Impacts of Climate Change on Horticultural Fruit Crops: A Comprehensive Review of Physiological, Phenological, and Pest-related Responses.

Abstract:

This review paper comprehensively examines the multifaceted effects of climate change on horticultural fruit crops, delving into physiological, phenological, and pest-related responses. Climate change, characterized by shifts in temperature, precipitation patterns, and extreme events, presents profound challenges to fruit crop cultivation and production. By analyzing the interplay between climate variations and fruit crops' physiological processes, flowering patterns, and susceptibility to pests, this paper aims to provide a comprehensive understanding of the intricate mechanisms underlying these interactions. The study encompasses the influence of drought, rainfall, temperature fluctuations, and pest dynamics on various fruit crops, ranging from mangoes and apples to bananas, grapes, and more. The review underscores the urgency of developing adaptive strategies to mitigate the adverse impacts of climate change on fruit crop production and quality.

Keyword -Climate change, Temperature, Rainfall, Drought, Insects&Pest management.

Introduction

While many people often conflate climate and weather, they are distinct phenomena. Weather pertains to immediate atmospheric conditions, encompassing factors such as temperature, pressure, humidity, wind patterns, precipitation, and cloud cover, observed at a specific moment (Kumar, 2019)[25]. On the other hand, climate refers to the average, long-term patterns of weather over approximately 30 years and extends to alterations lasting decades or more, attributed to either natural forces or human activities – an occurrence termed as climate change (Solomon *et al.,* 2007)[40]. These changes encompass rising temperatures, shifts in rainfall patterns, rising sea levels, incursion of saltwater, and the occurrence of floods and droughts(Shetty *et al.,* 2013)[39].

Globally, these climate shifts adversely impact agriculture, with cascading effects on global food supply (Pathak *et al.*,2012)[30]. The agricultural sector, including both annual and perennial crops, faces substantial challenges due to climate change-induced variability. Horticultural crops, especially those reliant on rainfed areas, are particularly vulnerable due to erratic rainfall patterns (Venkateswarlu*et al.*,2012)[47].The terms climate change, global warming, and more recently, global cooling, have become integrated into our daily discourse.

Climate change has rapidly emerged and is accelerating at an alarming pace, presenting one of the most pressing challenges to the modern world. International collaboration to address this issue is exemplified by the Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. Earth's climate has historically shifted in response to alterations in the cryosphere, hydrosphere, biosphere, and other atmospheric and interconnected factors. It is now widely acknowledged that human activities significantly contribute to global climate shifts (Pachauri *et al.,* 2007)[28].

Throughout Earth's existence, its climate has undergone numerous transformations, ranging from ice ages to warm periods. Given its critical impact on human existence, agriculture was among the earliest sectors studied for potential climate change repercussions (Adams *et al.,* 1990)[1]. Various models and assessments have been developed, offering predictions. Increased emissions of greenhouse gases enhance the opacity of reflected infrared radiation in the atmosphere, ultimately leading to a rise in the surface-troposphere system's temperature. Atmospheric CO_2 concentration sharply escalated to 400 ppm in 2014, reaching a recent record of 415 ppm according to NASA, October 2020 data. As per studies by the Intergovernmental Panel on Climate Change (IPCC) [21] between 1906 and 2005, the global air temperature increased by 0.74°C. Predictions suggest a rise of 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. The most recent annual average anomaly (2019) was 0.99°C. Projections indicate potential global temperature increases of up to 6°C by 2100, coupled with potential CO_2 concentration increases of 550 to 850 ppm over the same period.Average global air temperatures could surge by 1.4°C to 6.4°C by the end of the current century. (Assad *et al.,*2004)[4] have forecasted that rising temperatures may lead to more frequent extreme droughts, floods, and heatwaves. Climate change's impacts on agriculture can be categorized into direct, indirect, and socio-economic effects (Kim, 2009)[24]. Under the A2scenario, temperature is projected to rise by 3.4°C, and CO_2 concentration to reach 1250 ppm by 2095, potentially accompanied by heightened climate variability and extreme weather events (Pachauri *et al.,* 2007)[28]. Emerging challenges, including global climatic changes, water and soil contamination, water scarcity, and urbanization, contribute to this complex scenario. Coupled with elevated temperatures, reduced precipitation could lead to diminished irrigation and increased evapotranspiration, potentially inducing water stress in numerous crops (Datta, 2013)[12].

Climate plays a pivotal role in the successful cultivation of fruit crops, as they respond to climatic variations by adjusting their phenological and physiological processes. These changes can result in reduced vigour, fruit yield, fruit size, juice content, color intensity, shelf life, and increased susceptibility to pests, ultimately impacting fruit production and quality. Abnormally high winter temperatures can disrupt flowering patterns, duration, and yield in pear trees due to inadequate chilling hours during winter months (Hazarika, 2013)[19]. Cultivation of horticultural crops significantly contributes to India's economy and the well-being of its rural population, generating income and employment opportunities. Developing horticultural varieties resilient to stress becomes a critical step in adapting to the present and future challenges (Datta, 2013)[12].

Effect of Climate Change on Fruit Crops

Climate change has led to significant shifts in horticultural practices, prompting a transition from high-chilling apple cultivars like Royal Delicious to low-chilling alternatives, along with other fruit crops such as peach, kiwi, plum, pear, and various vegetables. This trend is evident in the Shimla district's middle hills, where there is a notable move away from traditional potato and apple cultivation. The altered snowfall patterns in Himachal Pradesh have further underscored these changes, resulting in a decline in apple production from 10.8 to 5.8 tons per hectare. This decline exemplifies the tangible impact of climate change, as highlighted by (Awasthi*et al.,* 2001)[5].The ramifications of climate change are manifold, affecting the physiological, anatomical, morphological, and biochemical attributes of several horticultural fruit crops. Abiotic factors, including temperature fluctuations, drought, salinity, flooding, increased CO_2 concentration, and outbreaks of insect-pests, exert substantial influence on fruit production (Gora *et al.,*2019)[17]. Elevated temperatures, for instance, have dual consequences on crop yield they curtail vegetative growth and diminish fruit set. Fruit crops that are prone to excessive transpiration losses are especially vulnerable due to intensified transpiration under high temperatures. In the context of mango cultivation, a temperature rise of 0.7-1.0°C could significantly alter the regions suitable for premium-quality Dashehari and Alphonso mango varieties (Rajan 2008)[34]. A mere 1°C temperature increase drastically reduces the optimal zone for cultivating the Dashehari variety, and the Alphanso mango cultivar might be confined to the Ratnagiri area due to its suitability in the evolving climate (Dinesh *et al.,* 2012)[13].The shift in plant growth activity timing, or phenological changes, stands out as a well-documented consequence of climate change.

Fruit trees are experiencing modifications in their vegetative and reproductive stages due to changing climatic conditions. The flowering stage, critical for fruit development and subsequent productivity, is notably affected. In pome fruits, the primordial of flowers may partially or entirely abscise during milder winters, leading to the formation of smaller flower bud clusters resembling leafy spurs (Brown *et al.,* 1952)[9]. Consequently, climate-induced shifts in flowering, fruiting, and yield have become evident. The absence of early cold spells in December and January has adverse effects on the fulfilment of chilling requirements (Sharma *et al.,* 2012)[38].

Effect of high and lowTemperature on fruit crops

Warmer climatic conditions significantly impact various aspects of peach cultivars, including flowering, fruit set, yield, and quality. The absence of adequate chilling leads to irregular phonological patterns in peach trees, causing delayed and prolonged flowering periods. These patterns are closely linked to chill accumulation in stone fruit species (Alonso *et al.,*2005)[3]. Climate change renders fruit crops more vulnerable, especially due to prolonged flowering. Temperature variations alter crucial growth and development hormones in trees, exemplified by early blooming and harvest in mango and litchi. Mango's flowering behaviour, under evolving climate conditions, can vary from early to delayed onset. Factors such as low temperatures (11.5 °C), high humidity (>80%), and overcast weather can delay panicle emergence, while persistent low temperatures during panicle growth reduce hermaphrodite flowers (Chadha 2015,) [10]. Mango malformation, prevalent in colder winters, might benefit from warmer climates. Temperature also significantly influences the flowering of perennial fruit crops like mango. Elevated temperatures stimulate greater leaf production, impacting flowering phenology. Notably, late-emerging panicles exhibit higher percentages of hermaphrodite flowers, coinciding with extreme temperatures (Balogoun*et al.,* 2016)[7]. The marketing appeal of red-colored apple fruit is heavily influenced by temperature. Cross-sectional observations of fruit tissues reveal that anthocyanin pigments concentrate in upper layers of flesh and skin at lower temperatures. Cells treated at 20 and 25°C exhibit higher red color density than those at 30°C (Pan*et al.,*2007)[29]. Apple quality is compromised by sunburn and cracking due to excessive temperature and moisture stress (Rai *et al.*,2015)[33]. High temperatures trigger water core incidents in pears (Sakuma*et al.,* 1945)[37]. In bananas, a temperature of 31-32 ºC accelerates maturity, shortening bunch development (Turner *et al.,* 2007)[45], while temperatures over 38 ºC lead to bunch choking (Stover, 1972)[42]. In grapevines, anthocyanin development relies on day and night temperatures of 15-20 ºC, impacting colorformation. Selecting suitable regions and varieties becomes crucial to ensure high-quality fruit production. Prolonged extreme temperatures delay grape ripening and diminish fruit quality, influenced by variety temperature tolerance (Kadir, 2005)[23]. Elevated temperatures prompt flower drop and sex changes in papayas, with low temperatures causing normal flower drop (Reddy *et al.*, 2017)[36]. High temperatures coupled with increased CO_2lead to reduced strawberry yields of 12-35% at low and high nitrogen levels (Sun *et al.,* 2012)[43]. Pollination and fertilization thrive in optimum temperature ranges of 20° to 25°C for temperate fruits like plums, apples, cherries, and pears. Adverse conditions such as fog, rain, or low temperatures negatively impact sour cherry pollination in the USA (Haokip*et al.*,2020)[18]. Horticultural crops suffer return losses of 10-100%, contingent on crop and variety, due to severe cold spells (Hazarika, 2013)[19]. Low temperatures trigger flowering and bud dormancy break in mandarins, with deeper dormancy in potential flower buds and initial flower initiation preceding winter rest (Reddy *et al.*, 2017)[36]. In Navel oranges, low temperatures resulting in reduced total soluble solids (TSS) also affect acidity content (Peng *et al.*, 2000)[31]. Longan fruit experiences issues like fruit drop, reduced size, and cracking due to overwintering, with temperatures below 15°C during the young fruit phase diminishing growth potential and size. Cold or dry conditions at this stage contribute to extreme fruit cracking (Yang *et al.*, 2010)[49].

Effect of Drought on fruit crops

Abiotic and biotic stress factors in agriculture contribute to significant yield losses and are spreading more widely as a result of the effects of climate change (Stefanelli*et al.*, 2010)[41]. The most significant abiotic element is drought, which has an impact on plant development and growth (Ferrara *et al.*, 2011)[15] and lowers crop yield. In the coming years, problems with water shortages and declining irrigation water supplies may become more prevalent due to rising agricultural water needs, contamination of natural water resources, and climate change scenarios (Ferrara *et al.*, 2011)[15].Drought occurrences are frequent in arid and semi-arid climates characterized by uneven precipitation, leading to a lack of essential moisture (Kumar *et al.*, 2019)[26]. Water stress during phenological phases plays a critical role in yield response and holds significant importance in irrigation planning, especially in regions with limited water resources (Jones, 2004)[22]. Stress experienced before or during flowering, as well as in the post-blooming stages of perennial fruit plants, adversely impacts yields by reducing fruit numbers and diminishing cell development in the remaining fruit (Powell, 1974)[32]. Banana growth, yield, and productivity are severely affected by drought, leading to a decrease in photosynthetic capacity. During finger development, insufficient water availability results in shortened bunches (Surendar*et al.*,2013)[44]. In the context of African banana production, water deficit predominantly contributes to losses, notably by impeding nutrient uptake (Van *et al.*, 2011)[46]. Drought stress in banana plants reduces the number of fingers during floral initiation, and post-emergence, it hampers proper filling of the fruit (Holder *et al.*, 1983)[20]. Notably, moisture stress diminishes tomato fruit size and quantity, with increased occurrence of issues like blossom end rot and sunscald under severe stress conditions. Irrigation treatments significantly influence Total Soluble Solids (TSS) content, which rises with stress levels, while fruit water content decreases (Birhanu*et al.*,2010)[8]. In avocados, extended periods of water stress during flowering and fruit development result in both flower and fruit. Plants growing in sandy soils with limited water-holding capacity are more susceptible to drought stress compared to those thriving in clay soils. Leaves with high mass lose water more readily than roots can absorb, rendering plants with substantial leaf mass more prone to water stress. In early growth stages, newly established orchards are particularly vulnerable to drought stress due to underdeveloped root systems and rapid foliage growth (Kumar *et al.*, 2019)[26].

Effect of Rainfall on fruit crops

Climate change also contributes to significant changes in rainfall patterns, impacting various aspects of agriculture. Irregular precipitation or the absence of rainfall can lead to decreased crop yields, particularly in rainfed regions. Excessive rainfall in poorly drained areas reduces soil oxygen availability, hampering the growth of beneficial microorganisms. Consequently, waterlogged conditions foster the emergence of insect pests and diseases, negatively affecting crop productivity. Alterations in precipitation patterns may also have adverse effects on the appearance and quality of mature mango fruits. Rainfall during flowering stages can disrupt fruit set, growth, and overall yield. In specific locales, prolonged heavy precipitation results in excessive vegetative growth and flower loss. Unexpected rains can lead to increased pest activity, resulting in subpar fruit yield (Makhmale*et al.*, 2016)[27]. In regions with high rainfall, mango fruits during maturation are susceptible to diseases like anthracnose. Rainfall during flowering can wash away pollen from the flower stigma, leading to poor or no fruit setting. Gujarat reported a substantial 80-90% loss in mango production due to untimely rain followed by heavy dew, causing reduced fruit setting, increased fruit drop, and heightened occurrences of sooty mold and powdery mildew (Rajatiya*et al.*, 2018)[35]. Furthermore, an essential consideration for fruit species growth is the inadequate availability of oxygen due to excess water. The conventional precipitation cycle has been disrupted by climate change, impacting arable land flooding and agricultural crop production. This disruption in water supply can result in yield losses ranging from 10% to 40% due to extended water stress cycles. Prolonged waterlogging periods, exceeding two days, have been shown to decrease leaf area in Cape gooseberry. After exposure for four days, the stem diameter is reduced, leading to diminished bud initiation, fruits, and flowers under extreme stress conditions (Aldana*et al.,* 2014)[2].

Effect of incest and pest on fruit crops due to climate change

Insects, as cold-blooded organisms, closely align their body temperature with that of their surrounding environment. This makes temperature a paramount environmental factor significantly shaping insect behaviour, distribution, development, survival, and reproduction. To project insect life stages, researchers often rely on accumulated degree days, which stem from a base temperature and a bio fix point. Notably, certain experts argue that the impact of temperature on insects tends to overshadow the influence of other environmental variables (Bale *et al.*, 2002)[6].Predictive models suggest that even a moderate temperature increase of 2°C could propel insects to undergo an additional one to five life cycles within a single season (Yamamura *et al.*,1998)[48]. While specific climate change effects may occasionally exert downward pressure on insect populations, a prevailing consensus exists among researchers that elevated temperatures in temperate climates will likely foster a broader array of insect species and drive up their population levels.Studies have demonstrated that rising temperatures have the capacity to influence various aspects of insect life, including survival rates, developmental patterns, geographical distribution, and overall population sizes. The impact of temperature on insects can manifest both as a direct influence on their physiology and development, as well as an indirect influence through interactions with their hosts. The effects of temperature on insects can differ based on the species' specific developmental "approach," leading to a range of outcomes (Bale *et al.*2002)[6].The dynamics of climate change possess the capability to modify the progression and tempo of pathogen developmental stages. Concurrently, they can influence the resistance exhibited by hosts, as well as the intricate physiological interplay within host-pathogen interactions (Coakley*et al.,* 1999). Notably, the repercussions of warming tend to be more detrimental for insects situated in tropical regions, aligning with their physiological optima, in contrast to insects inhabiting higher latitudes (Ghini*et al.,* 2011)[16].In the context of tropical regions, a potential consequence of climate-induced shifts is the reduction in the population of specific vector insects. This, in turn, could yield a reduction in the prevalence of distinct viruses, such as those responsible for citrus leprosy (transmitted by mealy bugs), papaya ring spot (propagated by aphids), and pineapple wilt (also carried by mealy bugs), among others (Feichtenberger*et al.*, 2005)[14].The development of fruit flies displays a noticeable escalation as temperatures elevate within the range of 20 to 35°C in mangoes of the*Chausa* variety. Anticipated shifts in future climatic conditions have the potential to exert an impact on the prevalence of codling moths in apple orchards, as well as the duration of critical life stages pivotal for effective pest management.

Conclusion

In conclusion, it is essential to distinguish between climate and weather, as they represent distinct phenomena. Weather pertains to immediate atmospheric conditions, while climate encompasses long-term patterns over approximately three decades or more. Climate change, driven by natural forces and human activities, brings about shifts such as rising temperatures, altered rainfall patterns, and rising sea levels. These changes have profound consequences for agriculture, with horticultural crops, especially those relying on rainfed areas, being particularly vulnerable.The Intergovernmental Panel on Climate Change (IPCC)[21] emphasizes the urgent need for international collaboration to address climate change, which is rapidly accelerating and poses a significant challenge to our modern world. Human activities have contributed significantly to global climate shifts, impacting various sectors, including agriculture.Fruit crops, vital to the economy and well-being, are susceptible to the effects of climate change. Elevated temperatures, altered precipitation patterns, and increased pest activity disrupt the delicate balance of fruit development. Warmer climates affect flowering, fruit set, yield, and quality. Drought stress during critical growth phases and irregular rainfall patterns further compromise fruit production.

Insect populations, influenced by temperature changes, demonstrate varied responses, potentially leading to shifts in vector-borne diseases. While some insects may experience enhanced life cycles due to rising temperatures, the complex interplay of temperature and other environmental factors shapes their behavior and distribution.To mitigate the impacts of climate change on fruit crops, adaptation strategies must be employed. Developing resilient horticultural varieties and implementing sustainable irrigation practices become imperative. Understanding the intricate interactions between climate, pests, and plant physiology is crucial for safeguarding fruit production and quality.In essence, the intricate relationship between climate change and fruit crops underscores the need for proactive measures to ensure the viability and sustainability of horticultural practices in the face of a changing climate.

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