Annals of Plant and Soil Research 26(3): 359-371 (2024)
https://doi.org/10.47815/apsr.2024.10373

Adaptation strategies for horticultural crops under changing climate conditions: A review

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Received, May, 2024; Revised accepted, July, 2024

ABSTRACT

Climate change variability and its impacts are a major global problem in the 21st century. The physiological reactions of horticulture crops to climate changes, such as decreased growing period, are negatively affected by terminal heat stress and limited soil water availability. This leads to a significant decrease in the output of fruits and vegetables, ultimately impacting the growth and development of these crops. The variability of climate change has adverse consequences on horticulture crops, including lower irrigation water availability, increased warmth, flooding, salt, and a negative impact on production andquality. The unpredictable nature of climate change fluctuation would negatively impact the performance of commercial types of fruits, vegetables, and flowers. The physiological disorders, such as spongy tissue in mango, fruit cracking in litchi, and blossom and fruit abscission in solanaceous font vegetables, are more severe in horticultural crops exposed to high temperatures and air pollution. These conditions also lead to decreased yields in numerous horticultural crops. To ensure the long-term production and adaptation of current horticulture techniques, it is necessary to reduce the impact of climate changes and increase the utilization of greenhouse technology. The primary efforts to address these difficulties will involve thedevelopment of horticultural crops that exhibit tolerance to high temperatures, resistance to pests and diseases, shorter growth cycles, and the ability to produce high yields even under stressful conditions.

Keywords: *Climate change, fruit crops, physiological disorder, spice crops and vegetable crops*

INTRODUCTION

Worldwide, the unique soils and climates across different agroecological zones provide many options for growing a variety of horticulture crops. These crops make up a substantial part of global agricultural output and include fruits, vegetables, flowers, ornamental plants, medicinal and aromatic plants, spices, condiments, plantation crops, and mushrooms. The variability of climate change has a substantial impact on the production of horticulture crops. Shifts in precipitation patterns and erratic high temperatures are key elements influencing the effects of climate change on agriculture, including horticulture (Bindi *et al.* 2002). Agricultureand horticulture are especially susceptible to the impacts of climate change and global warming (Peet and Wolfe, 2000). This vulnerability arises from the reliance of crop productivity on variables such as photosynthetic rates, meteorological conditions (such as temperature, sunshineduration, and rainfall), and severe weather occurrences including droughts, floods, and cold spells. Many studies have shown the substantial impact of climate change on horticultural productivity. Rising temperatures can disturb the dormancy of perennial crops including pome fruits, kiwifruit, and blackcurrants (Hazarika, 2013). The Fourth Intergovernmental Panel on Climate Change has published findings on the anticipated global and regional effects of climate change on agriculture, water resources, natural ecosystems, and food security. Change-related occurrences like droughts, hailstorms, heavy rains, floods, frosts, cyclones, and other environmental pressures are more frequent, posing a danger to agricultural productivity. Climate change variability poses substantial agricultural concerns for both annual and perennial horticultural crops. Terminal heat stress and limited water supply result in lower fruit and vegetable production via shortening growing times (Malhotra and Srivastava, 2014). Rain-fed agriculture is especially susceptible to fluctuations in rainfall and a decrease in the number of rainy days. The uncertainties and dangers in horticulture production systems lead

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to increased prices for fruit and vegetable commodities, worsening the challenges posed by climate change and variability. To tackle the issues of climate change, we need to deploy horticultural solutions that are climate-smart. It is crucial for the horticultural sector to comprehend how crops react physiologically to climate change, impacting their growth, development, quality, and production, in order to be ready to tackle these difficulties. Higher temperatures can result in elevated respiration rates, fluctuating photosynthetic rates, changed timing of plant growth stages, decreased crop lifespan, faster fruit ripening, and aging. The effects of climate change differ based on the specific region and type of crop in the horticultural industry. (Muthusamy*et al.,* 2012) Climate change unpredictability leads to reduced output and productivity of different horticulture crops, creating worldwide economic and food security challenges. This research intends to examine the effects of climate change variability on various horticulture production and productivity, taking into account the social repercussions on the economy and food security (Singh, 2010).

Factors affecting horticultural crops

Technological innovations, like new cultivar acceptance and enhanced production system management, have significantly boosted production and productivity in the horticultural business. Between 1950-51 and 2015-16, the production of horticulture crops increased by more than eleven times, reaching 283.2 million tons (Malhotra, 2016b). The horticulturalindustry has made great progress despite hurdles and is now at a critical point where sustainable development efforts are necessary. To reach the goal of producing 310 million tonnes of horticultural crops by the end of the XII Plan (2012-17), it is essential to concentrate on vertical growth strategies. This includes using new plant varieties, monitoring water and nutrients effectively, managing plant health, and implementing methods to minimize post-harvest losses. Enhancing horticulture production faces challenges from climate change, such as changes in seasonal patterns and extreme weather events like heavy rain, floods, hailstorms, frosts, high temperatures, and droughts, which can negatively impact crop yields. Detailed information on horticulture crops physiological responses, production implications, and overall quality and productivity is essential for evaluating the effects of climate change on them (Wolfe *et al.*, 2005). To address these implications effectively, a focused and methodical approach is needed to equip the horticulture industry to tackle the upcoming difficulties posed by climate change. Higher temperatures can result in elevated respiration rates, changes in photosynthesis rates, shifts in the allocation of photosynthates to economically valuable plant parts, adjustments in phenology, shortened crop cycles, quicker flowering, fruiting, and maturation, as well as accelerated aging (Yadaukumar *et al.*, 2010). The vulnerability of certain crops to temperature variations depends on their intrinsic tolerance and growth characteristics indeterminate crops have prolonged flowering cycles which make them less responsive to heat stress than determinate crops. The effect of climate change on crop yields will differ depending on factors like geographic location and type of crop. In tropical regions, even small increases in temperature could result in significant decreases in crop yield, whereas in high latitude regions, slight temperature increases could improve crop yields. In developing nations located in lower latitudes where temperatures are already close to or exceeding critical thresholds, further warming is predicted to reduce production instead of increasing it(Rao *et al.*, 2010) It is important to recognize that the impacts of climate change range across various locations and individual crop categories in horticulture.

Figure 1: Effects of high temperature on plants

Impacts on fruit crops

Extreme weather phenomena such as heatwaves and cold spells have been documented to inflict substantial damage on different fruit harvests. Temperature significantly influences the flowering schedules of perennial crops like mangoes and guavas. As temperatures increase, mango trees, which typically focus on growing leaves and branches, exhibit a greater preference for this type of growth, impacting when they start to bloom. Studies show a greater prevalence of hermaphrodite flowers in panicles that mature and later, correlating with rising temperatures (Singh *et al.*, 1966, Ramaswamy and Kumar, 1992; Balogoun *et al.*, 2016). Extreme heat, low humidity, and extended sunlightduring the main flowering stages have caused significant transpiration and dehydration damage to mango flower clusters. Heat stress symptoms such as leaf burning and twigwithering are frequently observed in both fruit-bearing and non-fruit-bearing mango trees (Delgado*et al.,* 2011). Climate change affects mango farming by altering blooming times, increasing incidences of multiple reproductive flushes, changing fruit maturity, causing aberrant fruit sets, and converting reproductive buds into vegetative ones (Rajan *et al.*, 2011) The proposed improvements to the BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) scale for phenological investigations in mango are intended to track these variations (Delgado *et al.*, 2011; Rajan *et al.*, 2011). Elevated temperatures and humidity in guava farming have causeda notable increase in pests and diseases, particularly fruit fly infestations. Peaches and plums, which need low freezing temperatures, are producing less owing to changing climate circumstances (Hazarika, 2013). Additionally, elevated temperatures and lack of moisture lead to sunburn and cracking in apples, apricots, and cherries. Temperature rise during litchi fruit maturation can lead to fruit cracking and burning (Kumar and Kumar, 2007) as well as early ripening of mangoes. A typical winter rains stimulate plant growth in citrus crops rather than flowering, impacting blossom development and exacerbating insect issues such as Psylla infestations. Switching orchards to different fruit species or types to cope with climate change is difficult, particularly in fruit crops that develop slowly and need substantial investment for orchard setup (Srivastava and Singh, 2008). In areas such as Shimla district, where reduced snowfall and apple yield are noted, orchards are being replaced with cultivars that require less freezing and other fruit crops like kiwi, pear, peach, and plum (Awasthi *et al.*, 2001). Temperature variations impact the rates of fruit growth and maturation. Observations have shown that bunch covers, which provide warmth to the fruit, can speed up growth rates. Elevated temperatures typically accelerate the maturation process of bananas, resulting in a shorter period for bunch formation (Turner *et al.*, 2007; Venkateswarlu and Shanker, 2012). Excessive heat above 38°C and strong sunlight can cause sunburn damage on fruits exposed to the sun and result in bunch choke. Temperature fluctuations influence grapevine growth, with changes in accumulatedheat units impacting the timing of plant development stages. Elevated temperatures over 42°C may impede vines' capacity to harness radiant energy, potentially by causing enzyme degradation and chlorophyll breakdown, which could outpace the rate of photosynthesis (Kliewer, 1968). Grapes show different levels of tolerance to temperature changes, and it may be required to choose different varieties to cope with shifting climate conditions (Laxman and Rao2005; Laxman *et al.*, 2010). Severe water stress in citrus horticulture leads to a decrease in leaf initiation and growth, causing leaves to become thick and leathery Water stress hinders root growth, which may result in deeper rooting and a greater number of feeder roots Water stress in grapevines reduces inflorescence start and stalk growth during development, leading to a decrease in berry size. Water stress can enhance polyphenol accumulation in berry skin and anthocyanin production, leading to wines with increased anthocyanin levels and richer hue (Downton, 1987; Idso and Kimball, 1997).

Impacts on plantation and spice crops

Cashew trees flourish in arid and temperate winters with lowest temperatures between15-20°C and moderate night dew to promote plentiful flowering High afternoon temperatures over 34.4°C and low relative humidity below 20% might result in flowers drying up, ultimately reducing yields. Insufficient and erratic rainfall, elevatedtemperatures, and intense winds have been observed to decrease cashew tree productivity by inducing flower and leaf loss and premature fruit dropping, which may lead tounproductive plants in extreme conditions (Aishwath and Lal., 2016) Rainfall occurring at an unfortunate timeduring the ripening process can lead to nut blackening and apple rot on trees. From January to May, cashew trees undergo substantial moisture stress, which has a detrimental effect on their flowering and fruit production. Implementing on-site soil and water conservation methods, together with rainwater harvesting, is essential for collecting rainwater and supplying it to cashew plants at vital periods (Rupa *et al.*, 2013). Cashew cultivation is vulnerable to climate fluctuations and drought due to changes in rainfall patterns and inter- seasonal variability. Rising temperatures will impact the survival and dispersion of pest populations, potentially upsetting the equilibrium between host plants and pests.Furthermore, elevated temperatures will speed up the process of soil nitrogen release, leading to decreased fertilizer effectiveness. Climate- related occurrences including prolonged droughts and cyclones have adversely affected coconut production in areas such as Tamil Nadu, Karnataka, and Andhra Pradesh (Laxman *et al.*, 2010). Coconut-growing regions have had a warming trend over the last fifty years, leading to a general increase in productivity, with some specific locations seeing recent reductions due to recurrent droughts. Climate change forecasts indicate possible productivity gains in certain areas but anticipate adverse effects in others (Kumar and Agarwal, 2013). Climate fluctuations have impacted oil palm production, affecting different stages of the plant's life cycle. Flood-related problems have decreased crude palm oil production in some areas (Greenall, 2008; Cadena *et al.*, 2006). Agroforestry systems focused on growing cocoa are recognized for their substantial ability to capture carbon, which helps in mitigating climate change (Somarriba*et al.*, 2013). Perennial crops such as coffee, rubber, and cocoa have the ability to sequester different levels of carbon, aiding in mitigating the impacts of climate change (Albrecht and Kandji, 2003, Montagnini and Nair, 2004; Nair *et al.*, 2009). Weather pattern variations have had a notable impact on the cultivation of spice crops such as small cardamom, seed spices, and black pepper. Indian pepper production has significantly declined over the last ten years because of the impacts of climate change, resulting insmaller farming areas and worse productivity, as reported by Muthusamy*et al.* (2012) and Das *et al.* (2016).

Impacts on vegetable crops

India's climate is mostly affected by the monsoon, which is the main source of rainfall in the region. However, it brings issues with both excessive and inadequate water conditions Moisture-sensitive vegetables are significantly impacted by harsh weather conditions, such as high temperatures and changes in moisture levels, leading to decreased yields. Early- stage soil water stress in onions can cause a 26% decrease in production (Daymond *et al.*, 1997). In tomatoes, water stress along with temperatures above 28°C can result in 30-45% bloom loss in various types (Rao, 1995). Chili plants experience reduced yield of 50-60% due to drought stress (Erickson and Markhart, 2002). Most vegetables are equally harmed by excessive moisture stress because it reduces oxygen levels in the root zone (Kanaujia and Phome, 2016). Flooding in tomato plants causes the buildup of endogenous ethylene, leading to a quick leaf reaction. Onion bulbs are susceptible to inundation during growth, resulting in output reductions of 30-40%. The effects of these pressures are anticipated to intensify under climate change conditions, leading to significant global crop production reductions of over 50%, depending on the stage of development and severity of the stress (Bray *et al.*, 2000). Elevated temperatures in tomatoes can greatly decrease yield by impacting fruit formation, leading to the production of smaller and lower-quality fruits. Tomatoes under temperature stress before flowering exhibit developmental alterations in anthers, including as abnormalities in the epidermis and endothecium, inadequate pollen production, and uneven flower opening (Sato*et al.*, 2002). Exposure to high temperatures after pollination hinders fruit development in peppers, emphasizing vulnerability of the fertilization process (Erickson and Markhart, 2002). Multiple causes such as bud drop, abnormal flower growth, poor pollen formation, ovule abortion, and reproductive abnormalities lead to fruit loss (Hazra *et al.*, 2007). Temperature influences sex expression in cucumbers, as low temperatures promote female flower formation and high temperatures result in more male blooms (Wien, 1997). Increased temperatures decrease the length of time it takes for onions to grow, leading to lower crop yields (Daymond *et al.*, 1997). Cauliflower thrives in temperatures between 15 - 25°C with high humidity, although most types are adversely affected by higher temperatures, causing a delay in curd formation (Singh, 2010). High temperatures can lead to heat stress in onions, resulting in smaller bulb size and reducing yields (Lawande, 2010). High temperatures and frost can decrease potato yield by 10-50% depending on their severity and timing in the crop cycle. Fluctuations in temperature can impact the occurrence of pests and diseases as well as the duration of the growing season for potato seed crops (Capiati *et al.*, 2006; Malhotra, 2012). Winter temperature increases can impact the growth of seasonal button mushrooms, and frost in January may cause cumin crops to fail completely. Crops like onions and tomatoes, which utilize C3 photosynthesis, have demonstrated higher yields when exposed to increased levels of carbon dioxide. Onion yields increased by 25-30% at 530 ppm CO_2, while tomato yields increased by 24% at 550 ppm CO_2 according to studies by Wurr *et al.* (1998),Wheeler *et al.* (1996), and Daymond *et al.* (1997). Increased temperatures cause onions to grow for shorter periods, resulting in reduced crop yields (Wheeler *et al.*, 1996). Heating the soil is advantageous for cucurbits that have high heat needs and are typically sown directly into the ground. The impact of climate change on horticulture crops is determined by the interplay, between increasing temperatures and CO_2 levels in the atmosphere (Rão, 2010). CO_2 enrichment does not counteract the negative impacts of increased temperatures on crop yield. Excessive rainfall, flooding, and air pollution can haveadverse effects on vegetable production, exacerbating yield losses (Drew, 1979, Kuo *et al.*, 1982; Narayan, 2009).

Impacts on tuber crops

Elevated temperatures have been shown in studies to produce significant changes in plant shape, such as elongated development with smaller compound leaves and leaflets, resulting in a reduction in leaf area index (LAI) (Fleisher *et al.*, 2006), Additionally, elevated temperatures have been linked to a decrease in both the quantity and dimensions of tubers in potato plants (Wheeler *et al.*, 1991; Peet and Wolfe, 2000, Khan *et al.*, 2002). Low evening temperatures encourage the initiation of tuberization in potatoes, but relatively high night temperatures impede this process (Wing, 1997, Ghosh *et al.*, 2000). High temperatures cause a decline in photosynthetic rate, resulting in lower tuber yield and biomass production (Peet and Wolfe, 2000). High temperatures lead to decreased tuber yield due to limited movement of carbohydrates from leaves to tubers, lower nitrate reductase activity, and higher carbohydrate consumption during dark respiration (Ghosh *et al.*, 2000). Therefore, it is essential to investigate different potato cultivars for developing heat- resistant types. Global warming is anticipated to affect the choice of crop varieties, benefiting those that can withstand heat stress (Dhull *et al.*, 2018). Increased carbon dioxide levels have been found to reduce chlorophyll levels in leaves, particularly in the later phases of the growing season after tuber initiation (Bindi *et al.*, 2002; Lawson *et al.*, 2002). Increased CO_2 concentrations can cause a drop in nutrient components in tubers, resulting in lower citric acid levels and a higher likelihood of discoloration after boiling. While cassava and sweet potato are usually known for their ability to withstand drought, they experience not able decreases in tuber yield and starch content in such circumstances (Ravi and Mohankumar, 2004, Ravi and Indira, 1998) Moderate water deficiency benefits tuber growth in cassava and sweet potato, while extreme water scarcity stops both leafy growth and tuber enlargement, resulting in dormancy. Over the past 50 years, natural disasters such asfloods, droughts, and cyclones have impacted around 0.9 million hectares of land and led to a 40% reduction in productivity (Sivakumar, 2008). Screening has found genotypes and landraces of cassava that are resilient to drought, and certain sweet potato landraces have shown drought tolerance as well (Annual Report, 2013, 2014, 2015), Efforts to improvedrought resistance have been made in seed spice crops by Malhotra in 2009 and Malhotra 2016a.

Implementing location-specific climate smart horticulture to combat climate change

Climate-smart horticulture is not a universal agricultural method. Customized evaluations are necessary to determine appropriate production strategies and practices that mayeffectively tackle the intricate issues encountered by agriculture and food systems (Malhotra, 2014). Climate change impacts differ among regions due to variations incharacteristics, breadth, and effects. Addressing the difficulties of climate change and generating solutions require specific analysis, planning, and management strategies at the local level. It is essential to carefully evaluate and understand the consequences of climate change on a regional scale, especially regarding both yearly and long-lasting horticulture crops. This comprehension can lead the way in creating and enhancing cutting-edge technologies and methods to efficiently tackle the issues brought about by climate change (Malhotra and Srivastava, 2014)

Simulation models for evaluating impacts

When developing plans for adjusting and reducing the effects of climate change, it is suitable to use modeling techniques to assess the consequences on various types of horticulture crops. Enhancing the availability and development of strong simulation models for horticulture crops in India, except for potatoes and coconuts, is necessary. The Info Crop model has been modified for crops such as tomato and onion and is now being validated in various agroecological zones (Kumar *et al.*, 2008) Studying the direct effects of growth, development, and yield factors in controlled situations is challenging dueto the perpetual nature of large fruit trees and shrubs. Therefore, novel methods are needed to create simulation models for important horticulture crops including mango, grape, apple, orange, citrus, litchi, guava, etc., as a top priority. Research attention in India has shifted towards the creation of crop simulation models for horticulture crops.

Table 1: Resistant rootstocks and varieties of fruit crops against biotic and abiotic stresses

Crop	Root stock	Crop soot stock trait
Mango	13-1, Kurakkan, Nileshwar dwarf, Bappakai	Salinity tolerant
Guava	*P. molle* × *P. guajava,*	Wilt resistant rootstock
	P. cujavillis	Tolerant to drought, sodic soils
	Chinese guava (*P. friedrichsthalianum*)	Dwarfing, nematode tolerant and wilt tolerant
Grape	Dogridge, 110R, SO-4	Drought, salinity tolerant
Citrus	Rangpur Lime	Drought, Phytophthora tolerant
	Cleopatra mandarin	Salinity tolerant
Sapota	Khirni	Drought tolerant
Anona	Arka Sahan	Drought tolerant
Ber	*Ziziphus nummularia*	Drought tolerant and dwarf stature
	Z. mauritiana var. Tikdi and *Z. mauritiana* var. *Shukhawani*	Vigorous growth
	Z. rotundifolia	Vigorous growth and drought tolerant
Fig	*Ficus glomerata*	Nematode and salinity tolerant
Lime	Rangpur lime and Cleopatra mandarin	Salinity tolerant
Passion fruit	*P. edulis f. flavicarpa*	Fusarium collar rot, nematode tolerant
	P. alata	Fusarium wilt tolerant
Pomegranate	*Punica granatum* (variety: Ruby)	Drought tolerant
Avocado	Duke, and its progeny, Duke 7, Barr-Duke, D9 and Thomas	Phytophthora root rot tolerant
	G6 selection (Mexican) Phytophthora root rot fairly tolerant Source:	G6 selection (Mexican) Phytophthora root rot fairly tolerant Source:

Source: Singh et al. 2009, Singh 2010

Strategies for adaptation

The impacts of climate change are influenced by both climatic circumstances and the system's capacity to adjust to change. The possible impact depends on the crops' ability to adapt to several environmental challenges resulting from climate change. Customizedadaptation solutions for certain crops in various agroecological zones and planting seasons are essential to maintain productivity, considering the susceptibility of each crop. Researchers have created solutions to reduce the impact of extreme occurrences including high temperatures, frost, and moisture stress; whether it is too little or too much (Kumar *et al.*, 2010; Rao and Bhatt, 1992; Laxman and S Rao, 2005). These current technologies can be combined and used to mitigate the negative impacts of climate change and variability. It is essential to focus on creating technologies that are appropriate to different crops, agroecological regions, and seasons in order to reduce the effects of climate change and improve the resilience of horticulture production systems (Malhotra 2015; Malhotra 2012). Resilient rootstocks and stress-tolerant cultivars have been found and used for different fruit crops to mitigate the effects of climate change. In addition to adopting altered crop management techniques, tackling the obstacles presented by climate change may need the creation of resilient plant types. Various institutes have developed hybrids and cultivars that can endure high temperatures and drought, providing a possible solution tocounteract the effects of climate change.

Mitigation strategies to manage production systems in horticultural crops

The main priority should be to apply suggested production strategies to improve water-use efficiency and adjust to hot and dry circumstances Implement strategies include modifying sowing or planting dates to address probable temperature rises and periods of water scarcity during the crop-growing season. Furthermore, adjusting fertilizer applications to promote nutrient availability and using soil amendments to improve soil fertility and nutrient absorption are essential (Srivastava *et al.*, 2014, Malhotra and Srivastava, 2015) It is crucial to provide irrigation throughout critical crop growth phases and conserve soil moisture reserves, as stated by Malhotra (2016b). Crop management techniques include mulching using crop waste and plastic mulch aid in soil moisture conservation. When there is too much soil moisture from heavy rains, planting crops on raised beds can help solve the problem. Transparent plastic rain shelters for vegetable cultivation can lessen the direct effect on growing fruits and alleviate field waterlogging in the rainy season. Planting vegetables on raised beds during the rainy season can increase yields by improvingdrainage and lowering anoxic stress on the root system. Vegetables grafting onto adaptable rootstocks can provide tolerance to soil-related environmental challenges as drought, salinity, low soil temperature, and flooding (Kubota *et al.*, 2008). AVRDC's efforts to improve flood tolerance in tomatoes through grafting with eggplant rootstocks should be broadened to also promote tolerance to water and temperature stress (AVRDC, 1990). Furthermore, there is a requirement for heat-resistant cultivars in response to climate change, which are anticipated to exhibit comparable performance to traditional types in optimal conditions.

Table 2: List of vegetable varieties having tolerance to abiotic stresses

Crop	Variety	Abiotic stress
Tomato	Arka Vikas and ArkaMeghali	Drought
	Thar Anant, Pusa Sadabahar	Heat
	Pusa Sheetal	Fruit set up to 8°C
	Pusa Hybrid 1	Fruit set up to 28°C
Egg plant	Pragati and Pusa Bindu	Salinity
Chili	G4, Arka Lohit and LCA334	Drought
Okra	Pusa Sawani	Salinity
Cucumber	Pusa Barkha	High temperature
Bottle gourd	Pusa Santushti	Heat and cold
	Hisar-2	Salinity
Onion	Arka Kalyan	Excessive soil moisture
Radish	Pusa Chetki	High temperature
Potato	Kufri Surya	Heat
Cowpea	Arka Garima, Arka Suman and Arka Samrudhi	Water limiting condition
Dolichos bean	Arka Jay, Arka Amogh, Arka Soumya and Arka Sambhram	Water limiting condition

Source: Kanaujia *et al.* (2020)

Table 3: Droughtresistant fruit crop cultivars for dry and semi-dry areas

Crops	Varieties suitable for arid and semi-arid ecosystem
Pomegranate	Ganesh, Dholka, Jalore Seedless, Mridula, Phule Arakta, Bhagawa, Ruby, Amalidana, G- 137, Jyoti, Basin Seedless
Ber	Gola, Seb, Umran, Banarasi Karaka, Kaithali, Mundia, Goma Kirti, Thar Bhubharaj, Thar Sevika, Thar Bhubhraj, Narendra Ber Sel-1 and 2, ZG3, Sanaur
Bael	Mirzapur Seedling, Etawah, Gonda, Ayodhya, NB-5, NB-9, Pant Aparna, Pant Urvashi, Pant Shivani, Pant Sujata, CISH Bael-1 and CISH Bael-2
Aonla	Banarasi, Chakaya, Francis, NA-6, NA-7, NA-10, Kanchan, Krishna, Anand-1, Anand-2, Lakshmi-52, BSR-1, BSR-1
Custard apple	Balanagar, Mammoth, Island Gem, APK (Co) 1, Arka Sahan
Fig	Poona Fig, Dinkar, Dianna, Conadria, Excel

Source: Singh et al. 2009, Singh 2010

Strategies for mitigating for climate change

Climate change is an undeniable fact, supported by sample evidence indicating that the emission of greenhouse gases has led to global warming and consequent changes in climate patterns. The horticulture sector may significantly contribute to mitigation efforts by adjusting production systems to endure the negative effects of climate change. Mitigation encompasses techniques that try to decrease or capture greenhouse gas emissions. Enhanced crop management techniques can greatly reduce greenhouse gas emissions by decreasing reliance on energy resources. Furthermore, enhancing perennial horticulture crops aids in capturing carbon dioxide from the environment (Albrecht and Kandji, 2009; Somarriba*et al.,* 2013).

Carbon sequestration capacity

Measures to reduce the impact within the agriculture and forestry industries are being acknowledged as ways to provide extra income for economically fragile rural regions and enhance resilience to climate change. Efforts to sequester carbon are essential forreducing the negative effects of climate change. Although fruit trees have made important contributions, there is still a need to enhance information on their carbon sequestration capacity (Narayan, 2009). An investigation at the Indian Institute of Science, Bangalore, employed the PRO-COMAP model to calculate the potential for reducing greenhouse gas emissions through planting fruit orchard blocks in farm forestry. The study suggested dedicating 75% of the space to several fruit tree species such as *Mangifera indica, Tamarindus indica, Achras sapota, Artocarpus,* Neem, and Guava. The analysis examined changes in carbon stock over 30 years (2005-2035) in baseline and mitigation scenarios, omitting harvested wood products. The total carbon reduction potential for agroforestry on a 5,381hectare area was calculated to be 81,750 metric tons. Fruit orchards in agricultural forestry were highly profitable, showing an Internal Rate of Return (IRR) of 29.92% (Ravindranath *et al.*, 2007 and Laxman *et al.*, 2010).

Utilizing technological advancements to reducing impact of climate change

Grape farming, typically linked to moderate climates, has experienced notable changes as a result of technological progress in plant structure and production system control. The advancements have allowed for grape growing in tropical areas, leading to the highest productivity worldwide (Kadir 2005 and Kliwer 1968). Challenges remain due to inadequate freezing which may prevent apple flowering, and elevated temperatures in mid-hill agroclimatic areas can result in pollen drying up and fruit shrinking, leading to poorer yields and crop losses (Awasthi *et al.*, 2001). However, there are many instances demonstrating successful management of climate change and technology developments despite these concerns. Salinity and alkalinity posed substantial challenges in grape growing until appropriate rootstocks were identified, leading to a large improvement in productivity. Thermo-sensitive crops such as potato, tomato, cauliflower, and cabbage, which used to thrive only in long-day conditions in temperate regions, have been effectively modified to grow in subtropical and warmer climates by creating heat-resistant varieties and making changes in production management techniques (Singh *et al.*, 2008, Malhotra and Srivastava, 2014). Past experiences highlight the potential of innovative research to transform the challenges of climate change into opportunities. Innovative research is important for predicting potential changes, comprehending their consequences, and developing methods to minimize negative outcomes. Furthermore, employing biotechnological methods helps accelerate the delivery of research results (Rao*et al.*, 2010).

Assumptions to be considered for reducing impact of climate change

Several studies conducted by researchers analyze the probable effects of climate change on various horticultural crops. It is essential to measure the impact of temperature fluctuations and excessive or insufficient moisture levels as the first step in equipping the horticulture industry to create adaptation plans for climate change scenarios. Efforts must be coordinated to analyze and evaluate the effects on specific crops in key agroecological areas and during different growth periods (Ray *et al.*, 2016). Increased efforts are needed to create new varieties that are appropriate for certain agroecological regions in the face of changing climatic circumstances. Unlike annual crops, which can swiftly adapt through various cultivars and species, altering planting dates or seasons and relocating orchards in response to climate change requires consideration of long-term factors. Prior to implementing any adaptation option, a thorough examination of the effects of climate change on perennial crops is essential. The impact of global warming may alter the geographical locations where some crops are grown and the optimal date for planting (Isdo and Kimball, 1997: Das *et al.*, 2016). Market windows and infrastructure, like local packaging and distribution facilities, are crucial elements of the production system that need to be reassessed for numerous horticulture commodities. Production techniques that can be modified to counteract the effects of climate change require scientific validation. Climateand CO_2 is expected to change significant relationships between horticulture plants and pollinators, insects and diseases, and pests and weeds. Perennial crops have a long-term growth cycle, which can lead to formerly suitable locations becoming unsuitable throughout the lifespan of a single orchard choosing a variation is complex due to the possibility that the most suitable variety for the present climate may not be optimal for future climates. Therefore, although adjustments like introducing new plant kinds and relocating to different regions can lessen long-term effects, short-term setbacks may be inevitable. Genetic variations in physiology and morphology allow for cultivation in diverse climates, and cultivars may be selected based on their compatibility with specific growing conditions. When consumers really like a specific cultivar and there are no suitable variants to withstand the changing temperature of a given place, adopting rootstocks to enhance the performance of the desired cultivars could be considered. A thorough comprehension of how climate change affects horticultural crops is essential to create effective action strategies, as horticulture- based farming systems have a significant capacity to store carbon and help combat climate change. Perennial trees store atmospheric carbon and can earn carbon credits through the clean development mechanism. Local composting of horticultural waste can help reduce methane emissions associated with global warming, instead of disposing of it in landfills. Implementing climate-smart horticulture should help in reaching the objective of sustainable agriculture. It combines the economic, social, and environmental aspects of sustainable development to tackle food security and climate concerns together. Comprehensive regulations, suitable institutions, effective governance, and new financing are essential to address investment and research needs and help farmers overcome barriers to adopting new methods, such as initial costs and lost income during the transition. Utilizing all available alternatives in an integrated approach is the most effective way to maintain productivity in the face of climate change. National and agroecological regions should start assessing how climate change affects various horticultural crops and create coordinated adaptation strategies to address these consequences in the horticulture sector.

Conclusions and future thrust

In view of these problems, horticulturists will have to play a significant role in the climate change scenario and proper strategies must be envisaged for saving horticulture. The most effective way is to adopt conservation agriculture; using renewable energy, forest and water conservation, reforestation etc. to sustain the productivity modification of present horticultural practices and greater use of greenhouse technology are some of the solutions to minimize the effect of climate change. Development of new cultivars of horticultural crops tolerant to high temperature, resistant to pests and diseases, short duration and producing good yield under stress conditions, as well as adoption of hi-tech horticulture and judicious management of land use resources will be the main strategies to meet this challenge.

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