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REVIEW ARTICLE

Impact of Climate Change on Vegetable Production and Management Strategies

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Abstract

Vegetables are an important component of human nutrition that encompasses great species diversity and are very sensitive to unpredictable climatic changes. In recent decades, there has been an increase in the frequency of events like drought, flooding, high-temperature, low temperature, salinity and changes of atmospheric CO_2 or ozone level which considerably affect morphological, physiological and biochemical changes in the plants. The occurrences of these types of abiotic stresses lead to membrane damage, oxidative burst, reduction of chlorophyll content and photosynthesis rate which ultimately affect the yield and quality of vegetable crops. The adoption of appropriate crop management practices and climate-resilient cultivars would help immensely in dealing with the adverse impacts of abiotic stresses. Alteration in planting dates, advanced irrigation technology, moisture-saving methods, use of plant growth regulators, use of plant growth promoting rhizobacteria, grafting technology, use of climate resilient cultivars and protected cultivation-like management practices can reduce the impact and intensity of abiotic stress enhance the production as well. Overall in this review, we have summarized the adverse effects of abiotic stresses that are induced by climate change and management strategies that enable to overcome the ill effects and sustain the production of vegetable crops.

Keywords: Climate change, vegetables, impact, abiotic stress, biotic stress.

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Introduction

Vegetables are defined as any kind of plant life or plant product that is consumed in either raw or cooked form (Ward 2016). They may be consumed as flowers, fruits, leaves, tubers, pods and seeds (Peet and Wolfe 2000; Chaudhary *et al*. 2022). Only 30 to 40 vegetable crops are commonly cultivated, although there are 200 vegetables all around the world (Chen *et al*. 2019a). Vegetables are an important component of human nutrition and are a rich source of fiber, protein, vitamins, antioxidants, carbohydrates and minerals (Pennington and Fisher 2010). Apart from the source of nutritional security, vegetable crop cultivation provides a constant source of income to the farmers. India is the second largest producer of vegetables after China with a production of 197.23 million tons from an area of 10.97 million ha area. In the total horticulture production, 59.58% contribution is from vegetables (Annual report 2021-22, DAFW, MoA & FW- GOI). In recent years, due to increasing price affordability and awareness about nutritional benefits, there has been a great surge in vegetable demand. Hence in this direction to cater to the growing demand of vegetables, sustained efforts have been made. But, abrupt changes in the climatic conditions have posed a serious threat to crop production across the world (Machado and Serralheiro 2017; Chaudhary *et al*. 2022). Vegetable crops are more prone to

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climatic changes compared with other horticultural crops (Giordano *et al*. 2021)

The average change in various climatic parameters such as temperature, rainfall, relative humidity and gaseous composition etc., over a period of time in a geographical area is referred to as climate change (Raza *et al*. 2019). Due to climate change, there has been an increase in the frequency of events such as drought and flood, high-temperature, low temperature and salinity, as well as changes in atmospheric CO_2 or ozone level which considerably affect the yield and quality of vegetable crops (Bulgari *et al*. 2019; Raza *et al*. 2022). It has been reported that due to global warming, there has been a decrease of 41% yield in vegetable crops since 1965 to 2016 (Scheelbeek *et al*. 2018). Thus, to achieve the targeted production of vegetable crops in the near future, to feed the burgeoning population across the globe there is a need to develop climate-smart interventions that counter the adverse environmental stresses (Malhotra and Srivastava 2014; Malhotra and Srivastava 2015). Therefore, the impact of climate change on vegetable production and various management practices suggested to overcome the adverse effects are discussed in this review.

Effect of Abiotic Stresses on Vegetable Crops

Effect of high-temperature stress

Since the last century, there has been a continuous rise in global air temperature and over the period. There has been a rise of 1.1°C temperature since 1850–1900. Averaged over the next 20 years global temperatures are expected to exceed 1.5°C warming (IPCC 2022). The increased atmospheric temperature compels the crops to face heat stress which causes morphological, physiological and biochemical changes that affect crop growth and yield (Laxman *et al*. 2014; Aleem *et al*. 2020). Although heat stress affects all the developmental stages *viz*. seed germination, vegetative, and reproductive stages of plants but the most significant damage occurs at the reproductive stage (Wahid *et al*. 2007). Heat stress causes lower pollen production, poor pollen viability, ovule abortion and flower drop that results in poor fruit set, particularly in cucurbits and solanaceous vegetables (Karapanos *et al*. 2008; Saha *et al*. 2010). The prevalence of warm and humid climatic conditions shift the flowering pattern in cucurbits such as the induction of female to male flowers which causes a reduction in yield (Lai *et al*. 2018). In tomato and chili temperatures above 37 and 40°C, respectively adversely affect pollen viability, and flower and fruit development which ultimately reduces the yield (Dahal *et al*. 2006; Mazzeo *et al*. 2018). Moreover, the temperature above 33°C in pepper causes pollen abnormalities which include shrunken and empty pollen (Erickson and Markhart 2002; Muller *et al*. 2016). In case of peas, the temperature above 28°C causes a reduction in yield and particularly short-duration cultivars are more vulnerable. The temperatures above 25°C affect the onion seed germination rate and percentage (Brewster 2008). In carrot, temperatures beyond 35°C leads to decreased cell membrane stability and increased relative cell injury (Nijabat *et al*. 2020). The tomato requires an optimum temperature in the range of 25 to 30°C and temperatures beyond this threshold affect the plant growth and development (Laxman *et al*, 2018). The adverse effects due to high temperature cause physiological and biochemical changes in tomatoes (Laxman *et al*., 2013) and higher antioxidative capacity induces tolerance (Laxman *et al*. 2014).

Further, the prevalence of high-temperature stress for prolonged days initiates the flowering of spinach and lettuce, which leads to a decline in the quality of the vegetables. Under severe heat stress, the plant's enzymatic activities are disrupted, resulting in an oxidative burst and damaged metabolism of the plant leading to senescence (Raza 2022). Thus, all these studies clearly indicate that high temperatures have adverse effects on vegetable crops.

Effect of cold (low temperature) stress

Cold stress or low-temperature stress, classified as chiling stress (0–15°C) (Wang *et al*. 2016) and freezing stress (<0°C) (Trischuk *et al*. 2006), is another important abiotic stress which hinders the metabolic processes in plants which affects the growth and development and reduces the yield as well as the quality of vegetable crops (Ding *et al*. 2019). Vegetable crops grown in tropical and subtropical climates experience serious freezing injury, even the freezing conditions prevail for a short duration. Most of the crops that develop in colder climates often survive with little freezing if the freezing conditions is not too severe (Shirani Bidabadi and Mehralian 2020).

The plasma membrane is considered as the primary site of cold stress, which causes alterations in the integrity and fluidity of membranes that lead to interruption in ion transport, denaturation of proteins and ultimately there is imbalance in normal cell metabolism (Wu *et al*. 2019; Orzechowski *et al*. 2021; Sharaf-Eldin *et al*. 2022). Cold stress leads to disruption of the integrity of intracellular organelles leading to the loss of compartmentalization. It also causes reduction and impairing of photosynthesis, protein assembly and general metabolic processes (Atayee *et al*. 2020). Some studies reported that low temperatures of 8 to 12°C reduce seed germination, crop growth, pollen tube growth, and the percent fruit set by reducing enzymatic antioxidant activities, increasing ROS, lipid peroxidation, hampering membrane stability, reducing chlorophyll biosynthesis and damaging the photosynthetic system in tomato (Bai *et al*. 2021), muskmelon (Risse *et al*. 1978), watermelon (Bradow 1990), Pakchoi (*Brassica chinensis* L.), cucumbers (Anwar *et al*. 2018a; Han *et al*. 2019; Zhang *et al*. 2020a), zucchini (Zhang *et al*. 2019) and pepper (Rehman *et al*. 2021). Cold

Table 1: Lowest safe temperature (°C) for vegetables and cold stress injury symptoms

Vegetables	*Lowest safe temperature (°C)*	*Cold stress injury symptoms*
Asparagus	0–2	Dull, gray-green, limp tips
Bean (snap)	7.0	Pitting and russeting
Cucumber	7.0	Pitting, water-soaked lesions, decay
Eggplant	7.0	Surface scald, *Alternaria* rot, seed blackening
Okra	7.0	Discoloration, water-soaked areas, pitting, decay
Pepper	7.0	Pitting, *Alternaria* rot, seed blackening
Potato	7.0	Mahogany browning, sweetening
Pumpkin	10.0	Decay, especially *Alternaria* rot
Squash	10.0	Decay, especially *Alternaria* rot
Sweet potato	10.0	Decay, pitting, internal discoloration
Tomato (ripe)	7–10	Water-soaking, softening, decay
Tomato (Mature-green)	13.0	Poor color when ripe, *Alternaria* rot

stress decreases chlorophyll content in eggplants (Wu *et al.* 2014). It also affects the ultrastructure of chloroplasts altering the light-harvesting chlorophyll antenna complexes and modifying thylakoid structures, thereby, reducing the photosynthetic ability and osmotic adjustments of potato plants (Wu *et al.* 2019). Moreover, temperature below 15°C in chili causes hampered plant growth, premature falling of flowers, low fruit set, and production of deformed seeded or seedless fruits (Ou *et al.* 2015; Airaki *et al.* 2012). The list of vegetables sensitive to chiling temperatures, the lowest safe storage/handling temperature, and the symptoms of chiling injury (Prasad & Chakravorty 2015) are depicted in Table 1.

Effect of Water Stress

Vegetable cultivation requires a constant source of irrigation but the scanty precipitation, higher evapotranspiration due to global warming and depleting groundwater have created deficit water situations which severely affect the yield and quality of vegetable crops (Seleiman *et al.* 2021). However, sometimes extreme rainfall particularly during the monsoon season also causes excess moisture stress to vegetable crops. Thus the vegetable crops suffer both excess as well as deficit water stress conditions under field situations.

Adverse Effects of Deficit Water Stress

Water stress has a great influence on the yield and quality of vegetables as they are very succulent and consist 90% water. The deficient soil moisture condition or below-normal precipitation for a longer period of time creates drought stress (Chaudhry *et al.* 2022). Drought stress causes alteration in morphological, physiological, biochemical and genetic responses in plants which ultimately lead to restricted crop growth (Vadez *et al.* 2012). Drought conditions for prolonged periods adversely affect the germination of seeds in onion and okra and the sprouting of tubers in potatoes (Arora *et al.* 2010). The adverse effects of drought stress on photosynthesis, and abscission of flowers and flower buds have been observed in susceptible cultivars than the tolerant cultivars of tomato (Bhatt *et al.* 2009). Drought stress during the reproductive stage induces flower abscission in tomatoes (Bhatt *et al.* 2009) and causes more than 50% yield reduction (Srinivasa and Bhatt 2012). In bell pepper (*Capsicum annuum* L.) imposition of moisture stress at late flowering-early fruit set stage causes 44% reduction in yield which is mainly due to lower fruit set and reduced fruit weight (Candid *et al.* 2009). Furthermore, moisture stress at 3 and 7 leaf stage causes 26% reduction in yield of onion (Gary *et al.* 2004).

Adverse Effects of Excess Water Stress

Most of the vegetables are highly sensitive to excessive available soil moisture. The presence of an excess amount of soil moisture than the optimum requirement is referred to as water-logging. Due to water-logging, the soil pores are filled with water and a condition of hypoxia (low oxygen concentrations) or anoxia (complete absence of oxygen) is created in the soils (Fukao *et al.* 2019). Water-logging causes wilting, epinasty, or downward curling of leaves and stems. The root system just cannot supply water and nutrients fast enough to prevent wilting and yellowing of leaves (Sairam *et al.* 2008). Epinasty occurs because water logging triggers accumulation of ethylene in the roots which causes downward curling of leaves and stems (Barrett-Lennard 2003; Yamauchi *et al.* 2018). Vegetable crops like tomato and capsicum sp. show reduced chlorophyll content, chlorophyll fluorescence, photosynthesis rate, leaf water potential and increased proline content under water-logging conditions (Bhatt *et al.* 2015; Ou *et al.* 2011) which ultimately causes substantial yield losses. Moreover, the onion crop is also sensitive to water-logging conditions due to its shallow root system. Srinivasa Rao (2010) has reported seven days of water-logging in onion cv. Arka Kalyan causes 86, 51, 46 and 47% reduction in photosynthesis rate, leaf area, fresh weight and dry matter, respectively. Among the various developmental stages in onion, the bulb initiation stage was found to be most vulnerable towards water stagnation and claims 50% reduction in bulb yield after seven days of water logging due to heavy incidence of purple blotch and twister diseases (Samra *et al*. 2006; Srinivasa Rao *et al*. 2010). In this way excess moisture stress has a considerable effect on vegetable crops.

Effect of Soil Salinity

It has been predicted that by 2050, due to the occurrence of climate change and anthropogenic reasons, half of the cultivable area of India will be salt-affected (Jogeswar *et al*. 2006; Corwin *et al*. 2007). Under salinity stress, the uptake of essential elements (such as K^+, Ca^{2+}, and NO_3^-) are inhibited and accumulation of Na^+ and Cl^- ions in plant cells takes place, which causes the development of osmotic stress (Paranychianakis *et al*. 2005). Salinity stress affects each and every stage of plant growth, such as seed germination, vegetative, reproductive and fruit-setting stages etc. Salinity stress alters the plant cell metabolism which leads to lipid peroxidation, loss of leaf chlorophyll, electrolyte leakage and reduced photosynthesis rate ultimately reflected in terms of a reduction in total yield (Sairam & Tyagi 2004; Machado and Serralheiro 2017). The sensitivity of vegetables toward salinity tolerance varies from crop to crop (Maas 1990) such as carrot, okra, peas and onions are highly salt sensitive, radishes, potatoes, tomatoes, cabbage, and eggplant are pumpkin moderately salt sensitive, whereas beetroot is moderately salt tolerant. Studies on the effect of salinity stress on tomatoes and chili showed that salt stress causes reduced germination percentage and increased germination time (Singh *et al*. 2012). Salinity stress during the flowering and fruiting stage reduces yield in tomatoes which happens primarily due to lower number of fruits (Zhang *et al*. 2017). It has been observed that wild-type tomato (*Lycopersicon pennellii*) has a higher tolerance to salinity than cultivated tomato (*Lycopersicon esculentum*) and the difference is mainly due to higher antioxidant enzyme activity (Mittova *et al*. 2002). Furthermore, salt stress also affects fruit length, fruit girth, fruit weight and the number of fruits per plant in chili (Balasankar *et al*. 2017). Being a salt-sensitive crop, 50% yield reduction has been reported in pea at salinity levels between 6 and 10 dS m^{-1} (Okcu *et al*. 2005) and likewise the 50% reduction in fresh fruit yield of okra has been reported at 6.7 dS m^{-1} (Minhas and Gupta 1993). About 50% yield loss has also been reported in potatoes at 11.8 dS m^{-1} (Ayers and Westcot 1985). The adverse salinity stress effects are observed across the vegetable crops.

Effect of Elevated Carbon Dioxide (CO_2) level

The atmospheric CO_2 level will reach close to 550 ppm by 2050. Apart from temperate (high temperature and low temperature) and water (drought and water logging) and salt stresses, the crops respond to increasing atmospheric carbon dioxide concentration which serves as the principal driver of climate change. The rising CO_2 level directly affects plants' metabolism, since it plays a pivotal role in plant metabolism and is directly involved in energy balance by regulating physiological processes such as photosynthesis and respiration. Increasing CO_2 level generally increases plant productivity by enhancing plant water use efficiency, photosynthetic capacity, and growth so-called "Carbon fertilization" effect (Rogers and Dahlman 1993; Fleisher *et al*. 2008). The productivity of C_3 and C_4 plants increases by 15 to 41% and 5 to 10%, respectively under increasing CO_2 levels (Lotze-Campen and Schellnhuber 2009; Brand *et al*. 2016).

The studies on the effect of elevated CO_2 on onion cv. Arka Kalyan showed that at bulb initiation and bulb development stages, the leaf number and area and pseudo-stem length increased at 550 ppm CO_2 level compared to the ambient level. The increase in total dry matter and bulb size resulted in a 25.9% higher yield as compared to ambient levels. The onion bulb quality was also influenced with a reduction in antioxidant content and flavonoids. However, the total phenols content increased under elevated CO_2 (Srinivasa Rao *et al*. 2009). In tomato plants, height was significantly higher at 550 ppm CO_2. The number of branches was higher at 700 ppm CO_2 as compared with 550 ppm and control. Plants grown at 700 ppm with higher leaf and root dry mass had higher total dry mass compared to plants grown at 550 ppm and ambient level. Increased number of flowers and fruits together with higher fruit set led to higher fruit yield at both 700 and 550 ppm CO_2 levels. The elevated CO_2 influences fruit quality. The fruits had lower content of phenols, flavonoids, ferric-reducing antioxidant potential, total soluble solids, and titratable acidity at elevated CO_2 levels compared to ambient levels. The ascorbic acid content was high at both 700 and 550 ppm. Carotenoids and lycopene content was higher at EC550 and control.

Some studies reported, mostly in leafy vegetables, that increasing CO_2 levels affect product quality by improving the concentration of sugars, ascorbic acid, flavonoids, phenols, and antioxidant capacity (Bisbis *et al*. 2018). Becker and Klaring (2016) reported that sugars, flavonoids, and caffeic acid derivatives increase in red leaf lettuce at 1000 ppm CO_2 concentration. Higher vitamin C content has been observed in lettuce, celery, and Chinese cabbage grown at 800 to 1000 ppm CO_2 (Jin *et al*. 2009). The increased content of total phenolic compounds, antioxidant capacity and total chlorophyll content and reduced content of several macro- and micronutrients have been reported in lettuce and spinach at 700 ppm CO_2 at 700 ppm CO_2 (Giri *et al*. 2016). Elevated CO_2 at 1000 ppm deteriorates many important nutritional parameters, such as protein, vitamin C, minerals (Ca, Mg, Zn, Mn, and Fe), essential fatty acids, and amino acids in tomatoes (Khan *et al*. 2013) and in root vegetables like carrot, radish, and turnip (Azam *et al*. 2013). In potatoes, the high atmospheric CO_2 (550–680 ppm) levels made alterations in tuber quality but whether these changes are positive (increasing dry matter, starch, and the vitamin C content and decreasing toxic compounds such as total glycoalkaloids, α-chaconine, and nitrate) or negative (reduction of protein, macro-micronutrients (N, K, Ca, Mg, Fe), total amino acids, and citric acid) depending on the quality parameter (Hogy and Fangmeier 2009; Kumari and Agrawal 2014). Moreover, some studies have reported that CO_2 levels at 700 to 1000 ppm increase the traits which are related to taste such as total sucrose, glucose, and fructose content, sugar/acid ratio, and coloration in tomato fruits (Khan *et al*., 2013; Wei *et al*., 2018). Further, the concentrations of titratable acidity, carotenoids, lycopene, anthocyanins, phosphorus, potassium, sulfur, copper, and manganese are observed to be not affected by elevated CO_2 (Dong *et al*. 2018).

Effect of Elevated Ozone (O_3) Level

Ozone (O_3) is a greenhouse gas and it is estimated that due to various anthropogenic reasons the global tropospheric O_3 concentration will reach 395 Tg by the year 2100 (Young *et al*. 2013). The increasing level of O_3 in the troposphere negatively affects plant growth and decreases the productivity of vegetables in the predominating fertile agricultural regions of India (Mukherjee *et al*. 2020). The pattern of O_3 concentration shows a 40 to 60 ppb (higher) range during the pre-monsoon/summer season and a 15 to 20 ppb (lower) range during the monsoon months over the northern, western, and peninsular regions of India (Kunchala *et al*. 2021). The O_3-induced plant damage is mainly caused by the stomatal uptake of O_3 into the leaf interior instead of direct plant surface deposition (Nouchi 2002). The impact of O_3 in crop plants depends on the amount of uptake and its reaction ability with cellular components to generate reactive oxygen species damage to the cell at the molecular, biochemical, and physiological levels and accelerate leaf senescence, resulting in a reduction of crop yield (Yadav *et al*. 2019; Sicard *et al*. 2020).

Suganthy and Udayasoorian (2020) have reported that potato (*Solanum tuberosum* L.) yield reduces from 4.56 to 25.5% when it is exposed to the elevated level of surface O_3 during the tuber initiation stage at a high altitude of Western Ghat. In tomatoes (*S. lycopersicum* L.) elevated O_3 causes a maximum reduction in yield during the late vegetative phase than the early vegetative and fruiting phases (Mina *et al*. 2010). Among leafy green vegetables, Palak (*Beta vulgaris* L.) is very susceptible to O_3 (Tiwari *et al*. 2010) and shows yield losses up to 25% at a high O_3 level (Kumari *et al*. 2013). A similar type of results have also been reported in *Amaranthus hypochondriacus* L. (Yadav *et al*. 2020b), *Rapahanus sativus* L. (Agathokleous 2017) and *Daucus carota* L. (Tiwari and Agrawal 2010). Elevated O_3 decreases seed protein in soybeans, which is correlated with a detrimental reaction to nitrogen fixation (Broberg *et al*. 2020). Exposure of common beans to O_3 at 40 ppb during the growing periods increases total lipids, phytosterols, dietary fiber, total phenolics, and antioxidant capacity, but decreases total amino acids content, total anthocyanins, some flavonols, and hydroxyl cinnamates (Iriti *et al*. 2008). In potatoes, the increased level of atmospheric O_3 (50–70 ppb) decreases the tuber's dry weight, proteins, and amino acids, reducing sugar content and micro-micronutrient content (Kumari and Agrawal 2014). Moreover, it has been reported that the yield of vegetables can be reduced by 5 to 15% when daily ozone concentrations reach greater than 50 ppb (Raj Narayan 2009). Thus elevated O_3 has an adverse impact on vegetable yield and quality.

Management Strategies under Changing Climate Scenario

There is a need of continuous effort, to sustain vegetable productivity under the changing climate scenario. The development of appropriate crop management practices and climate-resilient cultivars would help immensely in dealing with the adverse impacts of various abiotic stresses.

Adoption of Climate-resilient Varieties

The inclusion of climate-resilient varieties are important option to combat with abiotic stresses and improve crop yields. Major vegetable crop varieties with tolerance to drought, heat, flood and cold stresses are given in Table 2.

Grafting Technology

Grafting vegetable plants onto resistant rootstocks is an efficient method for controlling biotic and abiotic stresses and increasing the yield and quality of vegetable crops (Rouphael *et al.,* 2010). There are some reports that grafting of tomato on brinjal rootstocks improved waterlogging stress. It has been observed that eggplant rootstocks Arka Keshav, Arka Neelkanth, IC-354557 and IC-111056 impart flooding tolerance in tomatoes (Bahadur *et al*. 2015; Bhatt *et al*., 2015). Most greenhouse-cultivated cucurbits are grafted in China, Japan, Korea, Turkey and Israel, while grafted vegetables are cultivated on a commercial scale in more than 20 countries worldwide. Nearly 99% of watermelons in Korea, 94% in Japan, and 40% in China are cultivated using grafted seedlings for improved tolerance to biotic stress, nutrient deficiency/ toxicity, abiotic stress and heavy metal toxicity (Zhilong *et al*., 2017).

Seed Priming

The appropriate and timely alterations in cultivation approaches enable farmers to enhance production under adverse conditions. Seed priming is an important technique that can be employed to enhance seed germination rate, uniformity and early establishment in vegetable crops under salinity and water stress. Priming hastens the rapid mobilization of seed reserves through increased activity of the enzymes involved in respiration and catabolism of starch, proteins and lipids thereby faster mobilization of the nutrients towards the growing parts of the seedling

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

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

(Thakur *et al*., 2020). Priming of pepper seeds with 1 mM sodium chloride provides higher germination percentage and better seedling establishment under salt stress (Khan *et al*., 2009). Capsicum cv. California wonder seeds primed with Thiourea (1.3 mM), hydrogen peroxide (1.5 mM) and ABA (100 mM) showed tolerance to salt stress and had 100% seedling survival (Yadav *et al*., 2011). Tomato seeds priming with 25 mM KNO_3 leads to higher germination percentage and seedling fresh weight (Nawaz *et al*., 2011). Cowpea seed priming with 0.5% NaCl has a higher tolerance towards water stress (Menon and Savithri 2015).

Usage of Plant Growth Regulators

Usage of natural and synthetic plant growth regulators can improve abiotic stress tolerance in vegetable crops. Watermelon seedling treatment with 150 µM melatonin is effective in improving photosynthesis and biomass accumulation under salt stress (Li *et al.* 2017). Foliar spray of 24-epibrassinolide to tomato plants at four leaf stages helps the plants to withstand drought stress.

Plant Growth-promoting Rhizobacteria

Plant Growth Promoting rhizobacteria (PGPR) colonize in the roots and reduce the adverse effects of abiotic stresses (Khan *et al.* 2020). PGPR enhances growth regulator production, fertilizer use efficiency and antioxidant enzyme level and thus help to improve the plant productivity (Compant *et al.* 2010; Hima Bindu *et al.* 2018). PGPR induces root growth through supplementary production of phytohormones such as indole-3-acetic acid (IAA), gibberellins, cytokinins, and abscisic acid. The increased root growth then enables the plants to thrive under water-scarce conditions (Khan *et al.* 2016). *Bradyrhizobium* sp. has been identified as an agent that provides water scarcity tolerance in cowpeas (Barbosa *et al.* 2013). Tomato seed priming with with *T. harzianum* Rifai strain T-22 has been shown to alleviate abiotic stress factors like osmosis, salinity, chiling and high temperature (Mansouri *et al.* 2010).

Alterations in Cultivation Practices

Shifting of planting dates can be used as a quick adaptation strategy to counter crop yield losses in locations where episodes of heavy rainfall and high temperatures are anticipated. Water-saving irrigation methods such as drip (crops like cucurbits, tomato, chili, capsicum and brinjal) and sprinkler (crops like onion, carrot, radish and beetroot) can be adopted in areas where there is limited water availability. Agronomic practices like contour cultivation, contour strip cropping, mixed cropping, and minimum tillage can be adopted to conserve the *in-situ* soil moisture in areas that are prone to water deficit stress. Enhancement of soil organic matter content can also improve the moisture-holding capacity of the soil, which can be achieved by growing green manure crops and incorporating of farm yard manure. Furthermore, soil mulching with natural crop residue or plastic films is another method to conserve soil moisture, which also suppresses weed growth.

The impact of abiotic stresses in vegetable crops can also be minimized by the appropriate application of nutrients in root zone or foliar spray. Such as spraying of K and Ca induces drought tolerance and improves crop yields and quality in vegetable crops. Foliar application of calcium @ 20 or 35 mg L^{-1} and sulfur @ 5 or 10 g L^{-1} to chili plants enhanced salinity tolerance capacity (Mukhtar *et al*., 2016).

Protected Cultivation

Cultivation of crops under protected structures such as greenhouses, polyhouses and net or shade houses, protect the crops from unfavorable environmental conditions such as high and low temperatures, drought, flooding and soil pH stresses thereby improving plant productivity. In this row tomato, capsicum and parthenocarpic cucumber cultivation under protected cultivation fetches higher yield and quality fruits.

Conclusion

In conclusion, due to climate change, the frequency of extreme weather events like heat, cold, drought, flooding, salinity stresses and changes in the level of atmospheric CO_2

or ozone have been tremendously increased. The exposure of vegetable crops to these types of abiotic stresses reduces yield and quality. Some of the key physiological and biochemical effects of abiotic stresses are membrane damage, oxidative burst, reduction of chlorophyll content and photosynthesis rate. So to sustain the productivity of vegetable crops under changing climatic scenarios both adaptation and mitigation strategies are needed. Climate-smart production practices, climate-resilient varieties, use of PGPR, suitable cultural practices, diversified cropping systems and mulching are required to be adopted. Since adopting crop management options involves cost, a cost-effective combination of adaptation options need to be devised for different crops and regions. Thus, all strategies suggested here go a long way in overcoming abiotic stresses and supporting the farmers to sustain the productivity of vegetable crops.

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सारांश

सब्जियाँ विविध प्रजातियों का एक है समूह जो कि मनुष्य पोषण का एक महत्वपूर्ण घटक है तथा अप्रत्याशित जलवायु परिवर्तनों के प्रति ये बहुत संवेदनशील हैं। हाल ही के दसको में, सुखा, बाढ़, उच्च तापमान, कम तापमान, लवणता और वायुमंडलीय कार्बन डाई ऑक्साइड या ओजोन स्तर में परिवर्तन जैसी घटनाओ की आवृत्ति में वृद्धि हुई है जो पौधों में रूपात्मक, शारीरिक और जैव रासायनिक परिवर्तनों को काफी प्रभावित करते हैं। इस प्रकार के अजैविक तनावों की घटनाओं से झिल्ली की क्षति, औक्सीकरण क्षति, क्लोरोफिल और प्रकाश संश्लेषण की दर में कमी होती है जो सीधे तरीके से सब्जीयोँ की उपज और गुणवत्ता को प्रभावित करते है। उचित फसल प्रबंधन तकनीक और जलवायु प्रतिरोधी किस्मों को अपनाने से अजैविक तनाव के प्रतिकूल प्रभावों से निपटने में बहुत मदद मिलेगी। रोपण की तारीखों में परिवर्तन, उन्नत सिंचाई की तकनीक, नमी की बचत के तरीके, पादप विकास नियामकों का उपयोग, पौधों के विकास को बढ़ावा देने वाले प्रकंदों का उपयोग, कलम तकनीक, जलवायु प्रतिरोधी किस्मों का उपयोग और प्रबंधन कार्यो जैसे संरक्षित खेती से अजैविक तनाव के प्रभाव और तीव्रता को कम करके उत्पादन में भी वृद्धि की जा सकती है। कुल मिलाकर इस समीक्षा में हमने जलवायु परिवर्तन से प्रेरित अजैविक तनावों के प्रतिकूल प्रभावों और प्रबंधन रणनीतिया जो दुष्प्रभावों को दूर करने और सब्जी फसलों के उत्पादन को बनाए रखने में सक्षम हैं, को संक्षेप में विवरण प्रस्तुत किया है ।