Chapter 6
Impact of Climate Change on Perennial Vegetables Production and Mitigation Strategies

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Abstract Scientific fraternity is concerned about the global climate change because the variations in important climatic factors may have a significant impact on vegetable crop production, jeopardising global and local food security. Climate change may also have a significant impact on global horticultural processes and productivity. The changes in the growth patterns, flowering and fruiting capabilities of many perennial vegetable crops are inevitable. These vegetable crops are likely to face significant challenges due to altered seasonal factors, impacting dormancy, acclimation, and subsequent reproduction behaviour. In the result of climate change, new pests and pathogens may become popular and harmful in the locations where their activity was previously restricted. Water and nutrients become scarce in some areas, reducing prospects for cultivating perennial vegetable crops. Climate change modifies genotype x environment interaction for physiological and economic features in the crop plants. However, the abundance of germplasm with the vast range of species and genetic diversity offers a chance to develop climate resilient varieties, which will reduce the impact of climate change and ensure economic benefits to farmers. Modification of current horticultural operations and increased practice of greenhouse technology are some of the options to mitigate the effect of climate change. This chapter discuss the mitigation strategies of perennial vegetables for sustainable horticulture through good agronomic practices, breeding for heat and drought resilience, stimulating new and innovative ideas like grafting technology and genetic engineering to increase perennial vegetable production and quality.

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6.1 Introduction

Climate change has become an undeniable fact of the world in the present scenario. The continuous change in the ecosystem is the results of global warming, affecting the human health and nature including climate change, glacier retreat and melting, rise of oceans levels, forest fires, ozone depletion, agricultural cropping system and water scarcity (Shabir 2010). Climate change is raising the concerns over variables such as temperature and rainfall, which in turn can severely affect crop growth and compromise agricultural production and in the end food security. The world's climate is dynamic, plenty of evidences point towards the fact that it has been in a state of constant flux ever since the planet was sufficiently solidified and the atmosphere was formed (Dixon 2009, 2012). Since the surrounding environment play an important role in regulating the biology of plants and animals, natural events serve as some of the best signifiers of climatic change. According to Inter-governmental Panel on Climate Change (IPCC 2000), prominent changes in climate has been observed since beginning of industrial revolution, which had its peak in the eighteenth and the nineteenth century; industrialization is a major contributor to global warming. This led to a surge in climate based research and the development on climate modelling technologies. Scientists agreed on that human activity have been a major factor resulting in these changes today. Greenhouse gases accumulate in the atmosphere through combustion of fossil energy and greenhouse gases (GHG) emissions, e.g., CO_2, N_2O, CH_4 etc. (IPCC 2013). It has been expected that twenty-first century increase the average temperature of the Earth by 2–4.5 °C (IPCC 2013).

Vegetables are being cultivated for herbaceous succulents, and prone to several abiotic stresses. Most of the vegetables are vulnerable to adverse climatic factors results in loss of crop production. Environmental conditions vary in every season and location play a major role in vegetable production (Singh and Singh 2013; Solankey et al. 2021). Research on adverse impacts of climate change on vegetable production hence becomes a priority. Continuous increasing in world population has concern regarding the stability of the global environment, which considerably increases the food demand. Factors such as water availability, weather, and soil fertility are affecting agriculture productivity (Noya et al. 2018; Solankey et al. 2019). These factors such as uncontrollable weather conditions and plant exposure to the changing environments reduce quality of products. The possible way to reduce the dependence on weather conditions to a certain level is the use of good and advanced agricultural practices like greenhouse production or controlled environment farming. To ensure high food security and to fulfil the consumer demands, adoption of strategies is required to combat the challenges by climate change. Growing of crops by limiting their life span will affect growth and development

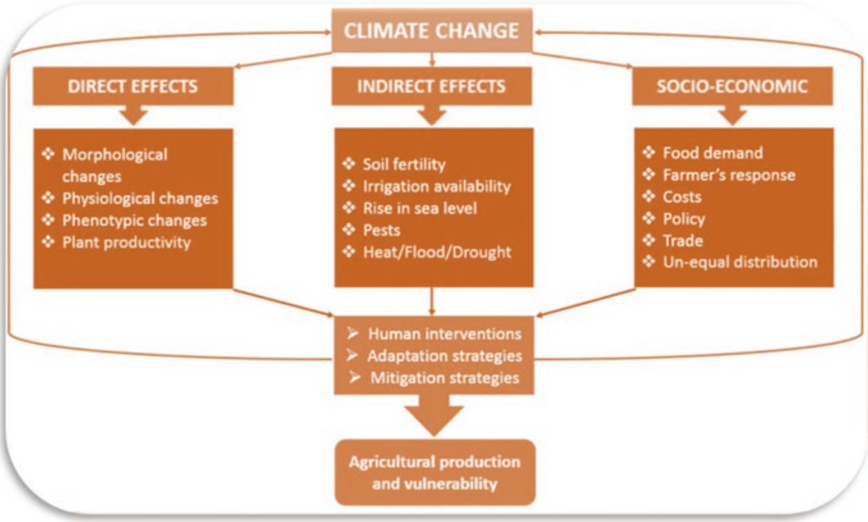

Fig. 6.1 Impact of climate change on agriculture. (Source: Raza et al. 2019)

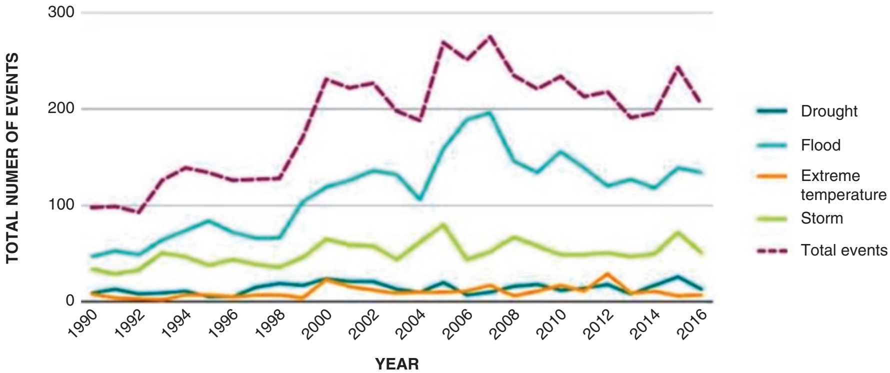

Fig. 6.2 Extreme events related to climate occurred during 1990–2016. (Source: FAO 2019 based upon data from Emergency Events Database)

because of decreased water availability and terminal heat stress, which cause a reduction in the horticultural production. Low and erratic rainfall in rainy season will primarily affect agriculture (Venkateswarlu and Shanker 2012). The effects of climate change on crop production are described in Fig. 6.1. Moreover, as per Food and Agriculture Organization, events of climate change increased dramatically as shown in Fig. 6.2.

6.2 Impact of Climate Change on Perennial Vegetable Crops

Perennial vegetables have the ability to deal with crises of nutrient deficiencies, crop biodiversity and climate change, but such crops are neglected and underutilized. Perennial vegetables have received little attention and only some individual crop species studied closely and in detail (Pimentel et al. 2012; Seemanthani 1964, Chadha and Patel 2007). Perennial vegetables are cultivated for their edible leaves (vegetative structures) and flower buds (reproductive structures). In the regions, where annual vegetables don't perform well, many perennial vegetables are best suited. Perennial vegetable crops include several halophytes, xerophyte, aquatic plants, and shade crops. Several shade tolerant Perennial vegetables are best suited to multi-strata agro forestry systems (Toensmeier 2007). Perennial vegetables as being region specific crops, very few are globally well known and traded crops. Perennial Vegetables are presently cultivated on 3.3 M ha, only 6% of the 52 M ha of total vegetable area globally. FAO reports 1.1 M ha in edible olives (*Olea europaea*) out of 10.6 M ha in total production across the globe, of which only 10% is utilized for table use (Lavee 1996). In India, only 1.5 M ha in asparagus (*Asparagus officinalis*), 0.6 M ha in avocado (*Persea americana*), and 0.1 M ha area is under globe artichoke (*Cynara scolymus*) production. India also has 38,000 ha area in the perennial drumstick (*Moringa oleifera*) (Ponnuswami 2012).

6.2.1 Elevated CO_2 Changes Yield and Quality of Produce

The advent of climate change is directly proportionate to the accumulation of greenhouse gases particularly CO_2, which emerge from the combustion of fossil fuels. Bisbis et al. 2018 revealed in a review that elevated CO_2 of atmosphere has the advantages by increase in CO_2 influx to the leaf, whereas reducing the stomata conductance concomitantly. This increases water use efficiency resulting in greater yield at a reduced water loss. Prolonged exposure to increased CO_2 may also influence quality of product, *e.g.,* enhancement in ascorbic acid, sugars, and greater antioxidant capacity, but probably it decreases some major and micronutrients availability such as magnesium, iron, and zinc in leafy vegetables (Dong et al. 2018).

6.2.2 High Temperatures Accelerate Plant Development

High temperatures fasten organ development and accelerate the plant development rate of vegetables, *e.g.,* flowering to fruiting. As a result, undesirable features may be encountered in the harvested products. These are the disadvantages of faster development of annual crops, which shorten the life cycle and reproductive system turns into lower yield potential. Productivity impacted negatively by temperature, by falling above or below specific thresholds at critical periods during crop development. Phenological development will be disrupted by photoperiod sensitivity of crops interacting with temperature. Some of the aspects affected by extreme temperatures during the reproductive stage which in turn accelerates the mechanism such as pollen viability and fruit formation (Hatfield et al. 2011).

6.2.3 Extreme Weather Events Reduce Yield and Quality of Produce

Extreme weather events are generally observed in terms of the season and average mean temperature of the month and include both extremely hot and low temperatures; as such extreme weather events include frost in winter as well as temperature above 30 °C in hot summer. It also includes hail or heavy rainfall with storms or drought; these events are directly connected to the temperature, rather form and intensify the precipitation or wind speed. An increasing frequency of extreme weather events is generally predicted by climate scenarios but these are with regional differences in their intensity and nature. Cultivating stress-resistant plants and to study their responses under different stresses is necessary for achieving food safety for an increasing global population. The plant response in relation to climatic stresses varies in the gene expression, physiological conditions, and metabolism. A very few reputed plant sensors have been recognized so far, though it was reported in many studies that plants are capable to sense any variation in surrounding environmental signal (Zhu 2016). The plant tissues are damaged and they respond consequently due to various environmental stresses, *e.g.,* transcriptional responses in specific tissues of roots against different stresses act differently (Dinneny et al. 2008). Factors such as drought, salinity, and chemicals effluence produce cellular signs like stress-responsive protein creation, increased associated solutes level, and more elevated antioxidant ratios. These primary stresses generate secondary stresses like osmotic and oxidative stress (Carvalho and Amancio 2019).

6.2.4 Effect of Temperature on Physiology of Perennial Vegetables

Different crop species at every stage of life cycle has varied responses to temperature and responses are based on phenological aspects primarily, *i.e.,* various stages of development of plant. The boundaries of observable growth are formed by a maximum and minimum temperature ranges for each species along with the increase in temperature to the optimum level, the growth (rate of node and leaf appearance) also increases. Compared to the reproductive development, the vegetative growth usually linked with relatively higher temperature requirement for most of the plant species.

Disruption of the pollination process limits the fruit bearing ability is a result of the exposure of the plants to extreme temperature ranges. A constant negative impact on plants is generally observed even though the degree of this impact varies among the species accordingly. The extreme effect on the atmospheric water vapour is one of the aspects of high temperature, is often overlooked. A decrease in the stomatal conductance results in high leaf temperature and a reduced photosynthesis is result of an increasing water vapour demand, which will lead to excess water transpiration through the leaf till the water supply will be restricted. Moisture stress can occur more rapidly if the plant is subjected to an extreme temperature because the plant becomes incapable to withdraw moisture from the deeper layer of soil to meet the increased atmospheric demand. The collective result of the hot air temperatures and the increasing atmospheric demand contribute towards negative effect of temperature extremes on the plant (Hatfield et al. 2011).

Climate change also manipulates the chilling requirements in some vegetable crops as a result of increasing temperatures throughout all the seasons. The influence of global warming inhibits winter dormancy may reduce the yield of many perennial vegetables. For example, asparagus goes into the dormancy and accumulates chilling of 0–7 °C over the winter period (Nie et al. 2016). Dormancy was consisting of two phases: (i) dormancy initiation and chilling temperatures accumulation, (ii) dormancy breakdown by high temperatures accumulation. Yields may be delayed and reduced as a result of a very high temperature during the first dormancy phase, which may extend the second dormancy phase length. In asparagus, with the increase of temperature by 3 °C, *i.e.,* from 2 to 5 °C, the duration of dormancy extends by 15 days (Nie et al. 2016). Moreover, the effects lead to reduced bud break and poor spear production.

It is quite clear from the finding of Kaufmann and Blanke 2017, that, the lack of chilling can be partially substituted by more forcing. The lack of cold hours in winter that induce flowering may be disallowed by higher temperatures in spring may be the result of climate change. Yamaguchi and Maeda 2015 successfully studied the breakdown of dormancy with the utilization of high temperature in Japan. A high temperature of 28 °C for 4 days or more is used to break dormancy during the forcing stage, resulted in rapid spear growth. It is revealed that high temperatures of 28 °C could break the dormancy of asparagus more quickly than chilling temperatures of 5 °C. However, negative effect on yield was also observed due to rapid sugar depletion when the high temperatures persisted for longer duration, *eg.,* 15–20 days.

6.2.5 Influence of Drought

Drought may be described as the absence or very less rainfall for a given period of time, sufficient enough for moisture depletion in the soil with a reduced water potential in the plant tissues. Climate change is expected to directly affect water availability and crop productivity, particularly in those vegetables affected by severe water stress conditions. Drought is the major cause of crop loss worldwide as it reduces average yield by 50% or more for most of the crop plants, it is a major crisis in the dry regions (Sivakumar et al. 2016). It has been suggested that a reduction in photosynthesis and photosynthetic assimilates amount allocated to floral parts is caused by moisture stress at flowering and this might cause an increase in the rate of abscission. Drought stress also causes metabolic impairment (Dias and Bruggemann 2010), apart from blocking the rate of photosynthesis by decreasing stomatal conductance (Yordanov et al. 2013). Solute concentration increases in the soil environment, which in turn leads to osmotic water out flow through plant cells, is caused by drought stress. This reduces productivity by inhibiting several physiological activities such as respiration and photosynthesis in most of the vegetables, caused by an increased moisture loss in plant cells (De la Pena and Hughes 2007). Moreover, water stress also reduces the biochemical capacity, which affects the availability and exploitation of sugar such as sucrose. This is indicated by a decrease in SPS (sucrose phosphate synthase) and inverse activity. A major role in the resynthesis of sucrose is considered to be played by the SPS and it sustains the assimilatory carbon flux from source to sink (Isopp et al. 2008). The effect of drought is intensified and crop yield is further reduced by high temperature accompanied with drought that promotes evapo-transpiration and affects photosynthetic kinetics (Mir et al. 2012). Drought is considered as the major climatic stress for a lot of Indian states *viz.*, Rajasthan, Haryana, parts of Gujarat, and Andhra Pradesh (Mitra 2001). A 2/3rd of the Indian geographic area receives very less rainfall (lesser than 1000 mm), is categorized by erratic distributions. Among the net sown area of agricultural crops, about 140 million hectares (approx. 68%) is classified as susceptible to drought conditions and moreover, 50% of such area are reported as 'severe', where drought occur more regularly and frequently (National remote sensing centre, India).

In Tree tomato (*Solanum betaceum*) cool temperature induce flowering, whereas high temperatures coupled with drought negatively affects flowering as well as fruiting (Carrillo-Perdomo et al. 2015). Significant reduction in yield and starch content in the vegetables like cassava and sweet potato also takes place, which were earlier considered to be drought tolerant crops (Ravi and Mohankumar 2004; Ravi and Indira 1999). For tuber growth, mild water deficit is favourable, but growth of aerial parts and bulking of tuber both cease and become dormant under unfavourable water stress conditions. About 0.9 M ha area is affected and production is decreased by 40% in last five decades due to natural disasters like flood, drought and cyclones (Sivakumar et al. 2016). Although at extremely high temperatures of 33–40 °C under sufficient moisture, cassava may satisfactorily sustain its biomass, however at the temperature above 30 °C, sucrose synthesis translocates from the leaves and synthesis of starch in tubers is drastically affected. When the available soil moisture goes below 20%, sweet potato yields decreased as it drastically reduces the number of tubers during tuberization period. Lignifications of tubers are induced and tuber growth is hampered due to water stress during tuber initiation period.

6.2.6 Increase in Soil Salinity

Changes in weather patterns due to climate change resulted in the increased frequency of rainfall or drought above the normal range for more than a decade (Ayanlade et al. 2018). Variation in temperature and precipitation highly influences the soil salinity. It has been studied that the increased temperatures and decreased precipitation for long term (30 years) showed a direct relation with increase in salinity in arid soils due to decreased leaching of salt from the soil. Salinity is a serious problem in many crop growing areas as it reduces the growth as well as productivity of several vegetable crops. A reduction in the productivity of many perennial vegetables, which are mostly sensitive throughout the course of development, is caused by excessive soil salinity. It causes a reduction in length and mass of roots, at the same time they may become thinner or thicker. It also causes a delay or advancement at maturity depending on the species. The species of the vegetable crop and the variety within a species determines the degree of growth inhibition by salinity. The germination rate is slowed by salinity, and at higher levels it also reduces germination percentage. Environmental interactions like temperature, relative humidity, solar radiation and degree of air pollution also mediate the severity of salinity response (Shannon et al. 1994). Reduction in growth, leaf colour and changes in root/shoot ratio and rate of maturity are some of the osmotic effects of salinity. Ionic effects are manifested more easily in leaves and meristem damage produces the nutritional disorders symptoms. Thus, ion like Na^+ or Cl^- may accumulate in leaves or other plant parts in high concentrations and results in burning of leaves (Shannon and Grieve 1998). Ion-specific stress arising from altered ratios of K^+/Na^+, leads to an increase in concentrations of Na^+ and Cl^-, is injurious to the plants. It is caused by an initial water deficit due to high solute concentrations in the soil imposed by salinity. Some of the impact of salt stress on a plant is loss of turgidity, leaf abscission, reduced growth, decrease in photosynthesis, decrease in respiration, loss of cellular integrity, wilting, necrosis of tissues and ultimately plant death (Cheeseman 1988). The soil microbes' population in the rhizosphere and their interaction with roots are also affected by salinity. *Rhizobium spp.*, which is associated to legumes, can tolerate more salt than the legume itself, but plenty of evidence shown that nodulation process and fixation of N_2 by some of the legume crops are weakened by salinity (Lauchli 1984). It has been suggested that mycorrhiza symbioses increase the salt tolerance of the plants by improving phosphorus assimilation (Hirrel and Gerdemann 1980).

In an experiment, the number of buds per plant and bud growth was reduced in artichoke, as only fewer harvestable buds were obtained from plant when salinity level increased in the soil resulting in yield loss. Since bud circumference is reduced significantly with the increased levels of salinity, total yield reduction is accounted by the significant reduction in the weight of individual bud weight (Table 6.1) (Francois 1995). However, the harvesting traits are least affected in asparagus crop (Francois 1987).

Table 6.1 Bud yield traits of artichoke grown at six levels of salinity during two growing seasons. (Francois 1995)

Soil salinity (EC_e) (dSm^{-1})	Total bud yield (t ha^{-1})	Avg. bud weight (g)	No. of buds/plant	Avg. bud circumference (mm)
		1987		
4.6	16.7	211	6.1	289
6.6	16.8	203	6.6	287
7.4	16.1	206	1.3	287
8.7	10.0	190	5.9	282
10.6	9.0	179	6.3	279
11.6	5.3	178	5.4	274
Significance’	L^{**}	L^{**}	NS	L^{***}
		1988		
4.4	17.1	256	5.2	274
5.9	17.1	234	6.4	275
8.3	13.3	214	5.1	275
10.4	8.5	189	5.2	264
11.3	5.2	180	4.9	258
13.8	4.1	179	4.0	260
Significance’	L^{***}	$L^{***,Q*}$	L^{*}	L^{**}

^{z}L linear, Q quadratic
^{NS,*,**,***}: Significance at P=0.05, 0.01 and 0.005

With increasing soil salinity, the reduction in root pressure may arise; it would provide a mechanism for Ca movement to the inner bracts. As a result, Ca deficiency occurred with reduced root pressure and low transpiration. Necessity to maintain low levels of soil salinity is crucial for maximum yield even though artichoke tends to be more tolerant to salt than most of the other vegetable crops. Content of Mg and K in the leaf blades and midrib is also affected by salinity. The deficiency of Ca within the bud increases and the size of the buds decreases when salinity levels become too high (Francois et al. 1991).

6.2.7 Flooding Interferes to Crop Growth and Production

Being flood-susceptible plants, flooding causes serious problem to vegetable crops through hindrance in growth and development (Parent et al. 2008). Slow gas diffusion in the water and consumption by plant roots and microbes leads to oxygen deficiency, is normally associated with the occurrence of flooding condition. Many vegetables are highly susceptible to flooding and genetic variation to this trait is also limited, particularly in tomato, however the crops like asparagus and taro are least affected. Inhibition of aerobic processes which is caused due to oxygen deficit in the plant root zone is the most common damage by flooding in perennial vegetables. Endogenous ethylene is accumulated and causes harm to the plants in flooded condition (Drew 2009). A typical response of tomatoes to water logging is the rapid development of epinastic growth of the leaves and it also involves the activity of ethylene accumulation (Kawase 2011). With rising temperatures, the flooding symptoms become more severe; usually after a short flooding at high temperatures, rapid wilting is observed ultimately leads to death of the plants in tomato (Kuo et al. 2014).

Plant response to abiotic stresses depends upon the stage of development, length and intensity of stresses (Kumar 2017). Reduced stomatal conductance of a plant is one of the earliest plant physiological responses to soil flooding (Folzer et al. 2006). Flooding generally leads to leaf water potential increase, which decreases the stomatal conductance ultimately leads to reduction in carbon exchange rate and elevate the internal CO_2 concentration. Flooding affects the vegetative as well as reproductive growth of the plants negatively due to physiological malfunctioning (Gibbs and Greenway 2008). Chlorosis of leaves, reduced shoot and root growth, reduced accumulation of dry matter and yield reduction are some of the negative results of flooding on sensitive crop plants (Malik et al. 2002). The water-borne pathogens spread easier by flooding, as plants can be predisposed to infection by droughts and heat waves, alongside with dispersal of spores through wind (Pautasso et al. 2012).

6.2.8 Insect Responses to Climatic Change

Climate change also influenced the biology and ecology of insect pests (Jat and Tetarwal 2012). An increase in fecundity and earlier completion of life cycle in some insects with short life cycles such as diamond back moth and aphids are caused by increase in temperature. As a result, insect produced more generations per year than their actual rate (FAO 2009). In contrast, several years may be taken by some insects to complete their life cycle. Soil acts as an insulating medium that leads to changes in buffer temperature more than the air, some of the insect species that live in soil for some stages or whole of life cycle is likely to suffer more than above the surface of soil (Bale et al. 2010). Rising in the temperature leads to movement of insect species to higher latitudes, while in the tropical areas specific pest species might be adversely affected by higher temperature. Developmental and ovipositional rates, outbreaks of insects and introductions of invasive species are increased by high atmospheric temperature (Kumar et al. 2020), whereas the insect diversity in ecosystems, reliability of economic threshold (ET) levels, and efficacy of insect biological control by fungi is decreased (Das et al. 2011).

6.2.9 Crop Adaptation to Extreme Overall Climate Stresses

The climate undergoes severe alterations with the raise of the Earth's average temperature, as a result becoming abiotic stressful. Various threats are posed to naturally prevailing crop species, so environmental changes are of big concern (Espeland and Kettenring 2018). Heat and drought are the most predominant stresses under field conditions hence they have a considerable influence on crops (Pereira 2016). It is quite obvious that plants, for their normal growth, development and flowering require an optimum temperature. Temperature fluctuations highly influence plant physiology (Hatfield and Prueger 2015). The grain production and yield is severely affected by heat stress, whereas sterility is caused by chilling stress, and the morpho-physiology of plants is negatively influenced by drought stress (Salehi-Lisar and Bakhshayeshan-Agdam 2016). Some of the impacts of these climatic stresses are severe agony on development and yield of plants, producing huge responses, including morphological, molecular, and physiological and biochemical modifications (Zandalinas et al. 2018). Overall, climate change and global warming have both negative and positive impacts on crop plants.

6.2.9.1 Positive Impact

1. Increased productivity from higher temperatures
2. Decline in moisture stress
3. Introduction of new crops
4. Acceleration in maturation rates
5. Prolonged growing season
6. Increased productivity from enhanced CO_2. (CO_2 fertilization only applies to some crops and will have small temporary benefits for higher latitude. (IPCC reports)

6.2.9.2 Negative Impact

1. Crop damage from extreme heat
2. Increased ground level ozone-toxicity to green plants
3. Stronger storms and floods
4. Warming stress
5. Waterlogged land
6. More soil erosion
7. Specialized mono-cropping, less adaptable
8. Decreased pesticides and herbicides efficiency
9. Planning problems due to less reliable forecast

10. Increased insect infestations
11. Torrential rain
12. Increased drought
13. Increased weed growth
14. Increased moisture stress
15. Increased crop diseases

6.3 Mitigation Strategies

6.3.1 Implications of Moringa Tree to Climate Change Mitigation

Since famine is connected to climate change, an important way to mitigate it by planting trees, which can sequester more carbon like *Moringa* (Amaglo 2013). Therefore, the need of implementation of climate smart policies can be built for more food systems development and combat climate change is of top most priority. *Moringa* tree has a great potential to not only store carbon, but also to improve the livelihoods of many farmers if it is grown on a much larger scale (Gedefaw 2015). According to Fuglie (2000), *Moringa oleifera* is called as "*Never Die Plant*", as it is highly adaptable to various soils and environmental extremes. Because of its numerous nutritional, medicinal and industrial values and greater adaptability, *Moringa oleifera* is proven as a suitable crop for mitigation of climate change (Ndubuaku et al. 2014). The tree acts as a good sink for CO_2 absorption and utilization because they produce heavy flushes even during the dry season. They contribute towards reduction of atmospheric CO_2 level, one of the major reasons of depletion of ozone layer and finally global warming. The tree is also considered to be an adaptable crop for climate change and to eliminate threats for food security (Ndubuaku et al. 2014).

When compared to the Japanese Cedar tree, Moringa tree may absorb fifty times higher CO_2 and 20 times higher than that of general vegetation according to the study of Villafuerte and Villafurte-Abonal (2009). A study on Moringa revealed that, a person emits 320 kg of CO_2 per year. A total of 23 Japanese Cedar trees absorbs this amount of CO_2 in 50 years of time; on the other hand, only 2 Moringa trees absorb this amount in 2 years. On an average one family car emits 2300 kg of CO_2/year; to absorb this CO_2 amount in 50 years, 160 Japanese Cedar trees are required; however only 10 Moringa trees are sufficient for this task in 2 years (Ndubuaku et al. 2014). Since Moringa tree sequesters more carbon through all plant parts, it may be a useful tool to combat global warming. Therefore, the impact of climate change can be mitigated by planting such an important tree on large scale.

6.3.2 Good Agronomic Practices

Several investigators have reported a lot of strategies for the farmers to deal with the climatic change for plant adaptation on the basis of series of experiments. The various useful approaches adopted by farmers to deal with climatic change are, the inclusion of practices such as modifying planting as well as harvesting time, selection of short duration crops, crop rotation, improved irrigation techniques and cropping schemes. These approaches are very beneficial for adaptability of the crop under abiotic stress conditions (Duku et al. 2018). To reduce the water logging of the field during rainy season, transparent plastic rain shelters may be used to prevent the direct impact on developing fruits for successful vegetable production as suggested by several researchers. The planting of vegetables on raised beds may increase the yield during rainy season because it improves drainage of water and reduces the anoxic stress to root zone (Welbaum 2015). Some of the other strategy to overcome the impact of climatic variation and to ensure good adaptability to the plants to assure food security is; sowing time modification, development and utilization of drought resistant varieties, and the introduction of new crops (Ali and Erenstein 2017). Implementation of techniques with the ability to boost development of crop plants under several climatic stresses is another plant adaptability approach. The soil moisture can be conserved by the practices like mulching with crop residue and with the use of plastic mulches. Excessive soil moisture in excessive rain also becomes a big problem in some instances; this could be overcome by the use of raised beds (La Pena and Hughes 2007). Some fundamental techniques to deal with climate stresses include the selection of sowing time, plant density, and better irrigation technology (Battisti et al. 2018). Use of fertilizers also plays a very vital role in the reduction of global warming effect and to support the plant for better adaptability. It is always advisable to maintain the soil fertility and increase productivity as it provides significant energy to the crop plants (Henderson et al. 2018).

6.3.3 Breeding Techniques

Plant breeding shows a lot of techniques in crop improvement under different abiotic stresses. By developing stress resistant cultivars, it provides a splendid option to ensure food safety and security and also helps plants to avoid various stresses throughout the crucial growth period of plant (Blum 2018). The use of genetic divergence analysis, inbreeding technology, assessment of germplasm, recombination and assortment to achieve plant perfection are the important parts for crop improvement. Morphological screening of germplasm not only identifies the lines with novel traits but also helps in the study of inheritance pattern of different vegetable crops (Kumar et al. 2018). For the breeding of new varieties based on morphological variability, genetic divergence study is considered to be very important method (Raza et al. 2018). Information on magnitude and nature of character association act as an important pre-breeding tool for efficient selection of novel resistant traits (Sharma et al. 2020).

Landraces are the important source for genetic studies, a wheat landrace maintained in data bank contains broader genetic base and is an important source for stress resistance as it is adjustable to varied climatic stress (Lopes et al. 2015). The screening procedure has identified 5 genotypes (CI-260, CE-534, CE-54, CI-848 and CI-308) and 9 land races (16, 7, 129, Narukku-3, TP White, CI-60, CI-4, CI-80 and CI-17) of cassava, are resistant to drought condition. Three sweet potato land races that have been identified as drought tolerant are VLS6, IGSP 14 and IGSP 10. A variety of sweet potato "Sree Bhadra" is found to be tolerant to drought is released by CTCRI, India (Annual Report 2013, 2014, 2015). Breeding for drought tolerance has also been tried in various seed spice crops (Malhotra 2009; Malhotra 2016). Molecular breeding alone or in integrated approach is the useful tool to develop cultivars resistant to abiotic stress using genomics technology like marker-assisted selection (MAS) by improving simple horticultural trait controlled by one or oligogenes for resistance (Kumar et al. 2021) and genome wide associated studies (GWAS) (Raza et al. 2019).

6.3.4 Genetic Engineering for Stress Resistance in Plants

Biotechnology is a powerful practice for manipulation of the genome of any organism for the benefits of mankind. The alteration of genetic structure through biotechnology is a potent and new strategy. The data from genetics are quite encouraging, may be exploited towards drought, salinity, heat and cold. A powerful finding to develop stress-resistant varieties is identification of stress-responsive TFs (transcriptions factors). These TFs can regulate the morphological characters of genes linked with different stresses in genetic engineered crops (Reynolds et al. 2015). There is a plenty of transgenic plants which are developed by genetic engineering to deal with the number of abiotic stresses. Compared to normal plants, genetically engineered plants exhibit considerable resistance against changing climate (Shah et al. 2016).

Various transcriptions factors are identified as plant-specific transcription factor which involves *AP2/ERFBP* group (Riechmann and Meyerowitz 1998). This group of *AP2/ERFBP* transcription factors is associated with different pathways related to plant growth and has role in responses towards abiotic stresses (Licausi et al. 2010). *AP2/EREBP* transcription factors are classified into 4 sub-families based upon their numbers and similarity. The sub-families consist of *DREB* (dehydration-responsive element-binding protein), *ERF*, *AP2* (Apetala 2), and *RAV* (related to *ABI3/VP1*). Two major subfamilies which are widely evaluated due to their function in biotic and abiotic responses of plant are *ERF* and *DREB* (Sharoni et al. 2011). In different water stress and chilling stress, the *DREB* has significant regulating ability (Stockinger et al. 1997).

6.3.5 Grafting Improves Stress Tolerance

Grafting the vegetables was first initiated during the twentieth century in East Asia, to minimize the effect of soil borne diseases like fusarium wilt, and to boost up the production of tomato, eggplant, and cucurbits, which are widely affected by the disease. Grafting in the present scenario became a regular practice in the vegetable cultivation in Korea, Japan and some other European countries (Martínez-Ballesta et al. 2010). It is rapid and alternative tool to the slow breeding technology aimed at increased environmental-stress resistance of the vegetable crops. Grafting serves as a promising tool for the modification of the root system for increasing its resistance to a range of abiotic stresses in the plants (Bhatt et al. 2013). Grafted plants are being utilized now to improve resistance towards drought, temperatures extremes, salinity and flooding, if suitable rootstocks are used (Martínez-Ballesta et al. 2010; Venema et al. 2008; He et al. 2009). However, degree of tolerance of rootstocks to various stresses also varies largely among different species, *viz.;* rootstocks from *Cucurbita spp*. are comparatively more resistant to salinity than *Lagenaria siceraria* (Matsubara 2012). It has been also revealed that melons when grafted using hybrid squash as rootstocks were found more tolerant to salt than the non-grafted plants (Yetisir et al. 2005). The cultivation of grafted plants in sweet pepper, eggplant and tomato and different cucurbits (watermelon, cucumber and pumpkin) has increased in past few years because of these beneficial effects of grafting (Hassell et al. 2008; Lee et al. 2010), alongside there is huge scope for such an efficient tool for various abiotic stress resistance in other perennial vegetables.

6.3.6 Developing Climate Resilient Vegetables

The most cost-effective option to encounter the changing climate is the use of improved and adapted germplasm in vegetables. However, most improved varieties represent a limited genetic variability including resistance to abiotic stresses. In order to achieve intensive and high input production systems, breeding the new varieties selected for the traits contributing to adaptation to low input and unfavourable environments would be of great importance. Genetic variation is an important factor for selection in improved and desirable parents from available germplasm for successful breeding programme (Debnath et al. 2020). The recognition of a new genetic variation for resistance to different climatic stresses could result in improved varieties well adapted to a broad range of climatic condition. The need is to identify and advance the genotypes with superior traits through greater combinations of the alleles at multiple loci. There is a great demand for the improved selection procedure to identify the superior genotypes with linked traits from wild species from the unfavourable environments to their cultivated varieties. Plants inhabitants to climates with varied seasonality are able to adapt more easily to changing environment (Pereira and Chaves 1995) and offer opportunity to identify the genes that provide such resistance.

6.4 Conclusion

At present time, with the challenge to meet food and nutritional security for growing population, the agricultural world is facing a difficult situation especially in the vegetable production. There is an urgent need to produce increasing amount of food from limited piece of land. With the result of increasing abiotic stresses and decline in favourable environment combined with the threat of global warming through greenhouse gases, the problem is aggravated at high extent. There is significant effect of raised temperature upon duration of crop, flowering and fruiting of perennial vegetables with very low economic yield and productivity. An immediate action is required to study climate change and its impact on crop growth, yield and quality, as the succulent and tender vegetables are very sensitive to heat, drought and flooding conditions. In order to determine the response of plants under abiotic stresses, there is an urgent necessity to explore the genetic basis for the mechanisms related to the response. To achieve better plant adaptation under abiotic stresses, physiological challenges present in the plants need to be studied and resolved on an urgent basis. Scientific community must focus upon adaptation technologies and the mitigation strategies for the crop plants. For inducing the resistance against abiotic stresses and to save agriculture in the future, there is a need to propagate improved cultural methods, cropping schemes, and different non-conventional strategies. Resilient crops under heat and drought can be developed through the help of breeding approaches. Certain significant strategies in the identification of the genes for changing climate are genome wide association studies (GWAS), genomic selection with high throughput phenotyping and genotyping.

Adaptation of improved vegetable production system in the changing climate will help in reducing malnutrition in developing nations through higher production and consumption of quality vegetables. There is an immediate requirement to develop sound adaptation strategies for mitigation of changing climate on productivity and nutritional quality of vegetables. Development of system for improved water use efficiency under hot and dry condition should be emphasised. Soil moisture can be conserved through mulching with crop residues and plastic mulches. In order to overcome excessive soil moisture due to flooding, crops can be grown on raised beds. It is necessary to identify germplasm with tolerance to high temperatures, drought and other climatic hazards, with the ability to produce higher yield. Genetic population developed to identify and introgress genes providing resistance to climatic stresses and to generate the tools for genetic engineering. It is necessary to continuously enhance conservation agriculture and to protect vegetable crops from extreme environmental conditions in the developing countries. Technical, socioeconomic as well as political considerations must be included in an effective extension tactic that needs to be in place. Finally, the key components of a sustainable adaptation strategy to climate change are capacity building and education.

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