

Review Article

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## Response of Fruit Crops to Climate Aberration, Its Possible Affect in North East India and Mitigation Strategies – A Review

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### ABSTRACT

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Climate change is a major threat to biodiversity, ecosystem services, and human well-being and will have impact on horticultural crops, due to erratic temperature regime, rainfall, more demand for water and enhanced biotic and abiotic stresses. Global warming has the potential to reduce available winter chill and thus greatly impact yield of temperate fruits and nuts. On the other hand, subtropical and tropical fruit tree species might have the opportunity to spread beyond their current latitudinal belts and to much higher elevations, while others will decline in increasingly adverse locations. Changes in plant phenology are one of the earliest responses to rapid global climate change and could potentially have serious consequences for fruit crops that depend on temperature and rainfall. However, the changes will not be only harmful, as CO<sub>2</sub> concentration may enhance faster photosynthesis and increased temperature may hasten the process of maturity. Temperature increase affects photosynthesis directly, causing alterations in sugars, organic acids, and flavonoids contents, firmness and antioxidant activity. Hence there is a need to protect these valuable crops for sustainability against the climate change scenario.

### Introduction

Climate on Earth has changed many times since the existence of our planet, ranging from the ice ages to periods of warmth. Due to its significance on human life, agriculture was one of the first sectors to be studied in terms of potential impacts of climate change (Adams *et al.*, 1990). Many models and modules have been developed, predictions have been made. According to studies carried out by the Intergovernmental Panel on Climate Change (IPCC), average air temperatures will increase between 1.4 °C and

6.4 °C by the end of this century. Assad *et al.*, (2004) predicted that in near future rising air temperature could induce more frequent occurrence of extreme drought, flooding or heat waves than in the past. Impacts of climate change on agricultural sector into three broad categories of direct effect, indirect effect and socio economic effect (Kim, 2009). The authors represented the effects of global warming on horticultural crops in ten different categories (fig. 1 and fig. 2).

The North Eastern Region (NER) of India comprising eight states, shares 8% area of the

country, has about 72% area under hilly ecosystems which is characterized by rough fragile marginal terrain and mild to excessive sloping land, rich biodiversity, unique ethnicity and socio-ecological set up. The region receives significantly high rainfall, its varied physiological features and altitudinal differences gives rise to diverse types of climate ranging from near tropical to temperate and alpine. The region has been identified as one of the biodiversity hotspots of India. The annual rainfall in the region is received mainly from south-west monsoon and starts from middle of May and continues till October. On an average, the NE region receives about 2450 mm of rainfall. The Cherrapunji-Mawsynram range receives rainfall as high as 11,500 mm, annually. The temperature varies from 15°C to 32°C in summer and 0 to 26°C in winter. The region has also suffered from climate change. The rich biodiversity of the region is a good indicator climate change effects over a period of time. The 'South Assam Meteorological Subdivision', covering mainly the hill states of Nagaland, Manipur, Mizoram and Tripura and parts of the Barail Hills in southern Assam, reported a significant change in seasonal rainfall. The summer monsoon rainfall is found to be decreasing over this region significantly during the last century at an approximate rate of 11 mm per decade (Das, 2004; Mirza *et al.*, 1998). Analysis of long-term temperature data for the region points to a distinctly rising trend in surface air temperatures. The annual mean maximum temperatures in the region are rising at the rate of +0.11°C per decade. The annual mean minimum temperatures are also increasing at a rate of 0.04°C per decade in the region (Das, 2004).

For any successful fruit crop cultivation climate plays an important role. Fruit crops respond to climatic changes by altering phenological, physiological processes. There

is loss of vigour, fruit bearing ability, reduction in size of fruits, less juice content, low colour, reduced shelf life and increasing attack of pests resulting low production and quality of many fruits. Abnormal high temperature during winter cause poor flowering, irregularity in flowering duration, pattern of flowering and poor yield in pear due to non-availability of sufficient chilling hours during winter months (Hazarika, 2013). The impacts of climate change in north eastern region are less studied and less known, making the future scenarios more uncertain for vulnerability assessment and risk management.

### **Resource availability**

The characteristic features of NE fruit crop production system is rainfed, use of local varieties, limited use of agro-chemicals, low moisture retention capacity of upland soil and traditional management practices. Problems of high rainfall (12.10% of the country's total precipitation), soil acidity, aluminum toxicity in upland and iron toxicity are abundant. The steep hilly slopes are vulnerable to sheets and gullies erosions, resulting in barren rocky slopes. The major fruit crops are pineapple (*Ananas comosus*), banana (*Musa spp.*), passion fruit (*Passiflora edulis*), khasi mandarin (*Citrus reticulata*) and kachai lemon (*Citrus jambhiri*). Recently temperate fruit crops like kiwifruit (*Actinidia deliciosa*) and plum (*Prunus domestica*) have gained popularity. Northeast India is the citrus depository, where many citrus species are originated. Khasi mandarin (*Citrus reticulata*) is widely cultivated and Sweet orange (*Citrus sinensis*) is also commercially grown in some of the places. Maximum genetic variability of *Musa acuminata* and *M. balbisiana* occurs in NE India. *M. flaviflora* is localized to Manipur and Meghalaya. Rich diversity occurs in *Pyrus*, *Rubus*, *Ribes* and *Prunus*. The Shillong plateau of Khasi hills in

Meghalaya have many *Prunus* species such as *P. nepalensis*, *P. undulate* and *P. cerasoides*. *Pyrus pyrifolia* var. *cubha makai* (*P. serotina* Red) and some of them are grown semi commercially in Meghalaya. A large number of other tropical and subtropical fruits belonging to the genera *Garcinia*, *Artocarpus*, *Phyllanthus*, *Annona*, *Averrhoa*, *Persia*, *Aegle*, *Passiflora* and *Tamarindus* etc., are found growing wild in the region. Jackfruit is indigenous to the region and grows abundantly in Tripura, Assam, Nagaland and Meghalaya with a large number of cultivars and land races.

### **Vulnerability due to vagaries of temperature and water availability**

High temperatures can increase the capacity of air to absorb water vapor and consequently generate a higher demand for water. Higher evapotranspiration indices could lower or deplete the water reservoir in soils, creating water stress in plants during dry seasons. Water stress is of great concern in fruit production, because fruit trees are not irrigated in many production areas of NE region. It is well documented that water stress not only reduces crop productivity but also tends to accelerate fruit ripening (Henson, 2008). During their development, high temperatures can affect photosynthesis, respiration, aqueous relations and membrane stability as well as levels of plant hormones, primary and secondary metabolites. Ultimately it causes morphological, anatomical, physiological, biochemical changes in plant tissues and as a consequence can affect growth and development of different plant organs. These events can cause drastic reductions in commercial yield. Seed germination can be reduced or even inhibited by high temperatures, depending on the species and stress level (Bewley, 1997). Ambient temperatures for the development of fruit crops are much narrower and depending

on the species and ecological origin, it can be pushed towards 0°C for temperate species from cold regions, similarly, they can reach 40°C in species from tropical regions. A general temperature effect in plants involves the ratio between photosynthesis and respiration. For a high yield, not only photosynthesis should be high but also the ratio photosynthesis/respiration should be much higher than one. At temperatures around 15°C, the above mentioned ratio is usually higher than ten, explaining why many plants tend to grow better in temperate regions than in tropical ones (Went, 1953). Higher than normal temperatures affect the photosynthetic process through the modulation of enzyme activity as well as the electron transport chain (Sage and Kubien, 2007). Additionally, in an indirect manner, higher temperatures can affect the photosynthetic process increasing leaf temperatures and, thus, defining the magnitude of the leaf-to-air vapor pressure difference, a key factor influencing stomatal conductance (Lloyd and Farquhar, 2008). Temperature is of paramount importance in the establishment of a harvest index. The higher the temperature during the growing season, the sooner the crop will mature. Kiwi grown under higher temperatures matured earlier than the same crops grown under lower temperatures. Due to rise in temperature, crops will develop more rapidly and mature earlier (Hall *et al.*, 1996; Wurr *et al.*, 1996). For example, citrus, grapes, melons etc. will mature earlier by about 15 days. Strawberries will produce more runners at the expense of fruits. Specific chilling requirements of pome and stone fruits will be affected hence dormancy breaking will be earlier. High temperature and moisture stress also increase sunburn and cracking in apples and increase in temperature at maturity will lead to fruit cracking and burning in litchi (Kumar and Kumar, 2007). Banana cultivation may suffer from high temperature, soil moisture stress or

flooding/water logging. In Banana, leaf production increases by one leaf per month for every 3.3 to 3.7°C rise in minimum or mean temperature from 10-20°C or 13.5 to 25°C respectively. Higher temperature (31-32°C), in general, increases the rate of plant maturity in annual species, thus shortening the growth stages, during which developing fruits and suckers absorb photosynthetic products. The temperature below 10°C leads to impedance of inflorescence and malformations of bunches. Chilling symptoms on leaves are not seen immediately but it may take 2 to 4 days to appear (Datta, 2013). In banana, Flooding for more than 48 hrs severely reduces growth and after 72-96 hrs, no recovery of mature shoots. Water logging in robusta plant reduces the bunch weight. Higher temperature 31-32°C, increases the rate of plant maturity & shorten the growth stages. High air temperatures 38°C and bright sunshine causes choked plant, sunburn damage to fruit. Dwarf Cavendish, temperature below 10°C leads to impedance of inflorescence and malformations of bunches. Choked bunches are prone to sunburn (Singh, 2012). Wild species of banana namely *Ensete glaucum*, *Musa cheesmanii*, *M. magnesium*, *M. balbisiana*, etc. are abundantly found in Manipur. The impact of climate change on these crops is of high relevance. Shortening the growing period, decrease in water availability and poor vernalization are expected to decrease potential yields. Plants requiring high humidity and water may face challenges for survival. Due to changing climate, high temperature conditions are expected to be prevalent throughout the growing period which will increase temperature stress on the crops. This can disturb the biochemical reactions in plants essential for normal cell function. The photosynthetic functions of higher plants will be affected adversely. Delay in monsoon, dry spells of rains and untimely rains during water stress period,

supra-optimal temperatures during flowering and fruit growth, hailstorms are some of the most commonly encountered climatic conditions experienced by the citrus growers over the past decade or so. In citrus severe water stress causes reduction in leaf initiation, leaf size gets reduced and leaves become leathery and thick. Root growth is adversely affected by water stress. It may lead to increased rooting depth and higher proportion of feeder roots. Rainfed cashew crop is highly sensitive to changes in climate and weather vagaries, particularly during reproductive phase. Cashew requires relatively dry atmosphere and mild winter (15-20°C) coupled with moderate dew during night for profuse flowering. High temperature (>34.4°C) and low relative humidity (<20%) during afternoon causes drying of flowers, resulting in yield reduction. Unseasonal rains and heavy dew during flowering and fruiting period aggravated the incidence of pests and diseases. All these situations resulted in reduction yield upto 50 to 65%. Monoembryonic mango cultivars tend to be more cold tolerant than polyembryonic cultivars, probably due to their origin of evolution. However, mango trees can tolerate temperatures up to 48°C for short periods and have limited tolerance to cold. Early flowering in the sub-tropics may result in a low fruit set because of several abnormalities caused due to low night temperatures coupled with unseasonal rains. Late flowering also reduces the fruit set because of pseudo-fruit setting leading to clustering disorder. High temperatures during panicle development in mango speed up growth and reduce the number of days for effective pollination when hermaphrodite flowers are available, which may lead to unsatisfactory production. Unseasonal rains coupled with variation in temperature and humidity can make mango trees flower during off season, but fruit set will be poor because of the showers. Rising temperatures cause desiccation of pollen and

poor pollinator activity resulting in low fruit set and, ultimately, a poor crop. Flower buds exposed to cold temperature during night may change into vegetative ones under the warm night conditions. In the tropics, cool winters followed by a rise in day temperatures as summer approaches may result in poor flowering. Cool temperatures during inflorescence development reduce the number of perfect flowers (Bhruguvanshi, 2009). In papaya, higher temperatures have resulted flower drops in female and hermaphrodite plants as well sex changes in hermaphrodite and male plants. The promotion of stigma and stamen sterility in papaya is mainly because of higher temperatures. In grapes, degree-days are important in determining the timing of various phenological events where, a temperature regime of 10°C and temperatures between 28-32°C are most congenial. Variations in temperature cause alterations in the developmental stages and ultimately the ripening time. Under a higher temperature regime, the number of clusters per shoot was greater and the number of flowers per cluster was reduced (Pouget, 1981). Kliewer (1977) demonstrated the loss of ovule viability in the varieties Pinot Noir and Carignane at 35°C and 40°C as compared to 25°C. High temperatures also reduce colour development. In the case of guava, it has been observed that red colour development on the peel of guava requires cool nights during fruit maturation. Varieties like Apple Colour, which have attractive apple skin colour under sub-tropical conditions, have red spots on the skin under tropical South Indian conditions (Rajan, 2008). In pineapple, the impact of temperature variations can be seen from studies where induction of flowering takes place because of reduction in temperature, short day lengths or both (Friend, 1981). The coincidence of long days with high temperatures results in irregular flowering. Cultivation of temperate fruits like apples moving to further higher elevations. Taking

the example of Himachal Pradesh where apple productivity in Bajaura valley decreased by 2–3% due to climate change. Apple has been replaced by off-season vegetables. In more recent years, apple in Kullu valley has been replaced by pomegranate and kiwi fruit. In over a decade, cooler Lahoul valley has recorded a remarkable increase of more than 122% in area under apple, while productivity of ruling seasonal crops like potato and pea has declined by 11–15% (Ghosh, 2012). Similar trends have been reported from Arunachal Pradesh. Bharali and Khan (2011) in a study from Mechuka of Arunachal Pradesh found that, 15–20 years ago the apples in Mechuka were sweet, but now the fruits taste sour. Earlier apples used to flower only once in a year during February. Now they flower twice a year, in late March and September. The flowers that bloom in March produce fruits, while those that bloom in September do not produce any fruits.

Extreme precipitation will cause crop yield variation. Increase in pest and disease incidence as well as increase in evaporation and runoff will decrease the soil moisture recharge. Pollination is crucial for reproduction of most flowering plants. Climate change may reduce the activity of pollinating agents and pose a serious threat to pollination services, which may lead to floral abortion. Climate change and CO<sub>2</sub> concentration is likely to alter key interactions between horticultural plants and pollinators, insect pests, diseases and weeds. Melting of ice cap in the Himalayan regions is likely to reduce the chilling availability for flowering plants. This may result in less abundant flowering or no bloom, while some other plants will be threatened. Evidences show that many plant species shift their geographical habitats to combat regional climatic variation. Many species are unable to acclimatize to the pace of climatic variations. Stability in environmental conditions is essential for

alpine regions, where many species may disappear altogether. So, these changes may increase the extinction risk.

### **Vulnerability due to exposure of carbon dioxide and ozone**

The greenhouse effect is primarily a combination of the effects of water vapor, CO<sub>2</sub> and minute amounts of other gases (methane, nitrous oxide, and ozone) that absorb the radiation leaving the Earth's surface. Since a significant part of all the energy emanated from Earth occurs in the form of infrared radiation, increased CO<sub>2</sub> concentrations mean that more energy will be retained in the atmosphere, contributing to global warming. CO<sub>2</sub> concentrations in the atmosphere have increased approximately 35% from pre-industrial times to 2005 (IPCC, 2007). Besides industrial activities, agriculture also contributes to the emission of greenhouse gases. CO<sub>2</sub> and O<sub>3</sub> concentrations in the atmosphere are changing during the last decade and are affecting many aspects of fruit crops production around the globe (Felzer *et al.*, 2007; Lloyd and Farquhar, 2008). If atmospheric CO<sub>2</sub> concentration is doubled, the overall growth of C<sub>3</sub> plant will increase, thus, resulting in increased marketable yield (30–40%). But the positive impacts of increased CO<sub>2</sub> concentration will be nullified by increased temperature and scarcity of water resulting in decreased production. Han *et al.*, (2012) showed the effects of CO<sub>2</sub> level on tree growth and fruit characteristics of 'Niiitaka' pear. Fruit weight was the highest in elevated CO<sub>2</sub> group, but lowest in elevated temperature group. Flesh firmness at harvest was the highest in elevated temperature group. Soluble solids content increased at harvest time in groups with elevated CO<sub>2</sub>. Rising CO<sub>2</sub> concentration alone may increase mango production and water use efficiency, but comprehensive studies predict decreases in yield of mango when increasing

temperature and changes in solar radiation are considered simultaneously. In grape elevated atmospheric CO<sub>2</sub> levels significantly effects fruit dry weight, with increase in tartaric acid and total sugars contents.

O<sub>3</sub> concentration in the atmosphere is also increasing. Even low levels of O<sub>3</sub> in the vicinities of big cities can cause visible injuries to plant tissues as well as physiological alterations (Felzer *et al.*, 2007). The effects of O<sub>3</sub> on vegetation have been studied both under laboratory and field experiments. Stomatal conductance and ambient concentrations are the most important factors associated with O<sub>3</sub> uptake by plants. O<sub>3</sub> enters plant tissues through the stomatas, causing direct cellular damage, especially in the palisade cells (Mauzerall and Wang, 2001). The damage is probably due to changes in membrane permeability and may or may not result in visible injury, reduced growth and, ultimately, reduced yield (Krupa and Manning, 1988). Visible injury symptoms of exposure to low ozone concentrations include changes in pigmentation, also known as bronzing, leaf chlorosis, and premature senescence (Felzer *et al.*, 2007). Additionally, Percy *et al.*, (2003) observed that O<sub>3</sub> exposure causes reduction in photosynthesis and increased turnover of antioxidant systems.

### **Abnormality in quality parameters and ripening**

Extensive work has been carried out for more than three decades focusing quality properties of fruit crops exposed to high temperatures during growth and development. Flavor is affected by high temperatures. Apple fruits exposed to direct sunlight had a higher sugar content compared to those fruits grown on shaded sides (Brooks and Fisher, 1926). Grapes also had higher sugar content and lower levels of tartaric acid when grown under high temperatures (Kliwer and Lider

1968, Kliewer and Lider 1970). Coombe (1987) observed that a 10°C increase in growth temperature caused a 50% reduction in tartaric acid content. Kliewer and Lider (1970) and Lakso and Kliewer (1975) verified that malic acid synthesis was more sensitive to high temperature exposure during growth than was the synthesis of tartaric acid. Fruit firmness is also affected by high temperature conditions during growth. 'Fuerte' avocados exposed to direct sunlight (35°C) were 2.5 times firmer than those positioned on the shaded side (20°C) of the tree (Woolf *et al.*, 2000). 'Hass' avocados grown under high ambient temperatures (45±2°C) had higher moisture content at harvest than fruit grown under lower temperatures (30±2°C). They also noted that higher temperature influenced oil composition, where the concentration of certain specific fatty acids increased. Avocados with higher dry matter content take longer to ripen which could pose a serious problem for growers planning to market their fruits immediately after harvest (Woolf *et al.*, 1999).

Thus, fruit growers, packers and shippers must pay close attention to ambient temperatures during growth and development as well as maturity indices to assure harvest at the appropriate time. Mineral accumulation was also reported to be affected by high temperatures and/or direct sunlight. 'Hass' avocado fruits exposed to direct sunlight showed higher calcium (100%), magnesium (51%) and potassium (60%) contents when compared to fruits grown under shaded conditions (Woolf *et al.*, 1999). High temperatures also appeared to reduce monoterpenes (Muscat flavor) in grapes. Linalool, an important monoterpene was also higher at low temperature (Zemni *et al.*, 2005). Antioxidants in fruit crops can also be altered by exposure to high temperatures during the growing season. Wang and Zheng (2001) observed that 'Kent' strawberries

grown in warmer nights (18–22°C) and warmer days (25°C) had a higher antioxidant activity than berries grown under cooler (12°C) days. The investigators also observed that high temperature conditions significantly increased the levels of flavonoids and, consequently, antioxidant capacity. Galletta and Bringhurst (1990) verified that higher day and night temperatures had a direct influence in strawberry fruit color. Berries grown under those conditions were redder and darker. McKeon *et al.*, (2006) also reported higher temperatures tends to reduce vitamin content in fruit crops.

Grape berries exposed to direct sunlight ripened faster than those ripened in shaded areas within the canopy (Kliewer and Lider, 1968). Ripening of 'Hass' avocados was also affected by exposure to high temperatures during growth and development. For fruits exposed to direct sunlight, pulp temperatures reached 35°C and required 1.5 days longer to ripen than those that grew in the shade (Woolf *et al.*, 1999). 'Fuerte' and 'Hass' fruits exposed to direct sunlight were firmer than fruits of the shaded areas. Cell wall enzyme activity (cellulose and polygalacturonase) was negatively correlated with fruit firmness, indicating that sun exposure, i.e., higher temperatures during growth and development, can delay ripening. However, in apples, treatments of 38 and 40°C for 2–6 days did not have marked effects on respiration, although ethylene production was reduced (Liu, 1978, Porritt and Lidster, 1978). The above studies suggest that changes in ripening behavior are likely to occur when fruit crops are exposed to higher temperatures prior to harvest.

### **Climate change effect on physiological disorders, harvest and postharvest**

Air pollution also significantly reduced the yield of several horticultural crops and

increases the intensity of certain physiological disorders like black tip of mango which is induced by coal fume gases, sulphur dioxide, ethylene, carbon monoxide and fluoride. Exposure of fruit crops to high temperatures can result in physiological disorders and other associated internal and external symptoms. It is also well known that exposure of fruit to temperature extremes approaching 40°C can

induce metabolic disorders and facilitate fungal and bacterial invasion. Frequent exposure of apple fruit to high temperatures, such as 40°C, can result in sunburn, development of water core and loss of texture (Ferguson *et al.*, 1999). Moretti *et al.*, (2010) enumerated the adverse effect to heat and CO<sub>2</sub> on fruit crops (Table 1 and Table 2).

**Table.1** Symptoms of heat and solar injury of fruit crops

Crop	Symptom
Apple	Skin discoloration, pigment breakdown and water soaked areas
Avocado	Skin and flesh browning, increased decay susceptibility, affect fruit size & capacity to 'store' mature crop on the avocados tree
Lime	Juice vesicle rupture, formation of brown spot on the fruit surface
Pineapple	Flesh with scattered water soaked areas, translucent fruit flesh, irregular flowering.
Strawberry	28-30°C runner production commences and flower production decreases

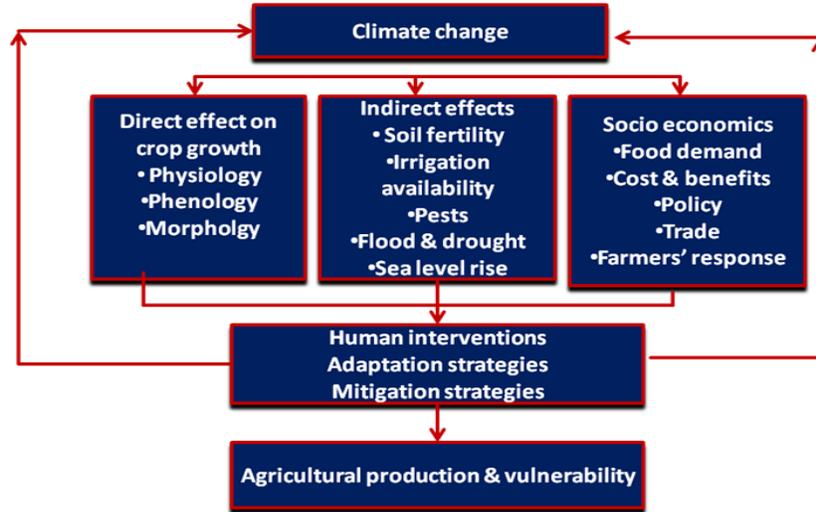
Source: Moretti *et al.*, (2010)

**Table.2** Physiological and quality parameters of fruit crops affected by exposure to increased CO<sub>2</sub> levels

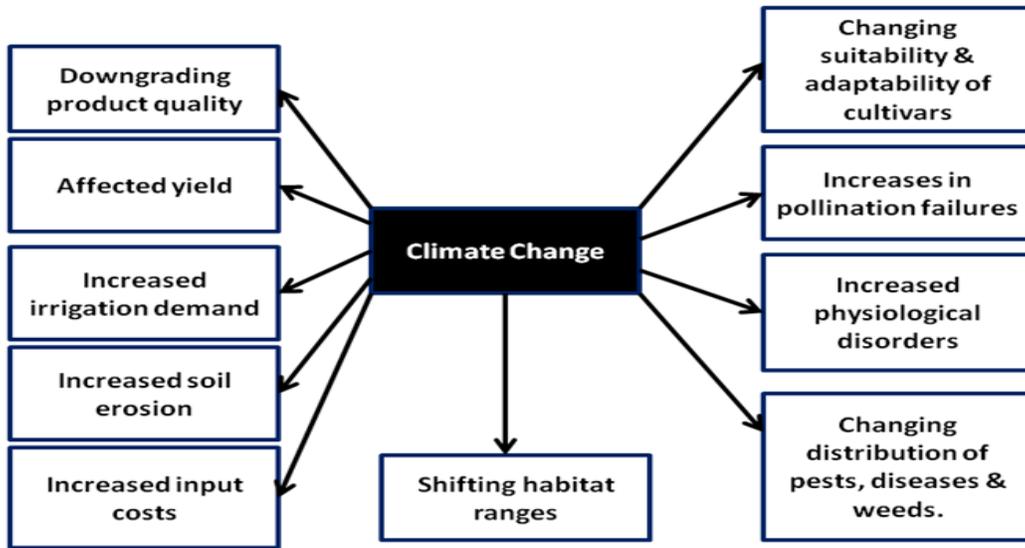
Physiological and quality parameter	Effect of high CO <sub>2</sub>	Crop
Respiration	↓	Blueberries
	↑	Lemon, mango
	=	Apples
Firmness	↑	Strawberry, raspberry
Colour intensity	↑	Grape
Alcohol	↑	Grape, mango, pear
Titrateable acidity	=	Grape
Ascorbic acid	↑	Strawberry, orange
Total phenol, Anthocyanin	↑	Grape, strawberry
Flavanoid, pH	↑	Grape
Volatile compound	↓	Mango
Antioxidant capacity	↓	Strawberry

Source: Moretti *et al.*, (2010)

**Fig.1** Potential impacts of climate change on the agricultural sector (source: Kim, 2009)



**Fig.2** Potential impacts of global warming on the Horticulture sector (source: Kim, 2009)



Climatic fluctuations are also known to affect post-harvest quality of fruits and affect food safety during storage. Fruit are generally cooled after harvest and before packing operations. It removes field heat from fresh produce, based on the principle that shelf-life is extended 2 to 3 fold for each 10°C decrease in pulp temperature. By reducing the respiration rate and enzyme activity, produce quality is extended as evidenced by slower ripening/senescence, maintenance of

firmness, inhibition of pathogenic microbial growth and minimal water loss (Talbot and Chau, 2002). It is anticipated that under warmer climatic conditions, fruit crops will be harvested with higher pulp temperatures, which will demand more energy for proper cooling and raise product prices.

Ozone also showed the capability of removing ethylene from the environment, inside cold rooms. Strawberries cv. Camarosa

stored for three days under refrigerated storage (2°C) in O<sub>3</sub> enriched atmosphere (0.35 µl l<sup>-1</sup>) showed a threefold increase in vitamin C content when compared to berries stored at the same temperature under normal atmosphere (Perez *et al.*, 1999).

### **Changes in pest and diseases incidence**

It is now recognized that climate change will affect plant diseases together with other components of global change. Direct effects on plant health by climate warming, increased pollutants and CO<sub>2</sub> concentrations will be accompanied by the easier introduction of exotic invasive species. Introductions of novel plant pathogens have already occurred in many regions, but climate changes are likely to often facilitate their further establishment and spread. High temperatures coupled with high rainfall and humidity help in building up ideal conditions for the growth of a number of disease pathogens. The powdery mildew disease in mango is a sporadic but serious disease of mango inflorescence that can cause up to 80-90% losses of the crop in extreme cases. Optimal disease development occurs at 10-31°C and 60-90% RH. Chhata *et al.*, (2006) reported that high humidity (85-90%), moderate temperatures provided favourable condition for the initiation of disease.

Correlations between weather parameters like different maximum temperature regimes and sunshine hours had negative correlations with disease development, while minimum temperature, humidity and wind speed had positive correlations. However, in a study conducted by Kumar (2010) has shown that in mango cv. Chausa the rate of development of fruit fly increased with the increase in temperature from 20-35°C. The percent larval survival, adult emergence and growth index also increased with an increase in temperature from 20 to 27°C and thereafter decreased up to 35°C. Thus a temperature of 27°C was

found to be ideal for survival and development of the immature stage and reproduction of *Bractocera dorsalis*. Downy mildew is found worldwide wherever grapes are grown, occurring primarily where warm, humid conditions exist during the growing season. Unseasonal rains coupled with higher temperatures during vegetative phases in grapes will result in damage due to this disease (Pearson and Goheen, 1988). Dry spell during flower emergence and fruit set affects flower initiation and aggravates incidence of pest (*Psylla*).

### **Future Line of Work**

Climate smart horticulture is not a single specific agricultural technology or practice that can be universally applied. It is an approach that requires site specific assessments to identify suitable production technologies and practices to address multiple challenges faced by agriculture and food systems simultaneously and holistically. There is need to analyze and understand about climate change at regional levels in relation to both annual and perennial fruit crops (Malhotra, 2017). Technological intervention for climate smart agriculture is an integral part of the local climate change action. Cover cropping, in-situ residue management and restoration of degraded lands for soil moisture conservation can improve C-sequestration. Integrated farming systems for soil and moisture conservation and nutrient recycling could be answer for better sustainability. Water conservation through *In-situ* methods like land configuration, mulching and *ex-situ* methods ponds, micro water harvesting structure (*jalkund*) can be helpful for orchards to coop up with water stress. Promotion of technologies that enhance biological N fixation and improve nutrient and water use efficiency to reduce N<sub>2</sub>O emission. Creating of new varieties, rootstocks suited to the changing climate may escape climatic

vagaries. Crop like grapes, where rootstocks Dogridge have shown remarkable adaptability. Several studies have shown that rootstocks have influenced the scion cultivars. Sharad Seedless recorded maximum water use efficiency (WUE) when budded on Dogridge followed by Flame Seedless on Dogridge rootstock at 50% moisture stress (Sathisha and Prakash, 2005).

Selection of appropriate rootstocks in various fruit crops like mango and guava to suit the changed climatic conditions could be one of the solutions for combating temperature change. Along with such rootstocks, one can consider the use of certain specific species that are better adapted to changed conditions. For instance, several fruit crops have modified physiological and morphological adaptations and withstood these changes well. Fig has adapted to retain high bound water in the tissue, by having sunken stomata, thick cuticle and waxy coating on the leaves. Underutilized fruits like ber (*Ziziphus mauritiana* L.), phalsa (*Grewia asiatica* L.) and tamarind (*Tamarindus indica* L.) also have sunken stomata, thick cuticle and waxy coating of the leaves. Indian gooseberry or Aonla (*Emblica officinalis* L.) have adapted by reducing leaf area, thereby reducing the transpirational area. Pomegranate (*Punica granata* L.) is fairly winter hardy and also drought tolerant. Aonla, being a hardy and drought tolerant sub-tropical tree, can be grown well under tropical conditions.

Papaya (*Carica papaya* L.) has adapted well to both tropical and sub-tropical conditions, which is also the case with guava. Through pruning and cultural manipulations, grapes, which are basically a temperate crop, are able to have their vines adapt well to the tropics. Pineapple being a CAM plant, has remarkable adaptability to different climatic regimes and has high water use efficiency. There are some germplasms like drought tolerant varieties of

pomegranate hybrid Ruby, annona hybrid Arka Sahan, fig selections like Deanna and Excel; salinity tolerant grape root-stock Dogridge (*Vitis champine*), mango rootstock Bappakai, guava *psidium nidle* and *psidium catellianum* and Rangpur lime and Cleopatra mandarin in citrus. These crops and many other fruit crops viz., custard apple, jamun, wood apple, bael, avocado, passion fruit and karonda could be considered as candidate crops under climate change conditions.

Future work can be carried out on the lines given below –

Evaluation of wild species, landraces should be probed thoroughly, which could be a source of resistant genes for tying over adversaries of the temperature.

There is a need to develop and test the performance of different genotypes across several environments so that their suitability can be judged.

Development or location of rootstocks that can tolerate biotic stresses induced by temperature regimes is needed.

Adoption of improved agro-techniques like mulching and cover crops in orchards will help in bringing down the orchard temperature.

Use of precision farming methods would help in maintaining the ground cover within the orchard thereby reducing the temperature and providing an ideal microclimate.

In conclusion the understanding how climate changes will impact mankind in the decades to come is of paramount importance for our survival. The aberrant climatic parameters directly and indirectly affect the production and quality of fruit around the world. Therefore, in the changing climate scenario we need to have a robust and systematic action plan to counter the ill effects and thereby sustaining our production, productivity and quality of fruit crops.

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