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12. Impact of Climate Change on Fruit Crops

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Abstract:

The world is on the brink of a major crisis. The global population is predicted to reach 9.7 billion by 2050, and along with rapid urbanization and changing living standards, this is leading to dangerous climate change. These changes are affecting food security, shelter, and overall biodiversity. We must take immediate action to prevent the earth from entering dangerous zones. This chapter highlights the critical role of fruit crops in the food security chain and emphasizes the impact of climate change on fruit crop production. It also discusses the problems facing fruit crop cultivation and offers climate mitigation strategies. These include using advanced fruit breeding techniques, integrated pest and disease management, and soil and moisture conservation strategies. The study also highlights the importance of AI-based techniques in mitigating the impact of climate change. Additionally, the chapter provides insights into research gaps and future strategies, along with international and agro-environmental policies and governmental involvement in climate change prevention strategies. Sustainable adaptation strategies must be implemented to maintain climate patterns and prevent further damage. We must act now to prevent a catastrophic outcome. By taking proactive measures and implementing sustainable adaptation strategies, we can ensure the safety of the planet and protect future generations.

Keywords:

Climate change, Urbanization, Mitigation, AI-based techniques.

12.1 Introduction:

12.1.1 Importance of Fruit Crops in Horticulture and Global Food Security:

It is estimated that by 2050, the world's population will reach 9.7 billion people. Sadly, India has the highest rate of child-wasting in the world, standing at 18.7%. Additionally, India ranks 111th out of 125 countries in the global hunger index for 2023, indicating severe undernutrition. This situation could be caused by a variety of factors, such as underproduction, climate change, government policies, and land use management.

Therefore, global food production will need to increase significantly to meet this demand while also reducing its environmental impact (Hunter *et al.*, 2017; Nations, U. N. I. E. S. 2019). To reduce world hunger, we need to focus on the food industry, which includes both the horticultural and agricultural sectors. While it is important to improve agricultural output, horticultural crops such as fruits are crucial for ensuring adequate nutrition and combating hunger. Moreover, fruit crops can contribute to poverty reduction by creating jobs and generating revenue (Pujar *et al*.,2017).

Fruit crops are of utmost importance in horticulture due to their high nutritional value, financial benefits, and critical role in ensuring food security. They provide essential vitamins, minerals, and nutrients that are necessary for a balanced diet, which leads to improved food security and a healthy lifestyle (Tandoh *et al*., 2023).

Furthermore, fruit crops act as a nutrient and carbon sink, helping to mitigate the effects of climate change. Therefore, it is essential to have conservation initiatives for native fruits to maintain sustainable food systems and increase genetic diversity (Srivatsava *et al.*, 2021).

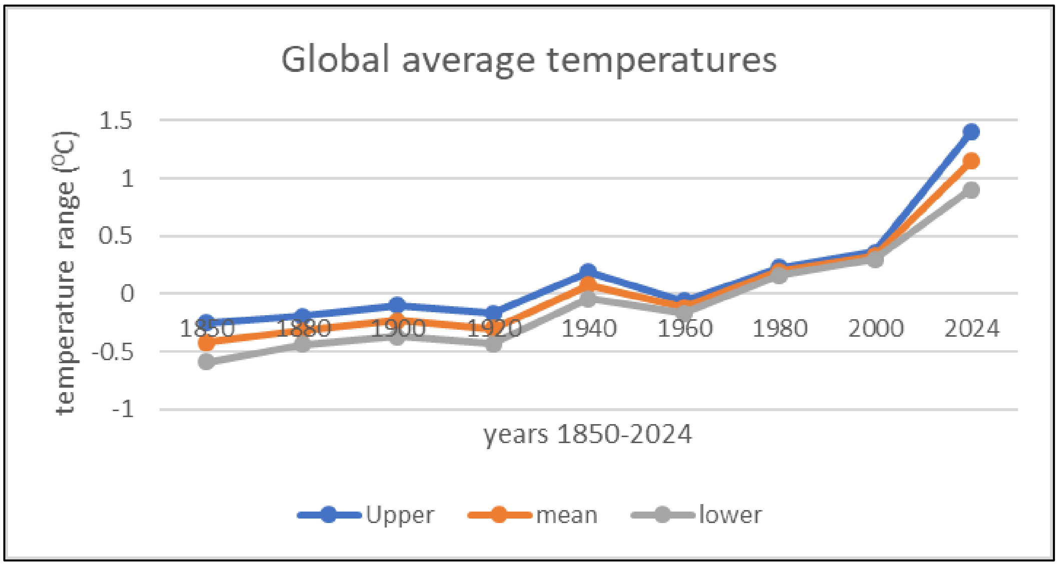
12.1.2 Introduction to Climate Change and Its Relevance to Agriculture:

Climate change involves periodic modifications in the Earth's climate, affecting global weather patterns and causing less predictable weather. This impacts agriculture-dependent nations like India, leading to frequent storms, floods, and cyclones. Human activity is the primary cause of rapid climate change, with global warming being a significant component. The melting of polar regions' ice and rising sea levels are causing erosion and coastal damage.

The IPCC predicts a 1.5°C global temperature increases between 2030 and 2050, affecting Asia, China, Pakistan, and India. India, the fourth largest global emitter, has announced a five-point action plan to reach carbon neutrality by 2070, aiming to reduce emissions to 50% by 2030 (Cai *et al*., 2016). Severe weather, viruses, pests, crop and land management, and climate factors impact agricultural productivity.

The complex system and interdependence of different aspects in agriculture present a major threat to food security in the region, which will also make it unreliable in the face of future climate changes. Therefore, it is essential to assess the harmful impacts of climate change on agricultural productivity and develop adaptation strategies to mitigate these effects (Rahman *et al.*, 2018).

Over the past few centuries, the burning of fossil fuels and extensive deforestation has caused a significant increase in greenhouse gas (GHG) concentrations in the atmosphere, leading to obvious global climate fluctuations. The global temperature increased rapidly from 2000 to 2020, reaching an average of 1.15C with a peak of 1.4C, indicating the extent of global warming during the decade (Figure 12.1). The rise in temperature has resulted in more hot days and nights and fewer cold days and nights. To reduce GHG emissions, it is essential to integrate measures for adaptation with mitigation strategies. Climate change impacts agricultural output, necessitating changes in crop cultivars, public attitudes, and practices. (IPCC 2021; Met office Hadley centre.2023 Zafar *et al*., 2018) (Figure 12.1).



Source: Met Office Hadley Centre (2023)

Figure 12.1: Average, upper and lower degrees of temperature ranges between 1850-2024 years

12.2 Climate Change Influences on Fruit Crops:

Tropical and subtropical fruits thrive in different temperature ranges. For instance, mangoes grow best between 25–30°C and require a rainfall of 9000–1000 mm per year. On the other hand, apples and other temperate fruits prefer temperatures around 10–20°C but need 21–24°C for active growth. Mango and litchi are two examples of tropical fruit crops that can endure temperatures beyond 45°C. Guavas are another tropical and subtropical fruit crop that can grow up to 1500 meters above sea level and can be harvested even in the winter (Verma. 2014) (Table 12.1).

12.2.1 Impact on Phenology of Fruit Crops:

Phenology denotes to the time variation of many physiological processes, and it is one of the most noticeable effects of climate change. Temperature, particularly low temperatures, has a significant impact on flower induction in temperate fruits. However, genotype, photoperiod, and temperature interact strongly to regulate flowering. Climate change has affected the phenological patterns of mangoes, which indirectly affects the vegetative and reproductive processes, leading to reduced production and quality. Rainfall and air temperature are crucial factors that play major roles in the vegetative and phenological phases of mangos and during the peak bloom period, a combination of high temperatures (35ºC), low humidity (49%), and heavy transpiration can cause dehydration and damage to mango panicles which result in leaf scorching and twig death, affecting both bearing and non-bearing mango trees. Climate change has also been reported to cause other consequences in mangos, such as early or delayed flowering, multiple reproductive flushes, irregular fruit set, and the conversion of reproductive buds into vegetative ones.

In addition, the timing of many trees blooms seems to be changing, indicating that dormancy-breaking mechanisms are evolving, possibly due to climate change. In citrus, premature winter rains can encourage vegetative flushes instead of blooming flushes (Rajan *et al*., 2013).

12.2.2 Impact on Flowering Patterns in Fruit Crops:

The changing climate is having a significant impact on the patterns of flowering and fruiting in plants, including mangoes. As mangoes are typically found in tropical and subtropical regions, they can withstand extreme temperatures. Mango flowering typically begins in January and is boosted by an optimal range of day and night temperature is 27/13°C. Anyhow Low temperatures below 10°C, high humidity levels above 80%, and gloomy weather can delay the flowering process. Studies have found that in panicles that emerge later, there is a higher proportion of hermaphrodite flowers, which is linked to higher temperatures (Balogoun *et al.*, 2016). The Western Himalayan climate in India leads to a significant deterioration in apple quality and yield due to increased temperatures during spring in the months of January to march. The earlier flowering coincides with spring frost, increasing the risk of frost damage to apple flowers. This climate also poses a threat to the harvest itself (Vedwan and Rhoades. 2001).

12.2.3 Impact on Pollination in Fruit Crops:

Raised temperatures can shorten the flowering period and the number of days required for efficient pollination. Heavy rainfall and cloudiness during flowering can result in low fruit set and flower drop. Moreover, high rainfall during full bloom may have a negative impact on pollination by washing away pollen and reducing pollinator activity. These are some of the effects of climate change on fruit crops, and there are resilience mechanisms in place to mitigate them (Rajan. 2012). Pollination insects and their performance are being affected by climate change in agricultural ecosystems. Extreme temperatures, whether too high or too low, can prevent fertilization, which in turn can severely impact crop yields and fruit set. Improper cooling can also diminish cross-pollinated fruits such as apple, cherry, and plum. The ideal temperature ranges for maintaining the quality of such fruits is between 20–25°C.

12.2.4 Impact on Fruit Quality:

A rise in temperature ranging from 0.7 to 1.0°C can lead to a shift in the ideal location for cultivating high-quality mango cultivars like Dashehari and Alphonso. Even a slight increase of 0.2°C in temperature can significantly reduce the regions suitable for the growth of red guava. Mandarins that are exposed to a temperature of 35°C in the sunlight are 2.5 times firmer than those that are in the shade and at a temperature of 20°C. The ripening process may tend to slow down when the temperature is high, as the activity of cell wall enzymes decreases. During the fruit's maturation process, hailstorms and rain can damage the fruit's quality and cause fruit drop, which can ultimately reduce the yield. There are various serious pests and illnesses, such as fruit fly, anthracnose, and mango stone weevil, which can attack during fruit maturation because of high humidity and unexpected rain (Makhmale *et al.*, 2016)

12.2.5 Impact on Post-Harvest Quality:

Crop photosynthesis is directly affected by changes in temperature, and as global temperatures continue to rise, it will have a significant impact on postharvest quality. This is because temperature changes affect crucial quality factors such as sugar, organic acid, and antioxidant production, as well as peel color and firmness. For instance, when grapes are grown in high temperatures, they tend to have lower levels of tartaric acid and higher quantities of sugar.

Similarly, the mango cultivar Chausa experiences a rise in fruit fly attacks when temperatures rise from 20 to 35°C. Additionally, mangoes of the cultivar Alphonso can develop spongy tissue due to a heat buildup inside the fruits (Makhmale *et al.*, 2016).

Table 12.1: Climate Requirements and Problems in Fruit Crops

Fruit Crop	Optimum Temperature	Chilling Hours (Temperate)	Annual Rainfall	Major Disorders Caused by Abiotic Stresses
Apple	15-24°C (59-75°F)	1200-1500 hours	100-1200 mm	Jonathan spot, Scald, June drop, Frost damage, sunburn
Grape	25-35°C (59-86°F)	-	900 mm	Pink berry, Blossem drop
Pomegranate	24-32	-	700-1100 mm	Fruit cracking, fruit drop
Citrus	25-30°C (77-86°F)	-	600-1500 mm	Granulation, Frost damage, salinity
Peach	23-26°C (68-86°F)	400-1200 hours	500-1200 mm	Tip burn
Pear	20-25°C (68-77°F)	800-1200 hours	600-1200 mm	Splitting and gumming
Cherry	15-30°C (59-86°F)	800-1500 hours	500-1200 mm	Sunscald
Plum	18-25°C (64-77°F)	600-1000 hours	500-1200 mm	Sun burn
Fig	28-32		850-1000 mm	Sun burn, fruit splitting, fruit drop
Avocado	20-30°C (68-86°F)	-	1000-1800 mm	Grey pulp, Tip burn
Mango	24-30°C (75-86°F)	-	1000-2500 mm	Spongy tissue, Blacktip, Jhumka, salinity, wind damage

Source: Fronza *et al*. (2018) and Kuden *et al*. (2013)

12.2.6 Impact of Precipitation Patterns on Fruit Crops:

The quality of fruits, irrigation needs, and access to water are all significantly influenced by the patterns of precipitation. Changes in precipitation patterns impact ecosystems and water availability.

The use of various irrigation techniques can enhance the production and distribution of water. Climate change exacerbates water demand issues, making eco-friendly water supply options crucial (Goutam *et al*., 2020).

However, India's irrigated areas are expected to require more water by 2025, and global net irrigation requirements will increase by 3.5-5% by 2025 and 6-8% by 2075 (Prathak *et al*., 2014). Water stress in papaya, banana, and banana plants can hinder growth, cause leaf abscission, and decrease photosynthetic rate.

Water stress before flowering is essential for fruit growth, while during vegetative stages, it can cause poor bunch formation and finger size. Micro irrigation effectively combats water stress, enhancing growth parameters and reducing unmarketable bunches, thus enhancing water use efficiency in various horticultural crops (Malhotra. 2010).

12.2.7 Impact of Extreme Weather Events on Fruit Crops:

Storms, floods, and droughts have a significant impact on fruit crops, both directly and indirectly, affecting their growth, physiology, and productivity. For instance, crops like pears, plums, and cherries may experience oxidative stress due to droughts, which disrupt the photosynthetic machinery. Floods can cause crop losses of up to 20% in multi-year crops such as vineyards and orchards, leading to significant harm in agricultural areas. Poor drainage and flooding can also adversely affect the yield of passion fruit fields, causing irreversible damage.

In China, droughts have long-term effects on crops, while floods have a temporary impact that varies in space and time. It is essential to understand these consequences to successfully manage disasters and agriculture (Alessio *et al*., 2023; Alisa *et al*., 2021).

12.2.8 Impact of Rising CO_2 Levels on Fruit Crops:

Elevated CO2 levels enhance photosynthesis, leading to improved fruit quality and fruit yield in various crops. Long-term exposure to CO2 stimulates plant growth, alters carbohydrate production, and enhances secondary metabolite accumulation, ultimately improving biomass and fruit quality. Optimizing growth conditions can enhance yield and quality in various horticultural crops (Hiromi et al., 2022).

Human emissions of greenhouse gases, including CO_2 and methane, are the primary cause of climate change. The metric tons of these gases have increased significantly, from 22.15 billion in 1990 to 36.14 billion in 2014. Addressing low living standards, energy poverty, and inadequate nutrition is crucial for achieving sustainable living standards. (Figure 12.2).

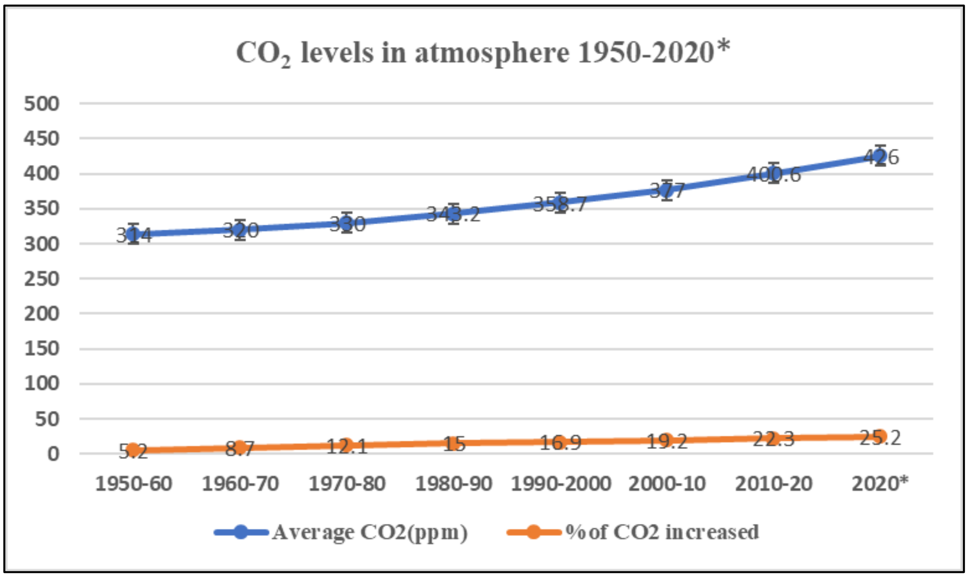


Figure 12.2: CO_2 levels in atmosphere range from 1950-2020* (Source: Arias *et al*., 2021)

12.3 Climate Change Impact of Abiotic and Biotic Stresses on Fruit Crops:

Fruit crops have become increasingly susceptible to pests and diseases due to changes in the environment caused by climate change. Climate change has altered the distribution of pests, leading to more severe infestations and an increased risk of invasive species. Additionally, the emergence of new strains of pathogens poses a significant threat to crop yield and productivity, impacting both agricultural and horticultural cropping systems (Leng *et al.*, 2023). The impact of climate change on pests includes changes to their life cycles, the number of generations, and hibernation habits, which can ultimately reduce the effectiveness of pest management techniques (Kour *et al.*, 2023). Climate change and an increase in atmospheric carbon dioxide may indirectly affect crops by altering pests and diseases, including aphids and weevil larvae, it has been observed that increased levels of CO_2 can lead to alterations in climate factors, which in turn can make subsequent occurrences more hazardous. Fungal spores are quickly inactivated by sunlight, low humidity, and extreme temperatures at below 18°C or above 35°C. On the other hand, hot and dry climates tend to reduce the incidence of fungal diseases such as anthracnose and powdery mildew in mangos (Alfonso and Brent. 2014).

Fruit crops can suffer from various physiological abnormalities when exposed to high temperatures and air pollution. Some common issues include spongy mango tissue, cracking, black spots, and fruit abscission. In desert soils, where the mean surface temperature can reach up to 52.40°C, clean cultivation may result in 15.55% to 18.33% spongy tissue (Katrodia and Sheth. 1989). Elevated temperatures and moisture stress can exacerbate sunburn and cracking in apples, apricots, and cherries. As litchi fruit matures, increasing temperatures can cause it to burn and crack. In 2009, the outer layer of custard apples had the highest black mark (35.63%), which may have been caused by high wind speed that year.

Due to the hot and humid weather, there has been a noticeable increase in pests and diseases affecting guava crops. The high temperatures and humidity have made fruit flies a more significant issue for guava growers. Additionally, crops like peaches and plums, which require lower temperatures, are showing signs of decreased yield (Hazarika. 2013). High temperatures and humidity can cause sunburn and cracking in certain fruits like apples, cherries, and apricots, while litchi can fracture and burn when it reaches maturity and experiences a temperature increase. The growth rate of fruit is significantly affected by temperature, which is why using bunch coverings to warm the fruit can increase its growth. In general, high temperatures (31-32°C) accelerate the pace of banana plant maturity, which shortens the time needed for bunch development. However, if fruits are exposed to sunlight and temperatures above 38°C, they can get sunburned can also cause bunch choking. (Stover and Simmonds. 1972).

12.4 Regional Variations and Vulnerabilities:

If the average global temperature were to increase, the current plant species and variations would relocate to new latitudinal zones with more favorable conditions. This could lead to a decrease in crop production in certain areas and an increase in others. For example, the shift of apple production in India from lower to higher altitudes is a clear indication of the impact of climate change on agriculture.

12.4.1 Beneficial Impacts of Climate Change on Fruit Crop:

Fruit crops can be affected positively or negatively depending on the environmental conditions, providing opportunities for cultivation in various climate zones. While increasing temperatures and atmospheric CO2 levels may have detrimental effects, they can also be helpful for some crops. For instance, C4 plants exhibit an increase in photosynthetic rate with a 55-degree temperature rise compared to C3 plants. However, it has been observed that C3 plant species continue to have a higher photosynthetic response across a range of several hundred ppm CO2, while C4 plant species quickly reach saturation as CO2 concentration increases (Rogers *et al.*, 1994). According to the NPCC report, farmers in temperate regions have benefited from climate change. The rising temperatures have caused the apple belt to shift 30 km northward, leading to the creation of new apple cultivation areas in previously unsuitable regions such as Lahaul and Spitti and the upper reaches of Kinnaur district in Himachal Pradesh. Furthermore, farmers in lower elevation regions are now switching from apple to kiwi, pomegranate, and vegetable cultivation (NPCC. 2007). Mango trees' ability to induce flowers is positively correlated with cold temperatures and negatively correlated with warmer temperatures. However, it benefits pollen viability, fruit set, and quick fruit growth in areas with cool temperatures during blooming. Climate change may potentially improve the quality of some fruit crops because pomegranates' hot and dry spell during fruit development increases the proline accumulation in fruit (Hanim Yildiz. 2009).

12.5 Climate Change Adaptation Strategies for Fruit Crops:

The institutional setup and decision-making environment play a crucial role in facilitating efforts to adapt to climate change. These efforts involve making changes to resources, procedures, and practices that are affected by a variety of institutional, cultural, environmental, and economic factors. In order to prepare for the impact of climate change in the agricultural sector, it is essential to adopt robust, relevant, and user-friendly frameworks for assessing adaptation.

12.5.1 Crop Selection and Diversification:

Diversifying crop types and choosing robust fruit cultivars are critical strategies for maintaining environmental resilience. These cultivars can withstand harsh environmental conditions such as drought, disease, and insect pressure. By combining these tactics, farmers can create resilient agricultural systems that can survive the effects of climate change. To develop new, sturdy fruit varieties, scientists, breeders, and growers must collaborate and conduct research (Anderson *et al*.,2020). (Table 12.2).

Table 12.2: Resistance Sources for Abiotic Stresses of Fruit Crops

Fruit Crop	Rootstock or Variety	Resistance Source for Abiotic Stress
Apple	MM.104,111,62-396	Drought tolerance, soil salinity resistance, frost resistance
Grape	SO4, 1103P, 420A	Drought tolerance, heat resistance
Citrus	Carrizo, Swingle	Salinity tolerance, waterlogging resistance
Peach	GF 667, Nemaguard	Calcareous soils tolerance, RKN resistance
Pear	*Pyrus calleryana, P.betulifolia*	Drought tolerance, soil salinity resistance
Cherry	Gisela, Colt, Mahaleb	Drought tolerance, cold resistance
Plum	St. Julien A, Myrobalan	Drought tolerance, cold resistance
Avocado	Duke, Topa Topa	Drought tolerance, soil salinity resistance
Mango	Gomera-1, Gomera-3, kurrukan,13/1	Drought tolerance, heat resistance, salt tolerant, calcareous soils

12.5.2 Water Management Strategies in Fruit:

Compared to traditional irrigation systems, drip irrigation is a more water-efficient method as it directly delivers water to the plant's root zone, reducing water consumption by up to 50%. This technique not only improves soil health and microclimate but also helps preserve soil moisture. In times of drought, rainwater harvesting devices can supplement additional water supply, thereby reducing the reliance on surface or groundwater sources. Farmers can also optimize their irrigation schedules by utilizing soil moisture sensors for better water management. Moreover, proper crop selection and management practices, such as trimming, spacing, and canopy control, can help reduce water requirements. Integrated water management practices, including drainage control, soil conservation, and water recycling, further minimize environmental impact and maximize water efficiency. Modern technology, such as automatic irrigation systems and remote sensing, can help improve water management capabilities (Abobata. 2021).

12.5.3 Crop Protection Strategies for Climate Change:

Integrated pest management (IPM) is a strategy that aims to effectively manage diseases and pests while minimizing the harm to the environment and public health. IPM includes cultural practices, integrated disease management (IDM), biological control, mechanical and physical control, chemical control, monitoring and early detection, and climate-adaptive tactics. Using physical measures, cultural practices, natural predators and parasites, and selective insecticides, IPM can create an unfavorable environment for pests and diseases. Climate-adaptive techniques such as changing irrigation schedules and planting schedules can also be developed to adapt to changing climatic conditions. By combining these measures, fruit crop growers can reduce the negative impact of climate change while maintaining environmentally-friendly farming practices (Bhupenchandra *et al.*,2022).

12.5.4 Soil Conservation and Management Practices:

Enhancing fruit crop's ability to withstand climate change requires the implementation of various soil conservation methods. These techniques include contour farming, terracing, windbreaks, mulching, conservation tillage, agroforestry, cover crops, effective irrigation, and soil amendment. Cover crops help increase the amount of organic matter in the soil, improve soil structure, and prevent soil erosion. Wind barriers provide refuge for insects that pollinate crops and also shield orchards from wind-related damage. Mulching, on the other hand, lowers soil temperature, prevents erosion, and preserves moisture. Agroforestry incorporates trees or shrubs into crop systems, while conservation tillage reduces soil disturbance and erosion. In addition, terracing and contour farming help with water conservation, soil erosion prevention, and runoff reduction. Proper water management is crucial during periods of drought or excessive rainfall. Finally, adding additives to the soil such as manure or compost enhances its fertility, structure, and ability to store water. Anti-traspirants, such as kaolin and chitosane, help lower fruit and leaf temperatures and minimize water loss. The greatest way to lessen frost damage to grapes cultivated in mildly cold locations is to use Bordeaux blend.

12.5.5 AI and Machine Learning Tools:

AI and machine learning algorithms are revolutionizing the agriculture sector by enhancing resilience to climate change. These technologies use historical weather data to predict future climate patterns, enabling farmers to adjust irrigation schedules and crop varieties. Machine learning algorithms process data from sensors, drones, and satellite imagery to provide real-time insights into soil health, moisture levels, and crop conditions. AI-powered systems can also identify stress, disease, or pest infestations in fruit crops, enabling prompt intervention. Genetic analysis and breeding also guide breeding programs for fruit varieties better suited to changing environmental conditions (Kaack *et al.*, 2022).

12.5.6 Adaptation Through Breeding Approaches:

Fruit crops are being developed to enhance their resilience to climate change, ensuring their sustainability and productivity in changing environmental conditions. Breeding approaches, such as MAS, maintain genetic diversity within fruit crop populations, providing a broader pool of genes for identifying suitable traits. Cross-breeding different varieties or species can result in hybrids with improved resilience. Techniques like CRISPR/Cas9 can be used to edit the genome of fruit crops, introducing beneficial traits or editing existing genes to improve stress tolerance.

Involving farmers, consumers, and other stakeholders in the breeding process ensures that developed cultivars meet their needs and preferences, ensuring food security and sustainability in the face of evolving environmental conditions (Anderson *et al.*, 2020). (Figure 12.3).

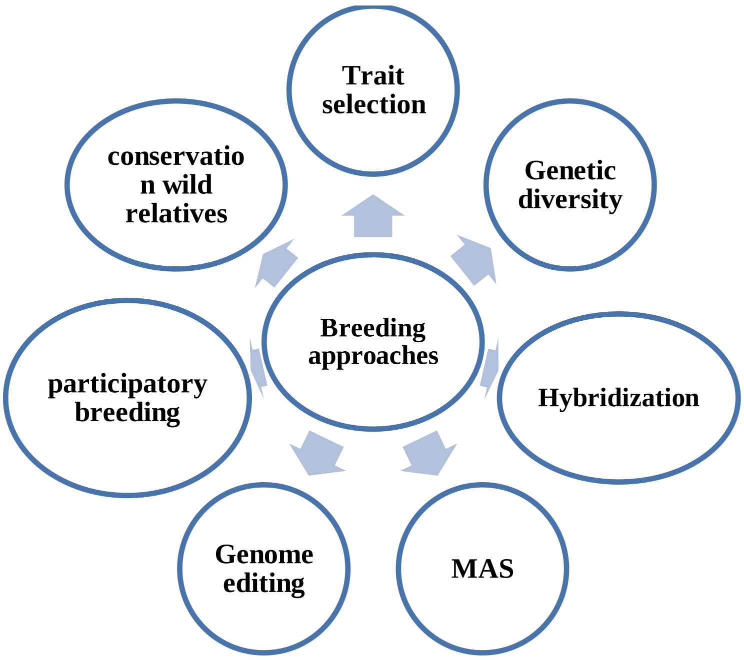


Figure 12.3: Breeding Approaches for Mitigation of Climate Change in Fruit Crops

12.5.7 Research Gaps and Future Directions for Addressing the Challenges Posed by Climate Change on Fruit Crops:

Recent research has highlighted the need for more studies on the impact of climate change on fruit crops. Existing research gaps include methods for mitigating climate change effects, genetic adaptability, interactions with pests and diseases, species-specific responses, and socioeconomic effects. Understanding these elements can enhance the effectiveness of solutions and customization of adaptation tactics.

To improve fruit crop production systems' resilience, reduce risks, and ensure sustainability, we need to adopt climate-smart farming practices, cutting-edge technologies, interdisciplinary cooperation, capacity development, and frameworks for long-term monitoring and assessment. These measures can help address the gaps and pave the way for future directions that can aid in developing more potent methods and minimize the effects of climate change on fruit crops (Farooq *et al.*,2022).

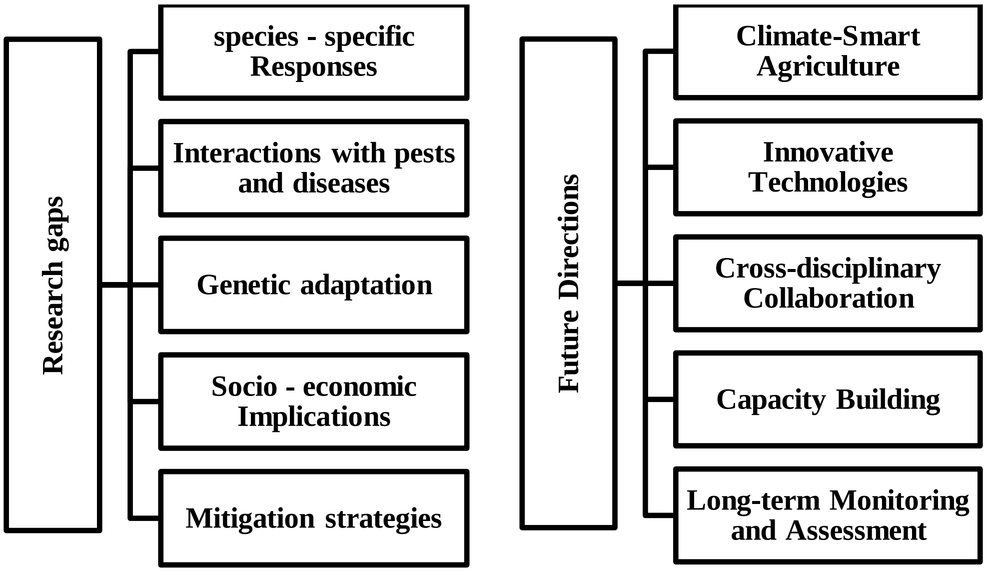


Figure 12.4: Research Gaps and Future Directions

12.5.8 Predicting Future Climate Scenarios and Their Impact on Fruit Crops:

Climate change is affecting the temperature and precipitation patterns, which, in turn, has a significant impact on the growth, development, and production of fruit crops. The rising temperature is affecting the fruit set, flowering, and ripening processes, resulting in lower production rates. Additionally, changes in precipitation patterns are impacting soil moisture content, insect and disease susceptibility, and water requirements, which can have adverse effects on fruit orchards. Extreme weather conditions like storms, heat waves, and frosts can also harm fruit orchards and interfere with the production cycle. Climate change is also impacting the quantity and dispersion of pests and diseases, which can further harm fruit crops. Therefore, to ensure long-term sustainability and resilient agricultural systems, it is crucial to understand and predict future climate scenarios (Egea *et al.*,2022).

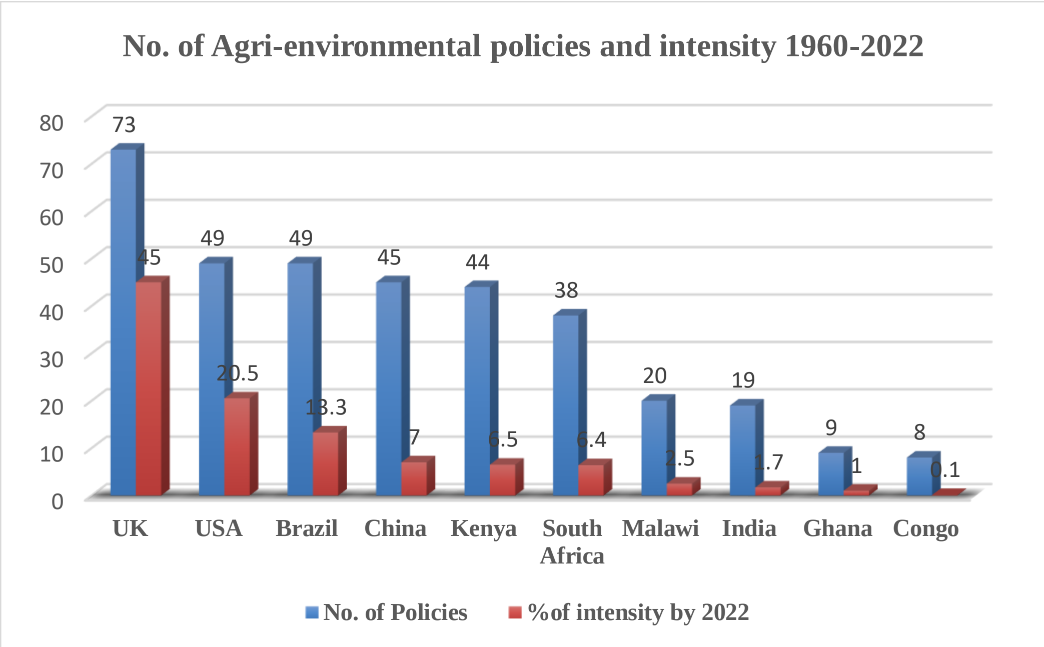
12.6 Policy Implications and International Cooperation:

12.6.1 Government Policies and Initiatives to Support Adaptation and Mitigation Efforts in Fruit Crop Production:

Governments allocate funds for research and development to create fruit crop varieties that can adapt to climate change and promote sustainable farming methods. They also provide incentives and subsidies to farmers who implement environmentally friendly practices. Extension services play a vital role in disseminating knowledge about the best practices for developing fruit crops.

Governments offer insurance programs to protect farmers against unfavorable weather conditions. Agroforestry is promoted through policies that aim to preserve biodiversity, maintain soil health, and mitigate climate change.

Water management policies ensure that fruit crops receive adequate water supply. Governments integrate fruit crop production into their plans for adapting to climate change, with a focus on identifying areas that are susceptible to climate change and implementing mechanisms to increase resilience (Kandegama *et al*., 2022).



Source: (David Wuepper *et al*., 2024).

Figure 12.5: Number of Agri-Environmental Policies and Their Intensity Between 1960-2022

12.6.2 International Collaborations and Agreements to Address Climate Change Impacts on Agriculture:

Climate change is a global problem that requires international cooperation and agreements. The United Nations Framework Convention on Climate Change (UNFCCC) has ratified the Paris Agreement, which aims to limit global warming to less than 2 degrees Celsius.

The Intergovernmental Panel on Climate Change (IPCC) provides scientific evaluations of the effects of climate change, as well as alternative strategies for adaptation and mitigation. Global research alliances, such as the Global Research Alliance on Agricultural Greenhouse Gases (GRA), develop research and technology to lower greenhouse gas emissions.

Developing nations receive assistance from international finance institutions such as the Green Climate Fund (GCF) and the Adaptation Fund, which help to mitigate and adapt to climate change. Bilateral and regional collaborations facilitate technology transfer and capacity building. Trade agreements also support climate change mitigation and sustainable agriculture. (Table 12.3).

Table 12.3: International Collaborations and Events and Agreements on Climate Change

Event /Agreements		Description
Paris Agreement, 2015	:	The UNFCCC is working towards limiting global warming to below 2 degrees Celsius, with efforts to achieve a 1.5-degree limit.
Intergovernmental Panel on Climate Change (IPCC)	:	Provides scientific assessments of climate change impacts, adaptation, and mitigation options
Global Research Alliances	:	Collaborative initiatives like the Global Research Alliance on Agricultural Greenhouse Gases (GRA) bring together countries to advance research and develop technologies to reduce agricultural greenhouse gas emissions.
International Funding Mechanisms	:	Multilateral funds such as the Green Climate Fund (GCF) and the Adaptation Fund provide financial support to developing countries for climate change adaptation and mitigation projects in agriculture.
Bilateral and Regional Partnerships	:	Countries engage in bilateral and regional partnerships to exchange knowledge, technology, and resources for climate-resilient agriculture
Agreements on Trade and Sustainable Development	:	Trade agreements increasingly incorporate provisions related to sustainable agriculture and climate change mitigation
Global Initiatives and Coalitions	:	Initiatives such as the Coalition of Agricultural Ministers for Climate Action bring together policymakers, researchers, and stakeholders to coordinate efforts, share experiences, and mobilize political will to address climate change impacts on agriculture at the global level.

Source: (Campbell *et al.*,2022)

12.7 Conclusion:

Fruit crops are a vital component of agriculture and food production, and the effects of climate change can have a significant impact on their growth and development. Climate change can cause changes in the growth location, flowering patterns, and fruit quality of crops, which can ultimately affect their yield and economic value. Moreover, the postharvest quality of fruits can also be negatively affected by climate change, leading to spoilage and waste. To mitigate these impacts, various strategies can be employed. For instance, selecting resistant or tolerant sources, using molecular assisted selection (MAS), gene editing, integrated disease management (IDM), integrated pest management (IPM) practices, and implementing soil and moisture conservation techniques can help counteract the effects of climate change. These strategies aim to ensure sustainable resource use, advanced AI-based techniques, and agro-environmental policies, while also addressing research gaps. By following these techniques, we can maintain fruit crop production, prevent damage from various climate conditions, and safeguard the environment.

It is crucial to prioritize research and development in this field to promote the continued growth and sustainability of fruit crop production in the face of climate change.

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