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Environmental Issues Related to Climate Change in Fruit Crops: A Review

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ABSTRACT

Climate change is one of the environmental problems that are faced by fruits in the sense that it affects the growth of crops, phenology, flowering, fruit setting, yield, quality, and adaptability. The increased level of greenhouse gases such as carbon dioxide and others is associated with increased temperature, changes in precipitation, drought, flooding, frost, hailstorms and many more. Fruit crops have their own climatic needs and therefore show differential reactions to changes in the environment. The current chapter looks into the environmental problems that are faced due to climate change and how they affect selected tropical, subtropical, and temperate fruits. The major emphasis will be put on mango, grape, banana, citrus, papaya, guava, litchi, pineapple, apple, peach, pear, plum, almond, cherry, apricot, kiwi fruit, and strawberry. Temperature and water regime changes may lead to modifications in flowering, pollination, fruit set, maturation, coloration, sugar-acid ratio, and increased susceptibility to various physiological, biotic, and abiotic stresses. In addition, temperate fruit crops will suffer from inadequate winter chilling and shifting cultivation zones. Adaptive and mitigative measures include effective irrigation, mulching, right varieties and rootstocks, canopy management, soil conservation practices, integrated nutrient and pest management systems, and climate-adaptive breeding programs. Genetic and biotechnological approaches, as well as increased efficiency in the use of resources, are considered key methods in sustainable fruit production in changing climate conditions.

Keywords: Climate change, Fruit crops, Global warming, Temperature stress, Abiotic stress.

INTRODUCTION

Earth's surface temperature has risen relatively fast over the last 30 years. The consequences of such rapid change are - global warming, change of seasonal pattern, excessive rain, melting of ice cap, flood, rising sea level, drought, etc. (Yadav et al., 2023). The rise in temperature is attributed to alarming increase atmospheric concentration of

greenhouse gases such as Water Vapors, Nitrous Oxide, Carbon Dioxide and Methane which lead to change in global climate. It is mainly due to interference of the human activities such as burning of fossil fuel, industrial process, transport, land degradation and deforestation during the last few decades (IPCC, 2007; Farooqi *et al.*, 2005). Since the beginning of the twentieth century, the average global temperature has risen about 1.4° F, with about two thirds of that rise occurring since 1960 (IPCC, 2013). A global warming trend, between 1880 and 2015 depicted in fig. 1 (map released by NASA) clearly indicates the tremendously changing temperature over the last 100 or so years.

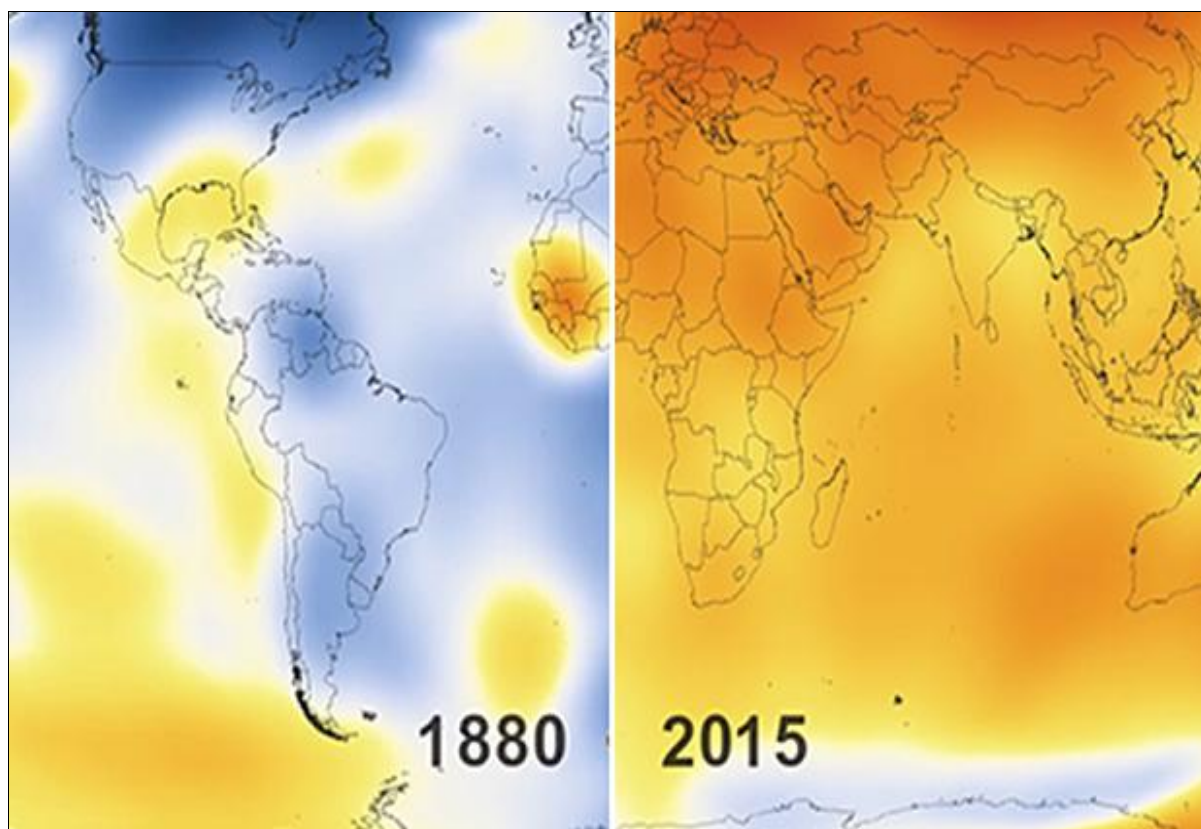


Figure 1. A global warming trend from 1880 to 2015 due to climate change. Blue colors represent cooler temperatures while hues of orange color signify temperatures warmer than average (Dlugokencky and Tans, 2015).

United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a change of climate that is attributed directly or indirectly to human activities that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. Edwards (1999) revealed that atmosphere serve as a central point for maintain in earth's overall standard temperature at level of 15°C. Among the different causes of climate change (global warming), one of the primary causes is "greenhouse effect" (Shah *et al.*, 2024). When the Earth radiates the energy back toward space, it is sent in longer wavelengths than the energy received. While most of these longer wavelengths are still lost to space, a portion is captured by several atmospheric gases which warms atmosphere (Venkataramanan, 2011). Additionally, some of this energy is reflected back, once again, to the Earth's surface by these gases, slowly warming the surface of the Earth, especially the oceans (Tate, 2001). Water vapor (36-72%)

and CO₂ (9-26%) are the major gases responsible for contributing to the 'greenhouse effect' (Karl and Trenberth, 2003).

In recent years CO₂ is becoming a major contributor as its atmospheric concentration shows a dramatic increase since the middle of the 19th century, from 278 ppm before the industrial era up to 401.62 ppm in December 2015 (Dlugokencky and Tans, 2015). This increasing CO₂ emission enhances the concentration of green-house gases (GHGs), which leads to increase in overall earth temperature (Brown, 1998; Trenberth *et al.*, 2001 and IPCC, 2007b). Agriculture sector as a base for whole world. But, increasing population and drastically changing climate are becoming a major problem for food security. The crop productivity mainly depends on climatic factors such as atmospheric temperature and rainfall (Wang *et al.*, 2009). Large number of fruit crops like mango, citrus, banana, grape *etc.* grown in different parts of the world. This requires varying congenial climate for their growth and production. The net effect of climate change on horticultural crops will depend on interaction effects of rise in temperature and CO₂ concentration in atmosphere.

Table 1. Climatic Factors and Their Impact on Horticultural Crops.

Climate Changes	Possible impacts on horticultural crops
CO₂ levels: Increase in levels	Potential for stimulation of photosynthesis and yields
Temperature: Increase in temperature, about 1-2 ⁰ C in winter and 1-5 ⁰ C in summer Decrease in temperature	- Reduced vernalisation (cold winter weather is required for flowering in temperate fruits). - Increased water requirement in summer resulting in increase in yields of rainfed orchards. - Spring frost causes damage to flowering and fruit set.
Precipitation: Decrease in summer rainfall Increase in winter rainfall and snow	- Induced stress conditions - Dry summers with extended drought spells impair the fruit quality (fruit size and color) - Increase in requirement for drainage systems in plains. - Good winter chilling ensuring optimal flowering and fruit set.
Weather extremes Increased frequency of torrential rains and very strong winds	- Increased soil erosion - Loss of humus and carbon content in soil
Hail storm During bud break to petal fall During fruit development stage	- Causes extensive damage to flower and fruits and injury to buds and spurs - Good crop year is turned off year - Decrease in fruit quality (spotted fruits)

Source: (Bisht, 2009)

In extreme scenarios the soils that are currently fertile could become barren and dry and the whole region may turn into desert. So, considering above background and introduction, the present chapter will depict the information related to impact of climate change on different fruit crops, their adaptation and mitigation strategies (Yadav *et al.*, 2023).

Climate Change Impact on Major Fruit Crops

Mango

Mango is one of the most popular and widely cultivated fruit in the tropics and the subtropics. In the present scenario of climate change, mango cultivation is adversely affected world-wide. Whiley *et al.* (1989) observed that mean leaf size of mango trees grown at 30/25°C (day/night temperature) was 300% larger than that of trees growing at 20/15°C.

Whereas Dambreville *et al.* (2013) did not find any significant effect of temperature on leaf size for leaves which developed in the mean daily temperature range of 20-28°C. Phenomenon of flowering in mango specifically confined to climatic factors (temperature) and mainly cool temperatures. According to Dambreville *et al.* (2013) and Sukhvibul *et al.* (1999), variation in temperature also has a negative effect on inflorescence size and on the number of flowers per inflorescence. Increasing temperatures may cause erratic flowering and rapid growth of mango fruits.

Male: hermaphrodite flower ratio mainly depends on temperature. In controlled environment, low temperatures (15°C day/10°C night) during inflorescence, reduces the proportion of perfect flowers and improves number of male flowers. In severe winter condition, mango pollens may lose viability, pollen tube growth may also slow down and development of ovary is affected. Ramswamy and Vijayakumar (1992) reported that south Indian cultivars produced greatest number of hermaphrodite flowers in later emerging panicles during high temperature. Whereas, Singh *et al.* (1998) found that panicle emergence during low temperature conditions (Dec-Jan) produce higher number of male flowers. Low temperature in northern India leads to formation of malformed panicles and clustering in mango. Olesen (2011) suggested that an increase of winter temperatures at 1.5°C, the estimated duration of mango fruit development decreased by 12-16 days (7-8%) in Australia. Excessive light could have a positive effect on fruit size through improved photosynthesis (Urban *et al.*, 2003). Increase in temperature leads to induction of stress condition, enhancing synthesis of secondary compounds and thereby improving fruit quality. Higher light intensity improves skin color for colored cultivars (Lechaudel *et al.*, 2013). The effects of drought on fruit quality are positive and negative and well-known in non-irrigated orchards. Drought reduces fruit size (Spreer *et al.*, 2009) and increases fruit quality, in relation to dry matter content and sugar concentration (Lechaudel *et al.*, 2005).

However, mango suffers severely in areas experiencing frequent rains or high humidity (>80%) during flowering period. Such conditions are not conducive to a good fruit setting increases the incidence of serious pests and diseases like powdery mildew and anthracnose. Air polluting gases like coal fume, sulphur dioxide, ethylene, carbon mono-oxide and fluoride significantly increase the intensity of certain physiological disorders like black tip of mango.

Grape

Grape is a delicious fruit, widely used for wine preparation as well as fresh consumption and for preparation of byproducts throughout the world. Quality grape production is mainly

dependent on climatic conditions of a particular season. In 21st century, climate change is becoming a serious threat for grape growers. The base temperature for grape is 10°C and temperatures between 22 and 35°C are most congenial. The variations in temperature cause alterations in developmental stages and ultimately the ripening time (Faralli *et al.*, 2024). Sudden or prolonged decrease in temperature in subtropical and temperate regions are a major limitation for grape production, which not only cause frost injury but also increase the incidence of pest and diseases. According to Bindi *et al.*, 2001, expected rise in CO₂ (8-14%) concentrations not only stimulate grapevine production but also improve quality by stimulating acid and sugar content in berries.

But at the same time, these positive CO₂ consequences with warmer temperatures decrease duration of active photosynthesis, higher respiration and shorter duration of development stages which ultimately reduce yield (Pawar *et al.*, 2025). Due to changes in solar radiation, UV-B radiation levels will continue to rise which will directly affect the grape composition and flavor development via alteration of secondary metabolites such as flavonoids, amino acids and carotenoids (Schultz, 2000). Temperature plays a very important role for wine production. White *et al.* (2006) studied the effect of climate change on wine production in the United States. On the basis of high-resolution regional climate model forced by the IPCC, he reported that premium wine grape production area in the United States could decline by up to 81% by late 21st century. Santisi (2011) commented that minor shifts in seasonal temperature can make the difference between a poor, good, or excellent quality of wine. Colder than normal temperatures lead to incomplete ripening with high acid, low sugar and unripe flavors while warmer-than-normal temperatures create overripe fruit with low acid, high sugar, high alcohol and cooked flavors. An upward shift in seasonal temperatures will dramatically shift the growing season, thereby changing the normal pattern of grape development toward an earlier onset of flowering, veraison, and harvest (Keller, 2010). Buttrose (1971) found that during water stress condition grape vine reduced inflorescence initiation shoot growth. Several researchers (Crippen and Ivlorrison, 1986; Matthews, 1987) reported that water deficit during stage I (when cell division is occurring) will generally reduce berry size more than water deficits during stages II and III (growth cell expansion).

Banana

Bananas (*M. acuminata* Colla) are the developing world's fourth most valuable food crop, following only rice, wheat and maize in terms of gross value of annual production (Frison *et al.*, 2004), and are the 12th most globally-important plant crop by value and quantity (FAOSTAT, 2010). It also serves as an important cash crop in Brazil, Africa, India, etc. In these subtropical regions, bananas are subject to suboptimum temperatures and short days as well as occasional cold snaps and killing frosts in the winter. Future climates (2020s) are expected to be less suitable in more than 70% of the global land areas (mainly tropical areas), but that there could be gains towards the subtropics that could both increase yields and expand areas suitable for *Musa* (Ramirez *et al.*, 2011).

Thornton, 2012 studied that rise in temperatures may increase suitable areas but also result in increased water demand, limiting banana cultivation to the areas projected to receive increased rainfall. Daily temperature in the range of 20-30°C is optimum for year round banana production (Simmonds, 1962). Calberto *et al.* (2015) suggested that at 38°C temperature, plant stops its growth while temperatures of 40°C are thermal danger point for survival of banana plants and also reported that temperature 6°C and 0°C cause leaf

chlorophyll destruction and frost damage respectively. Though banana can survive water stress for long periods of time, low soil moisture and extended exposure to extreme temperatures (above 35°C) can reduce banana production (Thornton and Cramer, 2012). Meanwhile, highland bananas are projected to observe significant yield loss due to increased risk of pest and diseases if the temperature increases by 2°C (Thornton and Cramer, 2012). Bergh *et al.* (2012) found that bananas cannot grow with monthly minimum temperatures below 0°C; they stop growing below 12°C or above 33°C and have optimum growth between 17.5 and 26.3°C.

However, variability in rainfall is expected to result in a loss of suitable areas in the lowlands (Ramirez *et al.*, 2011). High temperatures response to deform banana bunches and leaf damage. Blackbourn *et al.* (1989) found that fruits of 'Cavendish banana' failed to degreen, when ripened at the high temperatures of the tropics (>24°C) which might be associated with retention of chlorophyll and thylakoid lamellae. Banana is a herbaceous plant and is very sensitive to wind and waterlogged conditions. If rainfed subtropical bananas receive rainfall less than 200 mm/year or more than 4000 mm/year, it will definitely result in crop failure. They can grow optimally when rainfall is between 900 and 1760 mm/year and soil drainage is good (Bergh *et al.*, 2012).

Citrus

Citrus is a big group, including different types of edible fruits (Oranges, lime, lemon, Grape fruit *etc.*). It is well known for its fresh consumption, processing purposes and nutraceutical medicinal values in different parts of the world. Even though citrus is considered as one of the major fruits grown, yet the changing climatic conditions is becoming a major problem for citrus industry in the near future (Shah *et al.*, 2024). Like other fruit crops, citrus is also confined to a specific climatic requirement for its better growth and development. Under subtropical conditions, citrus flowering occurs primarily during the spring following the inductive winter season (Monselise and Halevy, 1964). At least 45 to 60 days of water stress are required to induce an economic level of flowering in a tropical climate (Cassin *et al.*, 1969; Borroto *et al.*, 1977; Lovatt, *et al.*, 1988), while more than 70 continuous days of water stress may be detrimental to tree health and productivity (Cassin *et al.*, 1969). Very high temperatures during bloom and for the following 2 to 3 months result in excessive fruit drop (Moss, 1973; Brewer *et al.*, 1977). Besides the effect of high temperature on whole fruit trees, studies have also been carried out on the effect of temperature on individual plant parts in citrus. Direct heat injury results in electrolyte leakage (Ahrens and Ingram, 1988). It has long been established that fruits grown in humid areas have a thinner peel than those grown in desert areas. Sweet oranges need relatively cool night temperatures to develop acidity and total soluble solids needed for good quality. So, fruit trees grown in hot tropical areas are low in acid and are insipid.

Changing climate affects the citrus fruits quality which limits citrus cultivation world-wide. Davis (1997) noted that fruits produced in Mediterranean region were fresh, relatively blemish free, brightly-colored because of low night temperatures and relative humidity. Whereas humid subtropical regions yield quality fruits for processing industries which have higher total soluble solids and juice. He also suggested that fruit quality is generally poor in the low tropics for oranges and mandarins, but improves at higher altitudes of the mid-tropics. In citrus (Valencia sweet orange) production may shift slightly northward in the southern states, but yields may decline in southern Florida and Texas due to excessive heat

during the winter (Rosenzweig *et al.*, 1996). Sugiura and Yokozawa (2004) predicted that due to impact of climate change the regions favorable for cultivating apples and satsuma mandarins will gradually move northward. They concluded that global warming will greatly affect the cultivation environment of 'Apples' and 'Satsuma' mandarins in Japan by the middle of the 21st century.

Papaya

Allan, 1963 reported that adverse climatic conditions cause poor development, resulting in degeneration of pollen mother cells and young pollen grains in some anthers. He also found that very little pollen is produced in early spring but abundant pollen is produced throughout the rest of the year. Papaya is susceptible to water logging but water stress conditions were also found arresting plant growth, induced leaf abscission and drastically decreased photosynthetic rate. A physiological disorder 'Freckle development' (exudation of latex from sub-epidermal laticifer arms), is mainly caused due to exposure of fruits surface to the cooler seasons (Allan, 2002). According to Kaiser *et al.* (1996) large diurnal temperature fluctuations may cause turgor induced latex exudation, resulting in freckle development. The fruits exposed to intense sunlight on the north and west sides show sunburn symptoms. This mainly happens when fruit surface temperature exceeds about 48°C, even though air temperature is only 36 °C (Savage and Allan, 1996). The heavy frost in northern parts of the country cause major loss to the papaya growers in India and abroad. Pereira and Allan (1994) found aborted seeds in the coldest months of the year.

Other tropical and subtropical fruit trees

Cold waves cause severe damage to guava fruit trees such as bronzing and dropping of leaves, fruit hardening, defoliation and drying of shoots, production of small size fruits, *etc.* Temperature higher than mean temperature result in less red color development on guava fruits, thereby current global warming led to decrease in area under red color guava cultivation. Flower initiation in litchi is best below 20°C, while the optimal temperature for leaf and fruit growth is about 30°C. Temperature below 2°C damages new leaves, while below 0°C can kill the trees (Menzel and Waite, 2005). Kumar and Kumar 2007 predicted that high temperature and moisture stress enhance incidence of sun burning and fruit cracking in litchi. 'Translucency of fruits', a common physiological disorder in pineapple induced water-soaked symptoms in fruit flesh. This disorder is associated with both higher (28/18°C, max/min temperature) and lower (23/15°C) temperatures three months before harvest (Paull and Reyes, 1996). Warm day/night (30/25°C) temperatures in 'Cherimoya' was found to be associated with damage of pollen and stigma which ultimately lead to low fruit set (Higuchi *et al.*, 1998).

Temperate Fruit Crops

Majority of temperate fruits (Apple, Pear, Peach, Plum, Almond *etc.*) are predominantly grown in European countries and other parts of the world. These fruit crops are specifically limited to its chilling requirement for flower induction. In recent years, due to increasing global warming the weather conditions becoming less efficient for fulfilling the chilling requirement of these crops. Hence, the cultivation of temperate fruits is shifting towards higher elevation, resulting in decreasing areas under these crops and increasing area under subtropical fruit trees. Some consequences of climate change on temperate fruits are decreasing of chilling hours, decreasing rainfall, advancement of flower initiation, *etc.* The

increased incidence of hailstorms during the growing period possibly associated with climate change (Follard and Karl, 2001).

It can be controlled by installation of hail nets but fruits grown under these hail nets suffer from lower fruit quality, less coloration, less firm fruit flesh, less sugar and possibly delayed ripening and harvest (Funke and Blanke, 2005). Many of the temperate fruit trees develop their vegetative and fruiting buds in the summer and these developed buds go into dormancy due to short day condition and cooler temperature in winter. Buds will remain in dormancy until they get sufficient chilling units (CU) of cold weather. As soon as buds get sufficient chilling hours, they start to grow in response to warm temperatures and develop normally. If the buds do not receive sufficient chilling hours during winter to break dormancy, tree will suffer some symptoms like delayed foliation, reduction of fruit set and also affect yield and quality.

In recent years Rana *et al.* 2008 observed significant reduction in average productivity of apples in north-western parts of Himalayas, due to inadequate chilling and is responsible for shifting of the apple belt to higher elevations. As a part of colour development, rapid accumulation of anthocyanin at cooler environment (mean monthly temperature of 18.6°C) whereas, warm temperature (mean monthly temperature of 25°C) associated with slower anthocyanin biosynthesis in 'Starkrimson Delicious' apples (Li *et al.*, 2004). Higher temperature (35°C) in mid-July and temperature (15.9°C) higher than normal during flower bud development period results in abnormal development of pistil in sweet cherry (Beppu *et al.*, 2001) and apricot (Rodrigo and Herrero, 2002). Similarly, Shen *et al.*, 1999 found that increase in temperature leads to increase in pollen development and increase tendency for aborted stamens. Ito *et al.*, 1999 studied that elevated CO₂ increased fruit size and fresh weight, but had no significant effect on fruit quality in 'Japanese pears. Similarly, Sugiura *et al.*, 2007 reported that fruit qualities in Japanese pears, peaches and Japanese apricot had clearly changed (reduction in color, increased fruit size, reduction of acid, softening and spoiling of fruits) due to increasing temperatures. According to Hopkirk *et al.* 1989 kiwifruit grown under high temperature (3-4°C more than the ambient temperature) during mid-march to mid-may had lower soluble solids, more firmness and higher starch concentrations in both core and cortex tissue. Rise in CO₂ level was found to increase the sugar: acid ratio and fruit volatile aroma compounds in strawberry (Wang and Bunce, 2004) and slight decrease in starch and minerals contents (Chen *et al.*, 1997). Carew *et al.* (2000) noted that temperature range above ambient level (22-25°C) results in reduction of node formation in raspberry. 'Albinism' is a major physiological disorder of strawberry. In this disorder development of white or pink coloration on the skin of fruits will occur and pulp remains pale. This disorder mainly observed in areas of warm weather and also favored by black polythene mulch, as it raises the soil temperature (Sharma *et al.*, 2003). Likewise, high temperature accelerates the development of water core in apple (Yamada *et al.*, 2004) and pear (Sakuma *et al.*, 1995). Kumar and Kumar (2007) confirmed that high temperature and moisture stress enhance incidence of sun burning and fruit cracking in apples, apricot, cherries and in litchi.

Adaptation and Mitigation strategies (Pawar & Sakhale, 2025)

- Adaptation of hi-tech horticulture and judicious management of land use resources (Dutta, 2013).
- Provide irrigation during critical stages of the crop growth.

- Use soil conservation practices like intercropping, growing of grasses, mulching, etc.
- Use efficient irrigation practices (drip irrigation) and integrated nutrient and insect pest management practices.
- Use of 'Anti Hail Guns' in the hail prone areas.
- Shifting of high chilling cultivars to higher altitude and grow low chill or subtropical cultivars in these regions (lower altitude).
- Use crops or varieties which are suitable for particular regions and tolerant to pest and diseases.
- Use canopy management practices like rejuvenation, training and pruning practices and their requirement to specific regions.

Table 2. Rootstocks or varieties of major fruits with their tolerance nature.

Crop	Varieties/rootstock	Tolerance nature
Grape	Dogridge, 1613 and Salt Creek)	Draought and Salinity tolerant
Mango	Bappakai, Turpentine, Olour, Chandrakaran, etc.	Salinity tolerant
Citrus	Rangpur lime, Cleopatra mandarin, etc.	Salinity tolerant
Banana	<i>Musa sikkimensis</i> , <i>Musa basjoo</i> , <i>Musa thomsonii</i>	Cold tolerant (Bakry, 2010)
Banana	<i>Musa balbisiana</i> , <i>Musa nagensium</i>	<i>Musa balbisiana</i> , <i>Musa nagensium</i> (Bakry, 2010)

Source: Bose and Mitra (1996)

CONCLUSION

However, the worst situation arising due to severe climate change is reduction in production, decrease in area under cultivation, rise in sea levels, problem of air pollution, etc. Strategies should be drawn up to identify the genes tolerant to high temperature, flooding and drought, nutrient efficient cultivars and production system for efficient use of nutrients and water. They should also address cultural practices that conserve water and promote crop. Development of climate-resilient horticultural crops which are tolerant to high temperature, moisture stress, salinity and climate proofing through genomics and biotechnology are the need of the hour.

Enhancing the adaptation of tropical production systems to changing climate is a great challenge and would require integrated efforts and an efficient and effective strategy to be able to deliver technologies that can mitigate the effects of climate change on diverse crops and production systems. Knowledge of carbon sequestration, especially through perennial horticulture, needs to be enhanced, which could be utilized for enhancing the income through carbon trading. Research must address all the strategies which can convert the challenges into opportunities. Concerted and integrated efforts with effectiveness and efficiency would definitely make us stronger to face the challenges and meet the ever-increasing demand for food and nutritional security by maintaining the quality and production of fruit crops. Keeping in view the current problems, the adoption of technologies as discussed in this chapter may be beneficial for farmers and researchers.

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