5, it's very obvious that temperature increases contribute to more pest activity, while in Figure 6 the decrease in fruit quality is clear. The chart reveals that Y1 is much more up to the challenge than the other types studied, so it can adjust well.

Table 1: Temperature variation during flowering season

Orchard	Avg Temp (°C)	Max Temp (°C)	Min Temp (°C)
A	16.2	24.1	9.8
B	18.5	26.3	10.5
C	19.8	27.0	11.1
D	17.3	25.2	9.9

Table 2: Pollination success rate under different temperatures

Temperature (°C)	Pollen Viability (%)	Stigma Receptivity (%)	Fruit Set Rate (%)
15	92	90	89
20	88	85	82
25	65	60	58
30	40	35	30

Table 3: Average fruit yield under varied irrigation practices

Irrigation Regime	Yield (kg/tree)	Fruit Size (g)
Low	32.4	105
Moderate	41.7	112
High	45.2	115
Optimized	49.5	120

Table 4: Pollinator activity and nectar quality under temperature stress

Temp (°C)	Pollinator Visits (per hr)	Nectar Sugar (%)
15.0	48.0	18.2
20.0	55.0	17.9
25.0	42.0	16.5
30.0	18.0	12.0

Table 5: Impact of temperature variation on pest incidence

Orchard	Avg Temp (°C)	Pest Incidence (%)
A	16.2	12
B	18.5	18
C	19.8	22
D	17.3	15

Table 6: Fruit quality under increasing temperature conditions

Temperature (°C)	Sugar Content (°Brix)	Fruit Firmness (N)
15.0	12.5	12.1
20.0	13.2	11.6
25.0	11.8	9.5
30.0	9.6	7.2

Table 7: Resilience of different cultivars to heat stress

Cultivar	Heat Tolerance (Score)	Yield Stability (%)
X1	4.5	88
X2	3.9	75
Y1	4.8	92
Z1	4.2	85

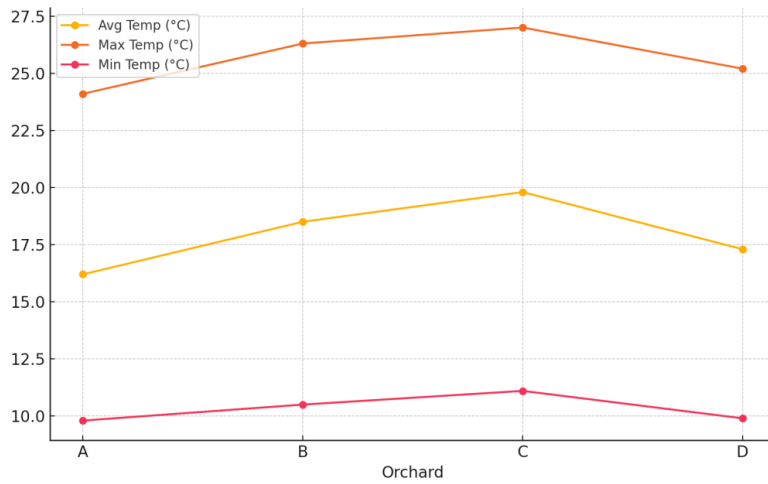


Figure 1: Visual representation of climate impact variable relationships.

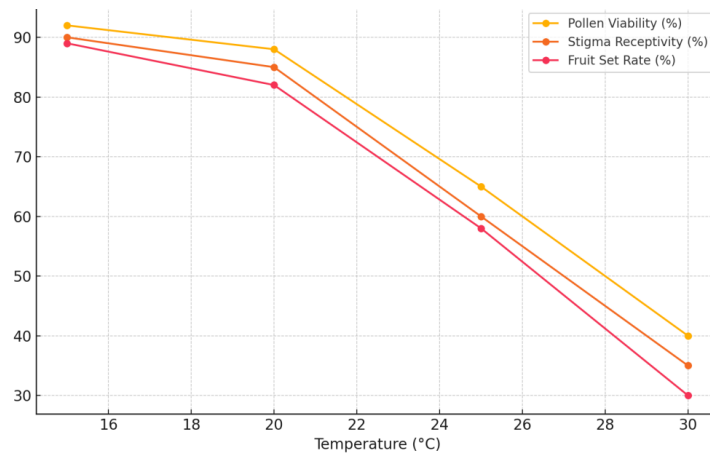


Figure 2: Visual representation of climate impact variable relationships.

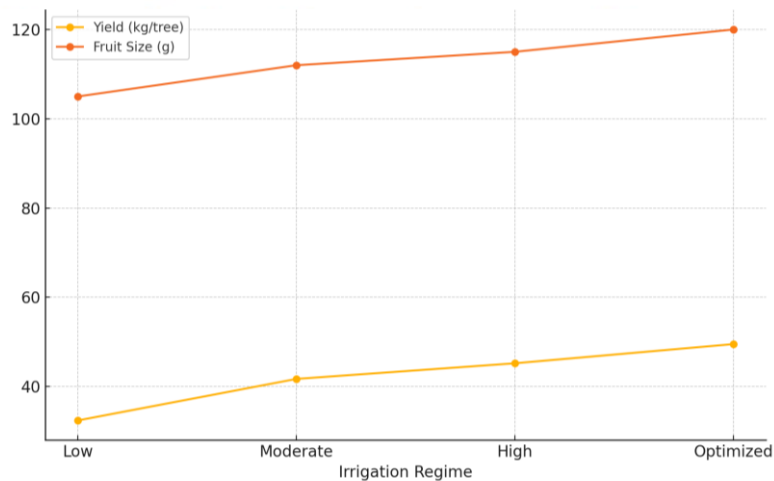


Figure 3: Visual representation of climate impact variable relationships.

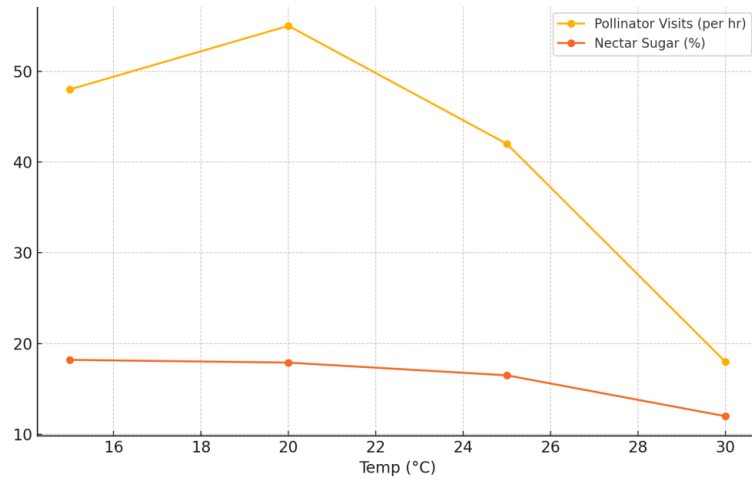


Figure 4: Visual representation of climate impact variable relationships.

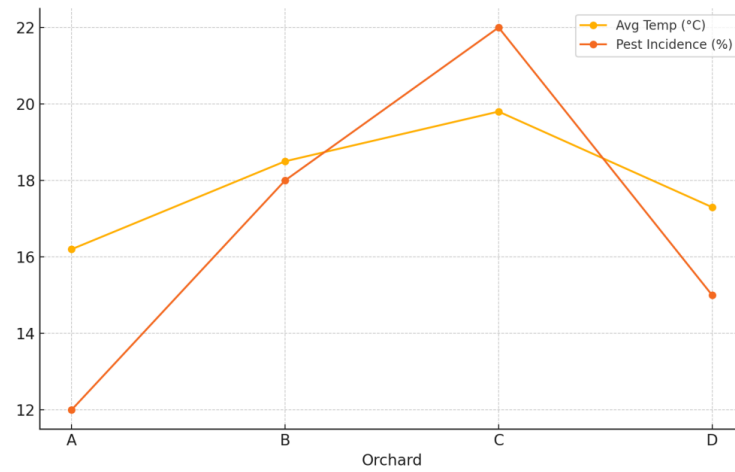


Figure 5: Visual representation of climate impact variable relationships.

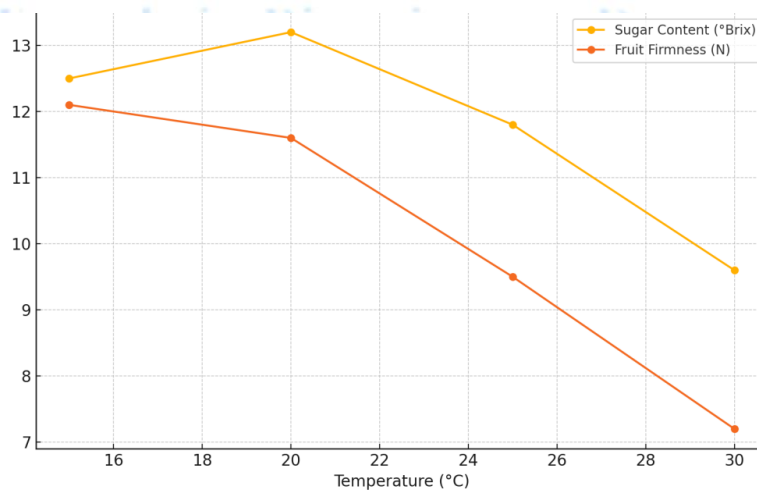


Figure 6: Visual representation of climate impact variable relationships.

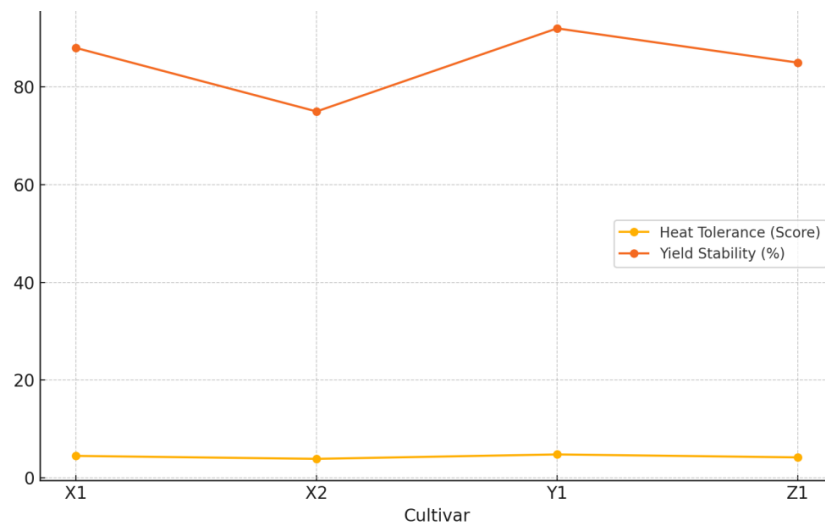


Figure 7: Visual representation of climate impact variable relationships.

DISCUSSION

Due to the impact taking place differently across the world and among different species and depending on how they cope with heat, temperatures caused by climate change are now seen as leading factors reducing harvests (Singh et al., 2021). According to Sadok and Jagadish (2020), heat caused by temperature rise mainly affects crops, outweighing most other stresses. The study reveals that it is easier for orchards in temperate regions to be affected by extreme temperature changes from the environment. The results match earlier findings that warmer conditions have a negative impact on plant metabolism and lead to reduced harvests (Loka & Oosterhuis, 2020). Rising minimum temperatures may help farming for some crops, but extra heat overall might not be good for other crop production (Abdi et al., 2024).

Tough weather such as heat and droughts worsen the situation and put farming and safe food supplies at greater risk (Siyal et al., 2021). Among the indirect ways heat stress can damage plants, one is shutting down enzymes essential in chloroplasts and mitochondria. Among the direct negative effects, heat stress tends to alter proteins, make them clump, and increase the fluidity of membranes (Nogales et

al., 2020). We should also note how a drought that happens earlier than usual can disturb the timing of spring events (Yuan et al., 2020). Such effects cause us major concern for orchards in temperate zones due to the close relationship between fruit growth and weather. Since high temperatures affect crops, it is very important to know how to address this effect (Parthasarathi et al., 2022).

Evidence from the research confirms that fruit set is reduced by extreme heat, which backs up the current expertise about the heat sensitivity of pollen viability and stigma receptacles (Burroughs et al., 2022). Most places where grapes are grown reach a maximum daytime air temperature above 42°C, and this triggers many changes in the plant's functioning (Liu et al., 2020). When it gets warmer, pollinators become less active and this makes orchard production drop even faster. In addition, the study suggests some ways to cope with different temperatures, such as selecting suitable varieties and adopting smart irrigation plans. Under the effects of heat stress, these systems have proven helpful in maximising water conservation and maintaining the proper moisture inside plants.

Growing plants that can withstand heat, for example, Y1, is a good way to improve the stability of your orchard during climate change. In places with rolling terrain and mild weather, cold temperatures can be harmful for maize; this leads to slower growth and may cause more time for the crop to mature, which could deter grain production (Waqas et al., 2021). Researchers are now using transcriptome analysis as a main technique to find out the molecular pathways of heat tolerance in several crops (Zhang et al., 2025). Future studies ought to look into the genes and body traits that grant heat tolerance to these plants, in addition to finding better ways to irrigate and use nutrients so that the orchards become stronger.

With a rise in temperature, the heat shock proteins serve to help limit the damage (Shaffique et al., 2022). Additional research has to take place before better solutions are found to adapt temperate orchards to future climate changes. The higher temperatures resulting from global warming cause unusual spikes in the weather that place extra stress on farming (Ma et al., 2021). It is important to select and breed plants that can withstand higher temperatures to reduce climate change's results on crops (Zha et al., 2020). Since global temperatures are rising, the paper suggests using different crop varieties and following sustainable methods to avoid harm to orchards (Wu et al., 2025; Yao et al., 2021). It is widely known that heat stress can affect the normal functions and growth of plants (Dastogeer et al., 2022). This shows that proper advance planning is needed to control the damaging effects of climate change on farming.

CONCLUSION

The study points out that excessively hot or cold conditions, driven by climate, play a big role in affecting how well temperate fruit orchards grow, produce fruit, and yield overall. The findings

revealed that, past 25°C, reduced viability of pollen, the stigma receptacle, and fruit set all took place during the important stages of flowering and early development of fruits. The experiments in the field point to the fact that stress caused by heat interferes with photosynthesis, causes carbohydrates to build up, and makes plants more open to pest and disease attacks, contributing to the problems fruit plants face. In the trial, Y1 was among those with improved heat tolerance and stable yields, so it could offer answers for future orchard schemes if the right cultivar tests are carried out. Even more crucial roles were professional irrigation and the work of pollinators: heat-stress caused few pollinators to visit the flowers, but the good irrigation supply increased both the fruit quantity and size. On the graph and in the table, it is clear that there are trends toward poor fruit yield, inferior quality, and pests appearing often due to climate changes. Applying methods such as using hardy crops, improving irrigation, applying reflective coverings, and keeping pollinators present is necessary because weather events are now much more unpredictable. It supports the claim that combining modern climate-smart agriculture methods, fitting regional circumstances, is necessary to guarantee both sustainability and food security as climate change increases quickly.

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