Chapter 12
Impact of Climate Change on Horticulture Crops and Potential Mitigation Strategies

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Abstract: Global weather patterns have been altered by the complex and diverse process of climate change for several decades or longer. A number of changes, including as increasing temperatures, altered rainfall patterns, and an increase in the frequency of extreme weather events, are its defining characteristics. Crop output is greatly impacted by climate change, and the effects can be either beneficial or negative based on a number of variables, including the crop type, agroecological location, and season. For example, greater temperatures and more rainfall in some areas may result in better crop yields. On the other hand, altered weather patterns in other areas can lead to crop failures, lower yields, and heightened susceptibility to pests and illness. Due to climate change, horticulture crop growth is anticipated to be significantly impacted. The available statistics and information point to increased water demand, biotic and abiotic stressors, and changed rainfall patterns as factors that would affect these crops' productivity. While increased CO2 can hasten photosynthesis and increased temperature can hasten ripening, it is important to take steps to lessen the negative consequences of climate change on sustainable production. Overall, to maintain sustainable horticulture crop production, action must be taken to positively adapt to the changes brought about by climate change.

Keywords: Climate Change; Horticulture Crops; Mitigation Strategies

1. Introduction

The term climate t refers to the general weather conditions that prevail in a specific geographical region over an

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extended period. It encompasses the overall pattern of temperature, rainfall, humidity, wind speed, and other atmospheric factors that determine the prevailing weather conditions of a particular area, which can affect its ecosystems, agriculture, and human settlements. It is essential to understand the climate of a region for sectors like agriculture, tourism, transportation, and energy. This helps in decision-making and planning to reduce potential climate change risks and impacts. Climate change, on the other hand, is the shift in these weather patterns that occur over a prolonged period and across different regions. Unquestionably, the continuous alteration of earth's climate resulting from human-induced activities, including burning fossil fuels, manufacturing processes, and transportation-related emissions, leads to significant changes in the global climate (Delfine et al., 1998, Coakley et al., 1999, Pielke, 2004, Pandey et al., 2018,)

Since the late 19th century, the planet has been experiencing a gradual but concerning phenomenon of rising temperatures. Researchers have found that the average global temperature has increased by about 0.08°C. The rate of warming has significantly accelerated since 1981, with an increase of 0.18°C per decade. This gradual increase in temperature has been linked to various environmental changes and challenges, with potentially far-reaching consequences for the planet's ecosystems, weather patterns, and human societies. The level ofcarbon dioxide in the atmosphere on earth has steadily risen in the recent past. In 1958, the level of carbon dioxide present in the atmosphere wasat 315 parts per million (ppm). However, this concentration had increased significantly to 425 ppm by the year 2023, at the rate of 2 ppm per year. Certain anthropogenic activities such as fossil fuel combustion, industrial processes, and deforestation have substantially contributed to the rise of atmospheric carbon dioxide levels. This phenomenon has led to

detrimental environmental impacts and escalating temperatures (Verchot et al., 2007).

The Intergovernmental Panel on Climate Change (IPCC) has reported that the impact of human-induced climate change on the environment is alarming and dangerous, causing significant disruptions in nature. It is becoming increasingly concerning to note that climate change poses a significant threat to horticulture, a vital agricultural component.

Horticulture, which is the science and art of cultivating fruits, vegetables, flowers, and ornamental plants, is highly dependent on weather conditions, and any significant change in climate patterns can harm the entire horticulture industry. Droughts, floods, heat waves, and storms are a few weather-related phenomena that have become more frequent and intense in recent years, causing considerable damage to horticulturists. As a result, it is crucial to develop and implement sustainable and adaptive measures to mitigate the effects of climate change onhorticulture and ensure the continued production of high-quality and nutritious fruits and vegetables for future generations.

The impact of climate change, particularly abiotic stressors like erratic rainfall and increased temperatures, significantly affects horticultural productivity. Climate change has resulted in various effects on horticulture crops, including sunburn and cracking in apples due to high temperature and moisture stress, the elevation of shoot length of grapevine due to the increased CO_2 concentration, and fruit ripening in tomatoes affected by the rise in temperature. This chapter will explore how climate change affects horticulture and propose sustainable ways to address this challenge.

2. CLIMATE CHANGE AND HORTICULTURE

Climate change is a complex and multifaceted phenomenon altering global weather patterns for several decades or more. It is characterized by various changes, including rising temperatures, changing rainfall patterns, and more frequent extreme weather events. Climate change significantly impacts crop production, which can be positive or negative depending on various factors, such as the crop type, agroecological region, and season. For instance, increased rainfall and warmer temperatures may lead to higher crop yields in some regions. In contrast, changing weather patterns in other regions may result in crop failures, reduced yields, and increased vulnerability to pests and disease.

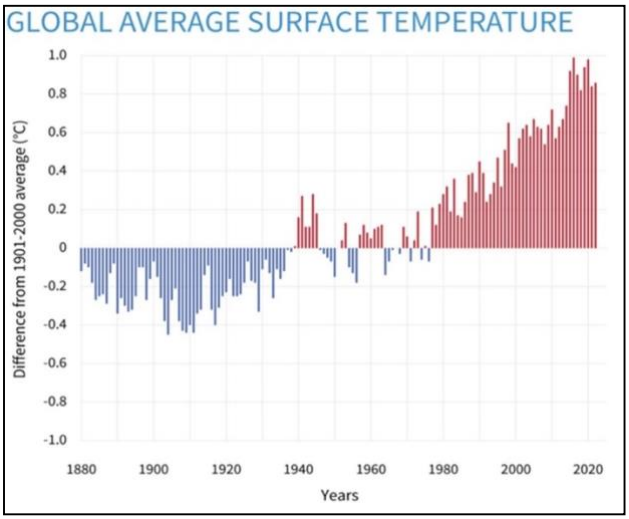

Figure 1. Comparison of surface temperatures to the 20th-century average from 1880 to 2022. Blue bars indicate cooler years and red bars indicate warmer years. Data sourced from NOAA Climate.gov.

The degree to which climate change affects horticulture production within an agroecological region is determined by the interaction between elevated CO_2 and warming. However, climate change's implications for agriculture, particularly horticulture, are primarily related to unpredictable rainfall patterns and high-temperature spells. These factors can significantly decrease crop productivity, affecting the overall food supply and increasing prices. Climate changes can result in various ecological and agro-economic shifts, significantly impacting agriculture and food security. These could involve shifts in latitude and altitude, severe geophysical occurrences, land deterioration, reduced accessibility to water, rising sea levels, and salinization of the soil and water. The Food and Agriculture Organization (FAO) has also highlighted the potential risks associated with these changes, as identified in a 2004 report.

- According to a recent study carried out by the Indian Institute of Spices Research in Calicut, the current areas that are suitable for cultivating spices may not remain viable in the next 25 years. The study used advanced GIS models to predict the changes in climatic conditions that could impact the growth of spices. It was found that several regions that are currently optimal for spice production may become less conducive to cultivation due to changes in temperature, rainfall patterns, and other environmental factors. On the other hand, there will be new regions that are currently unsuitable for spice cultivation but will become highly suitable. This trend is not just limited to spices but can also be applied to other horticultural crops.
- Higher temperatures caused by climate change can adversely affect various crops. For example, potatoes may experience a reduction in the tuber initiation process, while tomatoes may suffer from reduced quality and pollination. Crucifers may

experience bolting, while apples and capsicum may be affected in terms of anthocyanin production. Additionally, rising temperatures can cause blossom end rot and tip burn in tomatoes. Higher temperatures will cause a shift in agricultural production duration, resulting in a faster maturity period for photosensitive crops. The annual irrigation requirement will also increase, and the heat unit requirement will be achieved in a shorter time.

- Temperate crops will be impacted by a decrease in the winter regime and chilling duration in temperate locations. It is predicted that these changes will worsen environmental problems and undermine sustainable development, underscoring the pressing need to take immediate action to mitigate the consequences of climate change.

3. THE HORTICULTURE SECTOR OF INDIA

Over the past few years, the horticulture sector in India has been experiencing a phenomenal growth rate, surpassing the agricultural industry in terms of productivity and profitability. One of the primary reasons for India's advantage in horticulture is its favorable agro-climatic conditions, which make it possible for the country to produce fruits and vegetables at a lower cost. India is the second-largest fruit and vegetable producer in the world, according to the Agricultural and Processed Food Products Export Development Authority (APEDA). The horticulture sector in India has been strengthened by a low cost of inputs and a sufficient labor force.

The sector primarily produces fruits and vegetables, accounting for about 90% of the nation's horticultural output. This industry has significantly boosted India's economy by creating job opportunities for millions of people, especially in rural areas. The Indian government has also taken various initiatives and implemented policies

to promote and supportthe growth of the horticulture sector, such as the National Horticulture Mission (NHM) and theMission for Integrated Development of Horticulture (MIDH). These initiatives have helped farmers improve their farming practices, enhance productivity, and generate higher income.

Horticulture has emerged as a crucial contributor to India's agricultural growth, accounting for 30.4% of the country's Gross Domestic Product (GDP). Remarkably, this sector only utilizes 13.1% of the total cultivated area, making it highly efficient. The horticulture industry has recorded a significant increase in growth in recent years, outpacing food grain production and highlighting its immense potential.

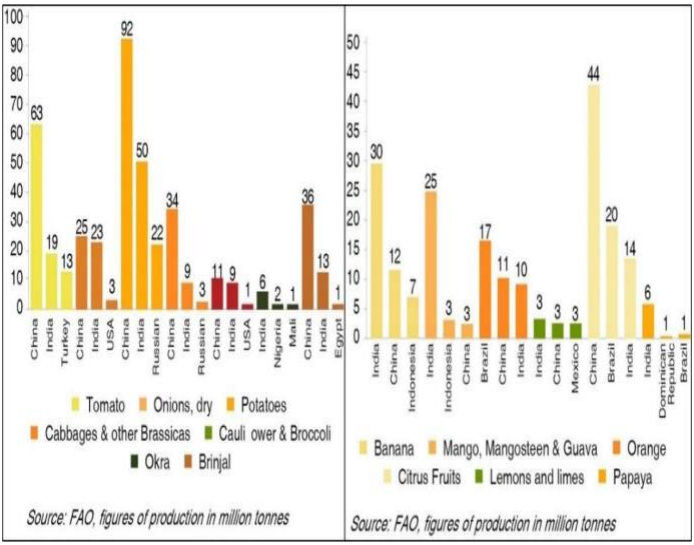

Figure 2. Top producers of vegetables (left) and top producers of fruits (right) globally

The agricultural industry provides most of the nation's food needs and creates employment opportunities in rural areas. Farmers can increase their earnings by diversifying their operations. It is worth noting that the productivity of horticulture has increased substantially since 2001-02, between 8.8 and 12.1 t/ha (TPH) in 2020–21. This increase in productivity has led to a high rise in production and land availability, surpassing the growth rate of food grains since 2012-13 (Padmanand et al., 2023).

The growth of the horticulture sector has also been facilitated by the adoption of modern techniques and advanced technologies, which have enhanced the quality and yield of horticulture crops. Overall, the horticulture industry has proved to be a game-changer for India's agricultural sector, contributing to its economic growth and development.

During the financial year 2021-22, the country's horticulture sector witnessed significant growth, with the total production estimated at approximately 341.63 million tonnes. The production of various fruits and vegetables contributed significantly to this achievement, with a major share in the overall horticulture output. Specifically, fruit production stood at 107.10 million tonnes, while vegetables were estimated at 204.61 million tonnes.

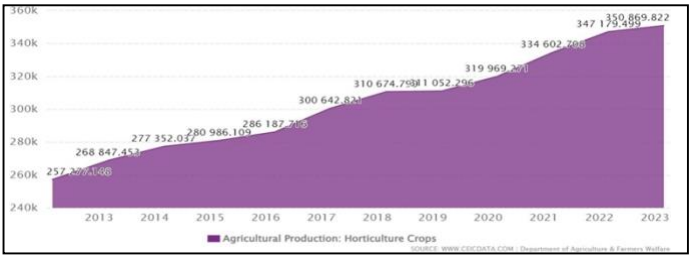

Figure 3. India's production of horticulture crops from the year 2013 to 2023

Exporting fresh fruits and vegetables from India has significantly contributed to the country's overall export industry. As per the Agricultural and Processed Food Products Export Development Authority (APEDA), India recorded INR 11,412.50 crore worth of fresh produce exports during the financial year 2021-22, indicating a significant surge in demand for Indian fresh produce in international markets. Some of the top export markets for Indian fresh produce include Bangladesh, the United Arab Emirates, Nepal, the Netherlands, Malaysia, Sri Lanka, the United Kingdom, Oman, and Qatar, which serves as a testament to the increasing demand for high-quality and fresh Indian produce across different parts of the world, offering several export opportunities for India's horticulture industry.

4. Effect of Climate Change on Crop Production

4.1 Climate Change Effects on Vegetables: Vegetable crops are highly susceptible to harsh environmental conditions, such as extreme temperature fluctuations and insufficient soil moisture, which can significantly impact their physiological and biochemical processes, resulting in low yields. These processes affect photosynthesis, metabolism, and enzymatic activity, reducing activity levels. Tissue damage caused by thermal stress is also a common occurrence. The ability of plants to reproduce is negatively impacted, as pollination and fruit set are reduced. Unfortunately, the changing climate has severely affected vegetable production, causing crop failures, reduced yields, poor quality, and increased pest and disease problems, making vegetable cultivation an unprofitable and unsustainable practice and raising concerns about the availability of nutrient sources in the human diet.

Not only rainfed vegetable cultivation but also water storage and irrigation availability are directly

impacted by climate change. Since water availability is limited, drought becomes a significant stressor for vegetable production, further stressing farming systems. Additionally, climate change can alter host physiology and resistance, as well as the pathogen's stages and development rates, affecting the overall quality of the crops and decreasing yields.

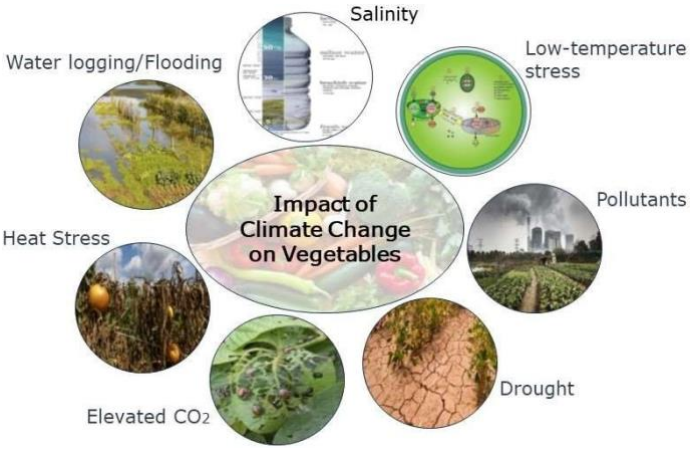

Figure 4. Climate change on vegetables

Vegetable crops with shallow roots are highly susceptible to damage caused by flooding, which is a significant threat. The main reason for this is that the excess water in the soil makes it difficult for the roots to access the required oxygen for survival due to air displacement in the soil, oxygen depletion, and root death. Consequently, plants may face difficulties absorbing nutrients and water, leading to stunted growth and increased vulnerability to soil-borne pathogen infections. These infections can have serious repercussions, such as

reduced crop yield and quality, adversely affecting farmers' livelihoods and consumers' access to fresh produce. It is important to take preventive efforts and guarantee adequate drainage to avoid flooding, which can be risky for crops with shallow roots. This may involve implementing techniques like constructing raised beds, setting up drainage systems, and selecting crops that are less susceptible to flooding. By following these methods, farmers can guarantee the health and productivity of their crops, even when faced with unfavorable weather conditions or other environmental obstacles (Baskaran et al. 2022). Moreover, the effects of flooding become more severe as temperatures increase. For example, Tomato plants have been observed to wilt and die quickly when exposed to high temperatures following a short period of flooding (Kramer et al. 1951). In the case of pea plants, the flooding for a few days leads to an increase in the ABA level (abscisic acid) in the roots, which results in ABA accumulation in the leaves and the partial closure of the stomata (Zhang and Davies, 1987).

The Consultative Group on International Agricultural Research (CGIAR) explained, the world's food security has been significantly impacted by unpredictable drought, with past famines attributed to it (Pingali and Kelley, 2007). This phenomenon is particularly relevant in vegetable production, given that over 90% of their makeup comprises water, making it a crucial factor in their productivity. Drought can impact the quality and yield of vegetables by increasing the solute concentration in the soil, causing water to flow out of the plant cells through osmosis. Thus, this can reduce the plant's water potential, damaging the membrane andaffecting photosynthesis.

Understanding the impact of drought on crops is crucial, as it can differ depending on the drought's timing, intensity, and duration. If crops are subjected to high levels of water stress, it may significantly reduce chlorophyll

range, electrolyte leakage, leaf-relative moisture content, and vegetative development. In the end, this can lead to reduced yields and lower-quality fruit. Drought, for example, can affect potato tuber sprouting and the germination of seeds in vegetable crops like onion and okra (Arora et al., 1987). Increased soil salinity poses a threat to vegetable production as well, particularly in irrigated agriculture. Due to increased evapotranspiration under hot and dry conditions, soil loses a significant quantity of water, which leaves salt around plant roots and eventually reduces the plant's ability to absorb water. Because of the high concentration of solutes in the soil, salinity initially leads to a water deficit in plants, which causes stress specific to particular ions and alters the K^+/Na^+ ratio. This condition also leads to a harmful accumulation of Na^+ and Cl^- concentrations, negatively impacting plant growth. Plants may exhibit a variety of distress signals when exposed to extreme salt concentrations. These include wilting, reduced growth, curled leaves, leaf loss, damaged tissue, and impaired seed growth. Salt stress can also lead to decreased photosynthesis, changes in respiration, reduced nodule formation, and decreased crop yield. If the exposure is severe, the plant's health can deteriorate to the point of death (Prasad et al., 2015, Yamaguchi and Blumwald, 2005).

4.2 Climate Change Effects on Fruits

Climate change significantly impacts plants, particularly regarding high-temperature spells and erratic rainfall patterns. This causes decreased fruit set and increased fruit breaking in pomegranate and litchi, directly impacting agricultural yield (Blanke, and Kunz 2009). Temperature rise due to climate change can also affect photosynthesis, leading to changes in organic acids, sugars, flavonoid contents, antioxidant activity, and firmness of crops. Additionally, the persistent increase in atmospheric carbon dioxide levels can adversely affect the

post-harvest quality of crops, reducing potato sugar content and increasing the incidence of common scab tuber malformation. Some countries are experiencing challenges with banana cultivation due to rising air temperatures and changing rainfall patterns. Low temperatures during the flowering stage cancause flowers to fall from mango, guava, litchi, and other fruit trees. Pollinators such as bees, moths, and butterflies are negatively affected by climate change, leading to a decline in their populations, geographic ranges, and pollination activities. Higher temperatures can cause various physiological disorders during fruit growth and development, such as black tips and spongy tissue in mangoes, fruit cracking, and citrus granulation.

Climate change profoundly affects the timing of different physiological activities, known as phenology. In particular, the induction of flowers in temperate fruits is significantly influenced by temperature, especially low temperatures. However, flowering in plants results from variouscomplex and intricate factors that interact with each other in a highly regulated manner. One ofthe most critical factors determining the timing and duration of flowering is the plant's genetic makeup. Other factors, such as the temperature, humidity, and availability of nutrients, also play a crucial role in regulating the flowering process. Additionally, the duration of light exposure, also known as photoperiod, is a critical factor that triggers the onset of flowering in many plant species. The interplay between these and several other factors determines the flowering process's timing, duration, and quality. In the Western Himalayan region of India, the production of apples is subject to severe negative impacts due to changes in the climate. The increase in temperatures during winter and spring, particularly from January to March, can cause apple trees to flower earlier, which coincides with spring frost. As a result, the risk of frost damage to apple flowers increases, ultimately decreasing the quality of the fruit (Vedwan and Rhoades 2001).

Table 1. Examples of harmful effects of climate change on vegetables

Source	Negative impact	Affected crop	References
Heat stress	Reduction in the number offruit sets, resulting in lower quality fruits.	tomato	Peet et al., 1992
Low temperature	Pitting, water-soaked lesions, decay	Cucumber	Baysal et al., 2004
Low temperature	Increased stomatal density	pea	Maksimovic et al., 2008
Frost	Blistered appearance, jagged lengthwise cracks	carrot	Caplan et al., 1998
Warm and dry periods	Bolting	Lettuce	Eriksen et al., 2016
Low temperature	Growth reduction	Muskmelon, watermelon	Risse et al., 1978, Bradow, 1990, Hassell, 1979
Flooding	Rotting	sweet potato	Thompson et al. 1992
Flooding	Inadequate growth, leaf browning, blackened root tips,and swelling at the shoot-root junction.	Pepper	Shahida and Sheik, 1976
water stress	reductions in tuber yield	Potato	Jefferies and Mackerron,1993
elevated CO_2 concentrations	Reduction in taste, color, andsize	Cabbage, potato, tomato	Behboudian and Tod, 1995, Vorne et al., 2002, Kim et al., 2010
Salinity	The leaves epidermis and mesophyll cells undergo thickening, resulting in anatomical modifications.	bean	Longstreth and Nobel, 1979

Bloom is one of the primary reasons for weather-related crop damage, mainly due to frost. Even a slight frost can cause a significant deterioration in fruit quality,

while severe frost can pose a severe threat to the entire harvest. The commercial cultivation of various fruit and nut trees depends on each tree cultivar's specific winter chilling requirement. Rising temperatures can impact the over-winter freezing requirements of temperate tree fruits, which may require replacing old cultivars or species with new ones better suited to changing conditions. This process can lead to variations in crop size and maturity stages at harvest, significantly decreasing yield and fruit quality.

Table 2. Examples of negative impacts of climate change on Fruits

Source	**Negative impact**	**Affected crop**	**References**
Heat	Dry, green, and brown discoloration on the skin	Muskmelon	Kader et al., 1974
Heat stress	Skin discoloration and pigment breakdown	Apple	Moretti et al., 2010
Heat	Skin and flesh browning; increased susceptibility to decay	Avocado	Moretti et al., 2010
Frost	Damage to flowers and fruits canresult in a loss of yield.	Cherry, apricot, apple	Kunz and Blanke, 2014
Lack ofchilling	Delayed flowering increases therisk of frost	Apple	Kaufmann et al., 2016
High temperature	fruit cracking, black spots, flowerand fruit abscission, etc.	custard apple	Katrodia and Sheth,1985
High temperature	Development of spongy tissue.	Mango	Katrodia and Sheth,1985
Water stress	Closure of stomata leads to lowerCO_2 assimilation, increased photorespiration, flower and fruit drop, and chlorophyll damage.	Citrus fruits	Luro et al., 2020
Elevated temperature	Extended and delayed flowering stages can negatively affect thequality of fruits.	Apple	El Yaacoubi et al., 2020

The decline of pollinating insects worldwide negatively impacts fruit production due to the harsh weather conditions and rising temperatures caused by

climate change, which hinder fertilization and lead to decreased fruit yield. Cross-pollinated fruits, such as walnuts and pistachios, are particularly vulnerable to reduced pollination rates due to excessive chilling, leading to lower crop yields. Meanwhile, temperate fruits like apples, pears, plums, and cherries require ideal temperatures between 20-25°C for successful pollination and fertilization.

In addition to the impact on fruit production, climate change is causing significant changes in plant pathogens' life cycles and behaviors. This leads to alterations in the resistance and physiology of host-pathogen interactions and shifts in the geographic distribution of pests. These changes are expected to have negative consequences, such as changes in population growth rates, an increase in overwintering, more frequent generations, longer developmental seasons, shifts in the timing of pest and crop growth stages, altered interactions between different insect species, and an elevated risk of invasion by migrant pests (Parmesan et al., 2007).

4.3 Climate Change Effects on Flowers

Our ecology depends heavily on flowering plants; thus, it's necessary to understand how temperature variations impact their natural activities. High temperatures can harm the production of flowers, nectar, and pollen, ultimately influencing the pollination process and the plant's overall health. This, in turn, can affect insect pollinators, which are crucial for the survival of many plant species. It is worth noting that while increased temperatures may have direct positive effects on some plants and insects, their physiological responses could result in conflicting effects on their interactions. By understanding these responses and their implications for plant-pollinator interactions, we can take the necessary steps to ensure our natural environment's long-term health and viability.

Plants have a unique biological process called vernalization that plays a vital role in their flowering during winter. The temperature significantly influences this process, and prolonged chilling periods at low temperatures can accelerate it. In-depth research conducted by (Blázquez et al., 2003) and (Capovilla et al., 2015) has shown that vernalization has a profound impact on various plant species, including wheat (Evans et al., 1981), and tulips (Rietveld et al., 2000). However, it is crucial to note that the temperature and duration required for vernalization vary significantly from one plant species to another, as evidenced by the latest findings (Marlin et al., 2021).

4.4 Climate Change Effects on Spice Crops

The effects of climate change on crops, especially spices, are a matter of great concern and a focus of intense study. Food crops are essential for human sustenance and nutritional security. However, spices are also gaining attention due to their potential to provide additional benefits such as nutraceuticals, phytochemicals, antioxidants, and more. However, Understanding climate change's complex and multidimensional consequences on spice crops necessitates a thorough analysis of the interactions between numerous factors.

Spice crop distribution and production are significantly influenced by climate and weather. The climate influences the habitat of particular spices, which are influenced by their genotype and phenotype. For example, temperature and rainfall have major effects on black pepper growth, whereas temperature, humidity, and soil moisture have a more substantial impact on cardamom cultivation. Similarly, the phenology of many spices differs from one spice to another and depends on the weather. This includes flushing, blooming, fruit development, and harvest time.

Table 3. Physiological and metabolic responses of flowers when exposed to abiotic stresses

Species	**Stress during flowering**	**Functional response**	**Metabolic response**
Arabidopsis thaliana	Heat (37°C, 3 h)	different genotypes may exhibit different characteristics or traits	Unfolded protein response
Gossypium hirsutum	Heat (>39°C: >31°C, day: night)	Anther abortion	Modifications to the epigenome, disturbances in the metabolism of carbohydrates, and triggering of hormonal signaling pathways.
Oryza sativa	*Drought (25% soil water content)*	*The growth of anthers and pollen can exhibit deviant patterns, leading to anomalous development.*	Downregulation of carbohydrate metabolic genes, resulting in aberrant carbohydrate metabolism.
Petunia axillaris	*Heat (≤35°C)*	*Reduction in flower weight and petal size.*	When temperatures rise, the amount of volatile organic compound (VOC) emissions increases, even when the overall internal pool of VOCs decreases.
Solanum lycopersicum	*Heat (38°C/2h)*	*The viability and germination of pollens have decreased.*	Flavonoids can build up in microspores.
Triticum vulgare	*Drought (39–48% leaf relative water content)*	*The number and weight of grains have been decreased*	Reproductive organs of susceptible genotypes showcase variations in the expression of carbohydrate metabolic genes and differences in sugar and starch content.
Ipomopsis aggregata	*Drought*	*Lower production of pollen and nectar.*	The nectar contains a reduced amount of sucrose.

Source: Borghi et al., 2019

Moreover, climate change can exacerbate spice growers' challenges, such as pests and diseases. For instance, the incidence of pests like the coffee berry borer

and the spice mite is on the rise due to changes in temperature and rainfall patterns. Similarly, warmer and wetter climate conditions contribute to spreading diseases like Fusarium wilt in ginger and turmeric.

According to recent research by the Indian Institute of Spices Research (IISR) using GIS models, several places that are currently effective in cultivating spices would no longer be viable in 25 years. This necessitates the exploration of new areas that are more suitable for spice cultivation. Commonly used spice black pepper needs high rainfall, tropical temperatures, and high relative humidity year-round, with minor variations in day length. It grows best in humid tropical conditions. Excessive heat and dryness are not well-tolerated by this spice. The amount and distribution of rainfall significantly impact crop cultivation and yield; black peppercultivation thrives with an annual rainfall of 2000 mm with a uniform distribution. However, it has been observed that increased rainfall can decrease productivity in the case of black pepper (Das et al., 2018).

The temperature range is a crucial factor that significantly influences crops such as black pepper, cocoa, tea, and cardamom growth and development. These crops are primarily grown in high-altitude regions, where temperature variations can significantly impact their growth. Astudy on high-temperature stress has suggested that it adversely affects fertilization, leading tolow fruit sets and poor crop yield during the post-pollination phase (Erickson and Markhart, 2002). The ideal mean annual temperature range for cardamom is between 18 and 23°C. Cardamom capsules may grow and ripen more quickly at temperatures over 25°C, which can result in premature development. However, leaves and young tillers may completely wilt after extended exposure to high daily temperatures of up to 32°C, resulting in stunted growth and alow yield.

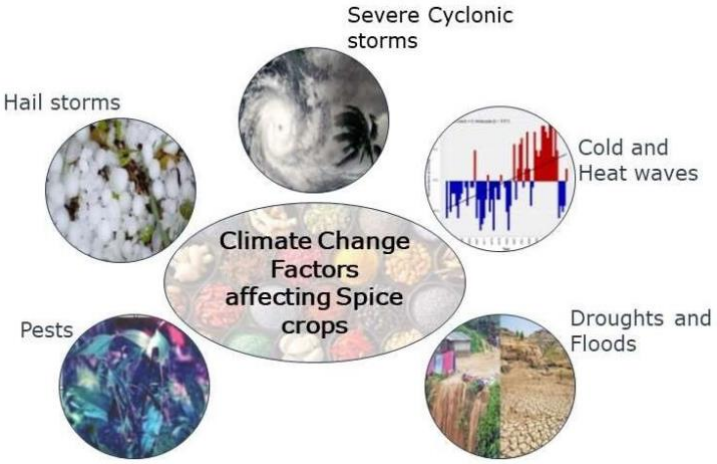

Figure 5. Climate change affecting spice crops

Furthermore, the temperature range also affects the quality and taste of these crops. For instance, if the temperature drops below the optimal range during the growth phase, it can reduce the crop's quality and flavor. Similarly, high temperatures can cause a bitter taste or loss of aroma in some crops. It is essential to maintain the optimal temperature range to ensure the growth and development of crops and to yield good quality produce. Farmers can use various methods such as shade nets, mulching, and irrigation systems to regulate temperature and ensure optimal growth. Furthermore, the combination of high temperatures in the air and soil can have a more severe impact on cardamom, reducing yield and increasing the prevalence of pests, omainly root grubs, nematodes, and whiteflies (Murugan et al., 2022). As for nutmeg trees, heavy rainfall and strong winds can significantly affect those with shallow roots, causing them to be easily uprooted, while their roots can rot due to excessive rainfall. Notably, the growth of cardamom plants is severely

restricted in regions with scarce water resources, making it challenging to cultivate them in such areas.

Table 4. Diseases of spice crops caused by extreme changes in the climatic factors

Climatic Factor	**Spice crop**	**Disease**	**Causal organism**	**Symptoms**
Heavy rainfall	Black Pepper	Quickwilt or Footrot	*Phytophthora capsici*	Phytophthora spores tend todevelop in the collar region of roots and stems.
Heavy and continuous rainfall	Clove	Twig blight	*Gloeosporium gleosporioides*	Brownish dead patches of different dimensions and configurations can be observedon the foliage. Leaves that are severely impacted become limp, sag, and ultimately desiccate.
Heavyrainfall	Fenugreek	Powdery mildew	*Erisiphy polygoni*	Gradually expanding white powdery spots develop on leaves,with visible yellow spots on the underside.
High temperature	Nutmeg	Black scale	*Saiseetia nigra*	The scales cluster together, black, oval, and dome-shaped.

Source: Das et al., 2018

3. Status of Indian Horticulture

While having great potential, the horticulture industry faces many challenges that limit its growth and profitability. One of the most significant challenges is the limited availability of operational landholdings, which restricts the amount of land available for cultivation. This limitation directly affects the number of horticultural crops produced annually, leading to decreased yields and lower farmer profitability.

Another challenge is inadequate irrigation, often caused by the need for more access to water resources in certain regions. This can lead to crop failure, reduced yields, and, ultimately, lowerprofits for farmers. Moreover, poor soil management practices pose a significant challenge forthe industry. Small landholdings make it challenging to rotate crops frequently, leading to soil depletion and reduced fertility over time. Due to limited space, implementing sustainable agricultural practices such as crop rotation, intercropping, and proper soil management can bedifficult for small farmers.

The horticultural sector is currently facing a daunting challenge posed by climate change. Theshifting weather conditions, floods, droughts, and other natural catastrophes have wreaked havoc on crop yields, resulting in significant losses for farmers. However, some solutions canease the effects of climate change. Farmers can adopt innovative techniques and technologies that can enable them to increase their output and profitability.

Despite the potential benefits of these solutions, small farmers, who require more land for cultivation, often need help to adopt the necessary technologies and techniques. These constraints include lack of access to financing, land tenure insecurity, and inadequate infrastructure. As a result, small farmers cannot grow their businesses and earn a decent livelihood.

Fortunately, numerous programs and initiatives can provide small farmers with the necessary resources and support to overcome these challenges. These programs include subsidized loans, technical assistance, and access to land through leasing arrangements. Small farmers can increase their yields, improve their livelihoods, and contribute to food security by providing these resources.

Crop yields are adversely affected by soil management techniques, including monocropping, excessive tilling, and overfertilization, because they reduce soil fertility. Farmers can maintain soil health and increase crop yields by implementing sustainable agriculture practices. Moreover, even during dry spells or droughts, there are ways to provide irrigation and protect crops. By working together and adopting a positive outlook, farmers can overcome the challenges presented by climate change and continue to thrive.

4. Mitigation Strategies to Enhance Horticulture Production

In the aspect of climate change, farmers and growers must proactively acclimatize their horticultural crops to ensure optimal production and quality. Such measures, known as adaptation strategies, play a dynamic role in mitigating the adverse effects of climate change and managing its associated risks. However, it is essential to note that these strategies must be tailored to each crop's unique characteristics and environment to be effective. By doing so, growers can improve water use efficiency, better manage hot and dry conditions, and ensure the long-term sustainability of their operations. Ultimately, adopting customized adaptation strategies is important for mitigating the impact of climate change on horticultural crops.

Changing the period of sowing or planting is one strategy to prepare for the expected raised temperatures and phases of water stress during the crop-growing season. This can help ensure that the crops are exposed to optimal growing conditions. Another way is to change fertilizer applications to enhance nutrient availability. This can be done using fertilizers better suited to the soil and crop requirements. Soil amendments can also be used to improve soil fertility and nutrient uptake. This helps ensure that the crops receive the nutrients necessary to grow

healthyand produce high yields. Providing irrigation during critical crop growth stages is another essential intervention. This helps ensure that the crops have access to water when they need it the most. It is also necessaryto conserve soil moisture reserves to ensure the crops are not stressed due to lack of water. Mulching with crop residues and plastic mulches can help preserve soil moisture. This is because the mulch is a protective cover that reduces water evaporation from the soil.

Growing crops on raised beds can also mitigate problems caused by excessive soil moisture due to heavy rain. This is because raised beds provide better drainage and aeration, which helps prevent waterlogging and root diseases. In addition, raised beds can help improve soil structure and reduce erosion. Overall, many interventions can be used to cope with the expected rise in temperature and periods of water stress during the crop-growing season. By implementing these interventions, farmers can ensure their crops are healthy, productive, and sustainable.

Using locally sourced natural pesticides and Integrated Pest Management (IPM) strategies is highly recommended for managing crop-related pests. Furthermore, appropriate irrigation practices can strengthen crops' ability to resist diseases. To ensure optimal crop protection, it is critical to select crop species that are well-suited to the specific climatic conditions of the area, conduct thorough research, and develop disease-resistant varieties. In areas prone to flooding and waterlogging, it is crucial to maintain a proper drainage system and thin the shade. Similarly, maintaining shade trees helps lessen the damage that hail, frost, and snow can do to crops. Planting more vegetation and increasing vegetation cover is essential in landslide-prone areas to prevent landslides. Bioengineering techniques can also be used to help prevent and recover from landslides.

Furthermore, proper management of drainage systems is necessary to prevent landslides in farmland (Suresh et al. 2022).

Agriculture is one of the industries most impacted by climate change, which seriously threatens food security. Farmers need to adapt to new conditions to continue producing crops sustainably. One such adaptation strategy is switching to more resilient crops that tolerate harsher climatic conditions and create new markets. In the upcoming decades, rising temperatures and altered rainfall patterns in Central America are expected to impact coffee output and quality. Nicaraguan farmers are growing ginger and turmeric next to their coffee plants as a countermeasure. In the short term, when coffee sales are down, growing alternative crops provides additional revenue. In fact, over the last three years, farmers have earned more than twice as much revenue from turmeric as from coffee due to the changing climatic conditions affecting coffee yields.

In the future, particularly in the most climate-vulnerable areas, crops like ginger and turmeric may potentially take precedence over coffee. In regions like Bangladesh that experience floods, droughts, and coastal areas, hydroponic gardens are an excellent strategy to lessen the fast-changing climate's detrimental effects on agriculture and fishing ecosystems. For the past twenty years, farmers in Bangladesh's waterlogged areas and floodplains have successfully used floating bed vegetable cultivation as an adaptation technique. Farmers can grow significant quantities of turmeric, ginger, and other vegetables using water hyacinth as the primary material, more than double what can be produced on average land. However, the cultivation of floating beds is threatened by salinity, a significant challenge for farmers to overcome (Alauddin et al. 2014).

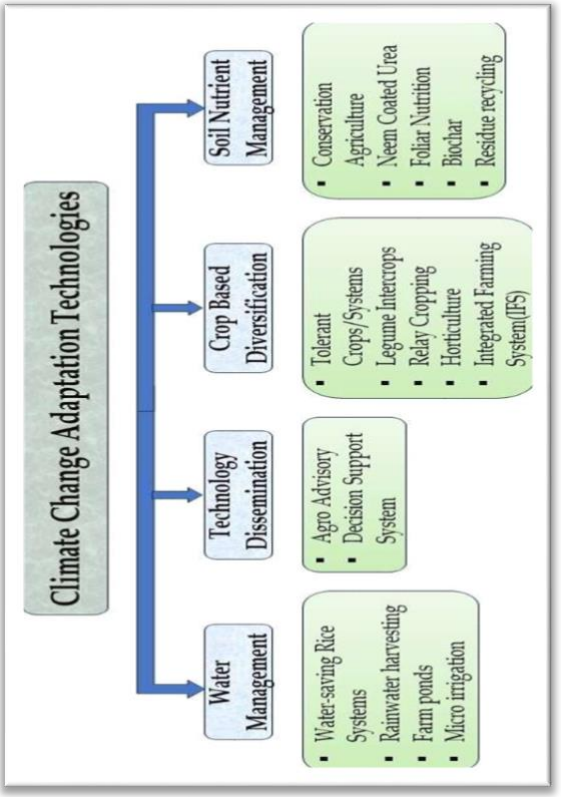

Figure 6. Climate Change Adaptation Technologies (Kumar et al., 2023)

Soil, a fundamental resource for absorbing atmospheric CO_2, has been depleted significantly due to traditional agricultural land use, mainly through the deforestation of tropical forests. To resolve this issue, researchers have assessed various high-density multiple cropping systems based on spices for their organic carbon and nitrogen pools. According to the results, integrated and conventional management strategies for black pepper produce lower organic carbon pools than organic management. The black pepper basin has been found to

have the highest organic carbon pools in high-density multiple cropping systems. On the other hand, coconut and nutmeg systems have been observed to have higher organic nitrogen. Composting organic waste products after spice processing can reduce methane gas emissions (Prasath et al., 2015).

Nitrogen-based fertilizers are an important contributor to greenhouse gas emissions. Therefore, Therefore, to guarantee the availability of vital nutrients without causing any adverse effects, it is necessary to alter the quality and quantity of fertilizers and manures. To increase nitrogen absorption and fertility, soil amendments must be used (Sharma et al., 1987).

As climate change continues to impact our planet, improving the genetics of crops is a crucial method to help them adapt to future predicted climates, ensuring sustainable production and food security. However, breeding crops to withstand the adverse effects of climate change is challenging due to the complex nature of abiotic stress tolerance. There needs to be more selection norms and more knowledge about the genetics of stress tolerance, which makes breeding for abiotic stress tolerance a complex process (Ong, 2002). The process of characterizing plants involves describing their traits and idiosyncrasies. Estimating the variance and diversity in the available germplasm and identifying valuable features are both aided by it. Breeding programs are then implemented to enhance crops using such information.

The degree of genetic variety in the population is the primary aspect impacting the success of genetic improvement. Any crop's germplasm is an invaluable source of genetic diversity. It provides the main core population supply needed for breeding. Selecting resistant plants from existing populations and creating variations from their offspring is a valuable strategy for agricultural

plant development. Orchard crops can play an influential function in lowering the impact of climate change. Several ways can increase energy-use efficiency in agriculture, such as improving fuel efficiency, using renewable energy sources like wind and solar power, minimizing or eliminating tillage, and more.

It is essential to use slow-releasing fertilizers and nitrification inhibitors to manage fertilizer, manure, and biomass. Synthetic fertilizers should be used in moderation, and their production should also be minimized. It is necessary to avoid leaching and volatilizing nitrogen from fertilizers during storage and application, which can be achieved by using highly effective nitrification inhibitors like Dicyandiamide (DCD), coated Carbide, neem cake, neem oil, and thiosulphate. When dicyandiamide is used with organic manures and urea, it can reduce cumulative N_2O emissions by 24.18-32.55%.

Using organic fertilizers, practicing reduced tillage, incorporating biochar, planting cover crops, intercropping, and adopting other cropping systems are all effective ways to increase the percentage of soil carbon and prevent soil compaction. These practices can also promote soil health by lowering the dependence on chemical fertilizers, pesticides, and herbicides. Additionally, they can support biodiversity and help protect natural resources while mitigating the impacts of climate change.

5. Conclusion

The growth of horticultural crops is expected to be impacted dramatically due to climate change. Available data and information suggest that altered rainfall patterns, rising water demand, and biotic and abiotic stresses will influence the production of these crops. Although higher levels of CO2 can lead to faster photosynthesis and warmer temperatures may speed up the ripening process, it

is crucial to implement measures that can help mitigate the adverse effects of climate change on sustainable production (Stoffella et al., 1988).

The influence of higher temperatures on reproductive biology is expected to be more significant. At the same time, reduced water supplies may reduce productivity. Despite the numerous studies conducted, accurately predicting the extent of the damage remains a formidable challenge. In this regard, a modeling strategy that uses well-validated crop simulation prototypes is essential to accurately determine the consequences of climate change. However, the availability and development of these models for horticultural crops need improvement. Reviewing the perennial nature of horticultural crops in a controlled environment is crucial to exploring the direct impact of various factors such as growth, development, and yield on large- sized fruit trees and shrubs. Developing simulation models using innovative methods to understand critical horticultural crops better. These models will help us identify the susceptibility of the current areas under these crops to climate change scenarios, and we can determine new target areas for potential shifting of species and varieties. Simulation models can also be used to suggest changes in management practices and study adaptation measures for reducing the impact of climate change. Overall, it is crucial to take positive measures to adapt to the changes brought about by climate change to ensure sustainable horticultural crop production.

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