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4. Impact of Climate Change in Vegetable Production

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Abstract:

Vegetables have always been an essential component of a well-balanced human diet as the key source of nutrients such as vitamins, proteins, minerals and fibers. In order to meet their fundamental nutritional needs, farmers undertook subsistence agriculture, which led to the vegetable cultivation and production initially. As the world's population gradually increased, the need for food spread throughout the world rather than remaining confined to a small number of households.

This also marked the beginning of exploiting nature for human benefit. Climate change is one of the negative consequences of human exploitation that has been observed which is gradually proving detrimental to farming, especially the production of fruits and vegetables. With disastrous effects like global warming, altered seasonal patterns, droughts, stressful biotic and abiotic conditions, salinity, and other physiological and biochemical changes, climate change is widely acknowledged as the greatest challenge to mankind today which also put vegetable crops at risk. Furthermore, these climatic factors have an adverse effect on the health benefits offered by naturally occurring secondary metabolites in vegetable crops, which include terpenoids, phenolics, fatty acids and alkaloids.

Due to the fact that most vegetables are climate-specific and sensitive, any slight or significant alteration in the atmosphere can cause an imbalance in the production of vegetables, which will reduce their marketability and economic worth and cause a significant loss of income for the grower. In the present chapter, knowledge will be shared on climate change, its impact on vegetable production and potential strategies for sustainable & resilient vegetable production under changing climatic conditions.

Keywords:

Climate change, Global warming, Sustainable, Vegetables

4.1 Introduction:

Climate is the statistical depiction of long-term weather trends in a particular place, usually measured over many decades. The process entails examining the mean and dispersion of pertinent meteorological factors over a period of around thirty years, as per the World Meteorological Organization (WMO). Climate change is a term used to describe a long-term alteration in the characteristics of the climate, such as its average conditions and variations that can be detected by statistical analysis. These changes often last for many decades or more. This definition was provided by the Intergovernmental Panel on Climate Change in 2001. As per the definition provided in Article 1 of the UNFCCC, "climate change" refers to a modification in the climate that can be linked to human activity, which directly or indirectly affects the composition of the global atmosphere, in addition to the natural climatic variations recorded over similar time periods. The issues related to climate change transcend national, ethnic and geographical boundaries, impacting all forms of life on our planet. Climate change, recognized worldwide as a major issue, refers to statistical variations in the properties of several climatic elements such as temperature, light intensity, rainfall, precipitation and the composition of atmospheric gases. Weather factors affect different phases of plant development, hence impacting agricultural yield. An essential aspect of maximizing crop output is having a comprehensive understanding of the connections between meteorological conditions and the various phases of crop development (Ray and Mishra, 2017).

Vegetables not only offer significant nutritional value but also tend to be more financially lucrative compared to staple food crops. Vegetables require more capital and expertise than basic crops do. The vegetable producing industry is currently the most vibrant in the entire nation. Since most vegetables need a moderate temperature to grow and develop, rising temperatures and dry soil are the main causes of crop yield loss because they disrupt physiological and biochemical processes including decreased enzymatic activity, metabolism and photosynthetic activity, as well as lower tissue temperature, impaired pollination and compromised fruit setting (Solankey et al. 2021). Winter vegetables are relatively more susceptible to adverse weather conditions compared to summer vegetables. Variations in the climate, such as heat waves, droughts and waterlogging can have direct impact on vegetable production throughout every phase of the crop growth cycle, including germination, pollination, flowering, fruit formation and yield (Afroza et al. 2010). Most vegetable crops benefit from rising CO2 levels in the environment as they promote photosynthesis and increase water-use efficiency, which raise yield, however, internal product quality may change or lead to down regulation of photosynthetic processes (Bisbis et al. 2018). Heat stress leads to reduced fruit set in fruiting vegetables, speeds up the development of determinate vegetables and shortens their window for photosynthesis. In both instances, it results in yield losses, deteriorating product quality and escalating production waste. Climate change affects the prevalence of pests and diseases, which leads to crop failures, yield shortage and a decline in quality, making the production of vegetables unprofitable. (Abewoy, 2018).

Globally water availability is diminished due to inadequate water usage and inefficient distribution systems, particularly in less developed countries. Low precipitation and high temperatures can reduce the amount of irrigation water available and increase evapotranspiration, which can cause more crop water stress, especially in vegetables that contain > 90% water. This can ultimately affect production and quality. Salt stress causes plants to lose their turgor, grow less, wilt, curl and epinasty, abscise their leaves, change in respiration, lose their cellular integrity, necrotize their tissues and eventually die. The current requirement is to switch from low yielding crops to the production system that better adapt crops to changing climatic conditions. To meet these issues, different crops have different breeding programmes. Creating resistant varieties that provide high-quality production in every situation is the primary objective of any researcher. Some technological inventions are absolutely necessary for the situation of crop production to drastically improve to cope with these challenges that can benefit the farmer in getting higher yield and enhanced quality ensures increased income, leading to improved living standards and dietary security.

4.2 The Effect of Climate Change on Vegetable Cultivation:

The on-going production of vegetables is adversely affected by climate change, encountering multiple challenges. Emerging evidence suggests that smaller farmers in developing nations are being impacted by extreme weather events like average temperature and precipitation, as a consequence of climate change, which is directly linked to increased greenhouse gas (GHG) emissions. The climate change impact on different categories of vegetables has been presented as under (Table 4.1).

Table 4.1: The effect of climate change on production of vegetable crops

Vegetable Crop	Physiological impact	References
(i)Solanaceous vegetables		
Tomato	Flower shedding and insufficient ovary development occur, with no fruit setting observed bove 35 °C daytime temperature. Lycopene synthesis in fruits is disrupted; leading to tissue damage such as sunscald and blotchy ripening	Hazra et al. 2007
Eggplant	Diminished pollen production, distorted flower buds and fruits, limited fruit and seed formation, and the development of brown, yellow or bronze spots on the fruit due to sunburn	Moharana et al.2021
Hot and sweet pepper	Reduced pollen production and fruit set lead to smaller fruit size. Fruits susceptible to sunburn necrosis are lost prematurely, while blossom end rot may develop. Furthermore, fruit ripening and color development are adversely affected	Aloni et al. 2001
Potato	Reduction or full blockage of tuberization, lowering sugar levels, physiological tuber weight loss	Sonnewald et al. 2015

Vegetable Crop	Physiological impact	References
(ii) Cole crops	Decreased rate of germination, length & fresh weight of root and shoot; delayed head maturity, wilting, leaf abscission in cabbage, delayed curd formation and reduced seed yield in cauliflower, early flowering and bolting in broccoli	Cheeseman 2008 Priyanka et al.2018
(iii) Root crops	Hard and bitter roots before marketable maturity. Warm temperature encourages early bolting in radish even before adequate root development. Beetroot produces stingy and tough roots, while turnip develops obscene, stiff and pungent roots. Small, forked woody, poorly and pithy flavored roots in carrot, leading to reduced biomass production	Pathak et al.2021
(iv) Bulb crops	Restricted seed germination in onion, decreased dry weight of shoot, net osmosis rate, reduced bulb size, Leaf chlorosis, limited shoot and root development, reduced plant yields and dry tissue gathering	Sivakumar et al. 2016
(v) Leguminous vegetables	Low germination, impaired crop stand, drop in flowering ratio, decreased no. of pods, seed abortion. Shorter shoot, smaller leaves in bean crop & decreased pod length	Durigon et al. 2019
(vi) Cucurbitaceous vegetables	Delayed fruit maturity, reduced sugar content in melons, deprived female bloom leading to decreased yield	Singh, 2010

4.3 Potential Strategies to Boost Vegetable Production under Changing Climatic Conditions:

The internal tendency of agricultural systems, particularly their capacity for adaptation, will determine the possible effects of climate change on agricultural output in addition to the climate itself. Farmers in developing countries require techniques to acclimate and reduce the detrimental effects of climate change on agricultural output, especially with regard to the yield, quality and production of vegetables. Plant stress physiology research is developing both new and existing technologies that may help lessen the effects of climate change on the production of vegetables. Nonetheless, farmers in developing nations are typically small holders with limited alternatives and they are strongly dependent on the resources found on their farms or in their communities. Thus, to improve the resilience of farming in less developed nations, simple, inexpensive and accessible technology must be employed. The World Vegetable Centre or AVRDC has been addressing how environmental stress affects the production of vegetables. Advanced breeding lines are being developed, and the germplasm of the major vegetable crops that can withstand extreme temperatures, flooding and drought has been identified. Additionally, efforts are being made to find germplasm that efficiently uses nitrogen. Research and development initiatives also include the creation of production methods intended to reduce the effects of varying weather on systems for producing vegetables and to increase water-use efficiency. Several viable tactics capable of boosting vegetable production in the context of changing climate scenario have been discussed under following sub-headings:

4.3.1 Protected Cultivation:

Among the most effective methods to protect our vegetables from adverse weather conditions such as high temperatures, hail, heavy rainfall, sunburn and snow in a climate that is constantly changing is to grow them in protected environments. This advanced agricultural technology allows for the regulation of both the larger and smaller habitats, which enhances early harvesting, optimum plant growth, longer and lifespan of crops, resulting in better yields of superior quality (Gruda and Tanny, 2015).

Cultivating vegetables in nurseries under protected buildings provides several benefits and protects our crops from both living and non-living pressures. A polyhouse with an enhanced microclimate yields higher crop output of diverse vegetables. When comparing the impact of open field conditions on tomato and capsicum crops, it was found that tomatoes had a higher rise in farmer output and revenue (Kumar et al., 2016a, b). According to Rao et al. (2013), the use of protected cultivation led to a 40% decrease in water use and an 80% increase in crop output compared to growing crops in open field settings.

4.3.2 Water-Saving Irrigation Management:

Key agronomic practices essential for maintaining yields during drought stress involve timely irrigation and preserving soil moisture reserves, especially when water is scarce or irregular. The frequency and volume of water application are influenced by various factors, such as climate, crop type, developmental stage, soil properties and irrigation system. There are diverse methods for applying irrigation water and the selection depends on factors like crop type, water availability, terrain, and soil characteristics. Irrigation water can be applied via drip, surface, overhead or sub-irrigation systems.

Although more than 80% of the irrigated lands worldwide use surface irrigation techniques, the application effectiveness at the field level is frequently between 40 and 50%. Water is delivered directly to plants through small plastic tubes in drip irrigation. Compared to typical surface watering methods, drip irrigation minimizes water losses from runoff and deep percolation, leading to water savings between 50 to 80%. Moreover, crop production typically increased by 10 to 50% per unit of water utilized through plant evapotranspiration.

As a result, drip irrigation requires less labour and may irrigate more plants per unit of water. Decreasing drip irrigation rates resulted in reduced occurrence of Fusarium wilt; however, for drought-tolerant crops like watermelon, there was no statistically significant difference in production between furrow and drip-watered crops. In general, low-cost drip irrigation saves money, reduces labour costs and increases plant density per unit of water, which helps farmers earn more money while conserving water.

4.3.3 Cultural Practices for Water Conservation and Crop Protection:

Certain crop management techniques, including mulching and using raised beds and shelters, help to preserve soil moisture, stop soil erosion, and shield vegetables from heavy rains, floods and other weather-related events. High-value vegetable production systems commonly use both organic and inorganic mulches. These protective coatings decrease runoff and erosion, reduce evaporation, control soil temperature, keep weeds from growing and shelter fruits from direct soil contact. Furthermore, mulch made of organic materials can improve the structure, fertility and other qualities of the soil. In tropical regions where rice is grown, rice straw is plentiful and often recommended for summer tomato cultivation. In comparison to non-mulched soil, mulching increased the development of eggplant, okra, bottle gourds, round melon, ridge gourds and sponge gourds in India. The use of polythene and sarkanda (*Saccharum* spp. and *Canna* spp.) as mulching materials produced the maximum yields. It is recommended to use rice straw in conjunction with dark-colored plastic mulch in the high-temperature lowland tropical regions. The rice straw lowers the soil's temperature during the day by shielding the plastic from direct sunlight. Bright colored plastic mulch blocks sunlight from penetrating the surface of soil. Vegetables like tomatoes experience yield losses from heavy rainfall during the hot rainy season. Tomato yields are improved when simple, transparent plastic rain shelters are used to stop water logging and rain impact damage to developing tomatoes. There is also a decrease in fruit cracking and the quantity of unmarketable fruits. The crops produced under plastic shelters yielded more because of the absence of rain damage and flood, together with the cooler ambient temperature. To lessen temperature stress, shade cloth can be utilised as another type of shelter. Additionally, shade shelters guard against damage from strong sunshine and direct rain. Raised bed vegetable gardening helps lessen the consequences of flood during the rainy season (AVRDC, 1981).

4.3.4 Grafting for Improved Stress Tolerance:

Vegetable grafting, which had its origins in East Asia in the 20th century, has now become a common practice in Japan, Korea and several European countries. Grafting is the process of joining the rootstock and scion, which are two live plant components, in order to create a single, growing plant. The primary use of this technology has been in the control and prevention of soil-borne illnesses that negatively affect the productivity of crops such as cucurbits, tomatoes and eggplant. However, when appropriate tolerant rootstocks are used, they may provide tolerance to environmental difficulties associated with soil, such as salt, drought, low soil temperature and floods. The salt tolerance of rootstocks varies considerably across different species. For instance, *Cucurbita* spp. rootstocks have higher salt tolerance compared to *Lagenaria siceraria* rootstocks. Tomato scions that are grafted onto *Solanum lycopersicum* x *S. habrochaites* rootstocks can withstand low soil temperatures ranging from 10^oC to 13^oC. On the other hand, eggplants that are grafted onto *S. integrifolium* x *S. melongena* rootstocks grow better in lower temperatures, from 18^oC to 21^oC, compared to plants that are not grafted. In general, plants have difficulty tolerating high soil wetness. Tomatoes are very vulnerable to excessive water, making them particularly sensitive among vegetable crops. In tropical climates, the combination of heavy rainfall and insufficient drainage results in waterlogged circumstances that reduce soil oxygen levels. This in turn, causes tomato plants to wilt, develop chlorosis, exhibit leaf epinasty and finally die. The genetic diversity is either insufficient or inadequate to tolerate high soil wetness without resulting in losses. Research undertaken at AVRDC - The World Vegetable Centre has shown that several eggplant accessions exhibit a significant level of flood tolerance. As a result, the Centre developed grafting techniques using aubergine rootstocks, which were discovered to have high resistance to excessive soil wetness and a good ability to be grafted with tomatoes. This was done to enhance the flood tolerance of tomatoes. Tomato scions that were grafted onto aubergine rootstock thrived and produced high yields throughout the wet season. In addition to providing flood protection, some genotypes of aubergine also possess drought resistance, allowing aubergine rootstocks to give protection against restricted soil moisture stress.

4.3.5 Development of Climate-Resilient Vegetables:

To effectively address the difficulties of climate change, farmers should use vegetable germplasm that has been improved and adapted to the current climatic circumstances. This approach is the most cost-effective technique. However, most modern cultivars only include a small portion of the genetic diversity, which includes stress tolerance. The discovery of new genetic variants that confer tolerance to different biotic and abiotic stressors has the potential to lead to the creation of improved cultivars that can thrive in a wider variety of environmental circumstances. It is possible to identify and encourage genotypes that have advantageous combinations of alleles at different locations, leading to enhanced characteristics. Nevertheless, it is crucial to use improved selection techniques in order to detect these exceptional genotypes and associated characteristics, especially in wild species that flourish in settings unsuitable for their produced equivalents. Plants native to areas with pronounced seasonal fluctuations have a greater ability to adjust to shifting weather patterns and provide opportunities to identify the specific gene(s) or gene combinations responsible for this resilience.

4.3.6 Development of Lines Tolerant to High Temperatures:

It is essential to produce breeding lines that are resistant to disease and heat and can adapt well to hot, humid tropical conditions. Additionally, low-input cropping methods are necessary for the successful growth of vegetables in the present situation of climate change. To achieve large yields, it is crucial to cross disease-resistant temperate variety with heat-tolerant tropical lines in order to broaden the genetic diversity of heat-tolerant cultivars. The development of heat-tolerant tomato lines included the use of heat-tolerant breeding lines and landraces from the United States (such as Tamu Chico III, PI289309) and the Philippines (such as VC11-3-1-8, VC 11-2-5, Divisoria-2). The reduced crop production in the heat-resistant varieties remains a matter of worry.

To meet the requirements of a shifting climate, there is a need for cultivars that can tolerate higher temperatures. These cultivars should be capable of producing yields similar to traditional varieties that are not heat-tolerant, but only in situations without stress. In order to uncover other causes of heat tolerance, it is necessary to analyze a wider spectrum of genetic variations. The AVRDC breeding line CL5915 has shown notable heat tolerance in Southeast Asia and the Pacific region. While heat-sensitive lines are unable to produce fruit at average field temperatures of 35°C, CL5915 exhibits fruit set ranging from 15% to 30%.

4.3.7 Drought Tolerance and Water-Use Efficiency:

Plants use many ways to endure water scarcity or drought stress. Plants have the potential to endure drought stress by reducing their life cycle duration in response to a steady increase in water scarcity. Intense dryness leads to significant oxidative stress on photosynthetic processes. Consequently, the capacity to disperse energy and provide metabolic protection against reactive oxygen species is crucial for survival in arid settings. Crop plants that are native to extremely dry regions rarely show tissue tolerance to severe dehydration. Insufficient and restricted genetic variability contributes to drought tolerance in *S. lycopersicum.* Additional species in the *Solanum* genus, including accessions of *S. cheesmanii, S. chilense*, *S. lycopersicum, S. lycopersicum* var. *cerasiforme*, *S. pennellii*, *S. peruvianum* and *S. pimpinellifolium* represent valuable sources of resistance. *S. chilense* for instance, exhibits a longer primary root and a more extensive secondary root system compared to cultivated tomato varieties. *S. chilense* can withstand wilting five times better than cultivated tomatoes, according to tests conducted during droughts. Unlike the cultivated *S. lycopersicum*, *S. pennellii* can increase its water usage efficiency during drought conditions. (O'Connell et al. 2007).

4.3.8 Tolerance to Saline Soils:

The inherent genetic and physiological intricacies of salt tolerance render conventional breeding programs rather inefficient in enhancing crop tolerance. In order to attain successful breeding for salt tolerance, it is important to possess effective screening techniques, a wide range of genetic variation and the capacity to transfer genes to the desired species. Nevertheless, cultivated species exhibit little variation and the majority of commercially grown tomato cultivars have relatively slight susceptibility to increased salt. Pepper plants have a significant decrease in yield, fresh and dry weight, shoot height, root length and germination when exposed to salt stress. Pepper genes from varieties such as Demre, Ilica 250, 11-B-14, Bagci Carliston, Mini Aci Sivri, Yalova Carliston, and Yaglik 28 may be used to create pepper cultivars that have improved germination in the presence of high salt levels. Wild species populations have been used to transfer quantitative trait loci (QTLs) and gain insights into the genetics of salt tolerance. Identifying the mechanisms that enable plants to tolerate salt at various stages of growth and incorporating genes that promote salinity tolerance into vegetable varieties would accelerate the creation of cultivars that can withstand high or fluctuating levels of salt in different production environments.

4.3.9 Climate-Proofing through Genomics and Biotechnology:

Recently, genomics has advanced beyond just sequencing full genomes to developing novel and effective genetic and molecular techniques, which allow for the discovery of genes and a thorough comprehension of their activities. This has enabled the genetic modification of genes associated with environmental stress tolerance. These techniques need significant financial investment but provide speedier and perhaps more impressive returns. Several successful efforts have been implemented using these molecular technologies. Both national and international institutions are reorienting their efforts towards plant molecular genetic research in order to improve traditional plant breeding methods and harness the capabilities of genetic engineering to increase and maintain agricultural productivity.

4.3.10 QTLs and Gene Discovery for Stress Tolerance:

Since polygenes are thought to be the primary mechanisms behind tolerance to a variety of abiotic stresses, including heat, cold, drought and waterlogging, little is known about their genetic composition (Ainsworth and Ort, 2010).

The researchers' objective is to clarify the genetic control of tolerance by discovering quantitative trait loci (QTL) in mapping populations that exhibit segregation. Jha et al. (2014) recorded the impact of several variables on the capacity to withstand heat and the variation in quantitative trait loci (QTL) across different crops.

In addition, they emphasized the identification of Quantitative Trait Loci (QTLs) linked to heat tolerance in several plant species, such as cowpea tomato and potato. Multiple markers linked to heat tolerance traits have been found in many crops, facilitating the process of selecting desirable traits (Driedonks et al. 2016). QTLs for heat-tolerant traits, such as increased chlorophyll fluorescence and canopy temperature at different phases of crop development, have been successfully identified.

Increased chlorophyll fluorescence levels suggest the presence of heat-resistant photosynthesis. On the other hand, lower temperatures in the canopy, which are linked to extensive root systems, may indicate effective water absorption (Pinto and Reynolds, 2015). Table 4.2 presents the discovery of several quantitative trait loci (QTLs) for abiotic stressors in vegetable crops, as reported by many studies.

Table 4.2: Identification of QTL(s) related to abiotic stresses in different vegetable crops:

Vegetable crop	Abiotic stress	No. of QTL(s) identified	Reference
Tomato	Heat	6	Ventura et al.2007
Lettuce	Heat	Htg6.1	Argyris et al.2011
Potato	Heat	9	McCord et al. 2011
Common bean	Drought	14	Mukeshimana et al. 2014
Pea	Frost Drought	161 10	Klein et al.2014 Iglesias-García et al.2015

4.3.11 Transgenics in Stress Tolerance:

Transgenic plant development is a contemporary approach to enhance tolerance to abiotic stress. Tomatoes cultivated in controlled environments and genetically modified to express the osmotin gene have shown resistance to high salt levels and water scarcity.

These modified tomatoes have exhibited enhanced germination, higher proline levels and increased relative water capacity (Goel et al. 2010).

The limited commercialization of vegetable transgenics is mostly attributed to consumer aversion, which arises from concerns around the ingestion of these genetically modified foods in their raw and unprocessed form. The lack of consistency in transgenic expression and transformation across various crops has hindered the progress of vegetable production. The research seeks to assess the impact of transgenics on human health, biodiversity and the environment providing an alternative and pragmatic method for addressing plant stress factors, particularly abiotic stress. Various trangene(s) used by researchers for enhancing stress tolerance in different vegetable crops have been presented in Table 4.3.

Table 4.3: Transgene(s) for enhanced stress tolerance in different vegetable crops

Vegetable crop	Transgene	Impact	Reference
Potato	Nucleoside diphosphate kinase 2 (AtNDPK2)	Enhanced drought and salinity tolerance	Tang et al.2008
Tomato	CaXTH3, xyloglucan endotransglucosylase/hydrolase gene	Enhanced drought and salinity tolerance	Choi et al.2011
Sweet potato	Spinacia oleracea's chloroplastic BADH gene (SoBADH)	Maintenance of photosynthetic activity, accumulation of glycine betaine and cell membrane integrity. Tolerance to oxidative stress	Fan et al.2012

4.4 Conclusion:

Vegetable crops suffer from reduced production, productivity and quality as a result of their high vulnerability to harsh weather conditions. The impact of increasing global temperatures on crops is of significant importance among the many consequences of climate change. It is essential to create adaptation strategies tailored to crops that include all possible choices to maintain productivity and output.

This is important since various crops and agro-ecological sectors have variable levels of vulnerability. Efficient nutrient and water management techniques should specifically target the influence of salinity on plant development, taking into account the fact that various plants possess variable levels of salt tolerance. Hence, it is crucial to conduct further research to discover and develop genotypes that are resilient to climate change and utilize advanced technologies. This is necessary to maintain a sustainable production system, safeguard food security and uphold nutritional quality in the midst of an uncertain global environment.

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