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CLIMATE SMART BREEDING OF VEGETABLE CROPS : A REVIEW

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ABSTRACT

Both our well-balanced diet and the Indian economy depend heavily on vegetables. Vegetable components have strong medicinal significance because of their antioxidant and anti-carcinogenic qualities. Our nation is blessed by nature with an enormous range of land, soil, and agroclimatic conditions. Unfortunately, however, the effects of climate change such as variations in seasonal and monsoon patterns brought on by global warming as well as biotic and abiotic elements under changing climatic conditions are having a negative impact on crop output. Vegetable agriculture is rendered unprofitable by frequent crop failures, low yields, quality reductions, and an increase in pest and disease concerns. The two main effects of rising temperatures on vegetable production are drought and salinity. Because vegetable crops are highly susceptible to weather fluctuations, abrupt temperature increases and erratic precipitation at any stage of crop growth can interfere with normal growth. A combination study of genomics and phenomics will provide a clear understanding of the environment's effect on the transformation of a genotype into a phenotype; the deployment of genome editing with speed breeding and phenomics can help in fast-track crop breeding; overall, the innovative technologies will potentially keep helping us in designing future climate-smart vegetable crops. Modifying the current vegetable systems will be necessary to potentially mitigate the effects of climate change in order to enhance the production and consumption of safe vegetables, thereby reducing malnutrition and mitigating poverty in developing countries.

***Keywords* :** climatic change, abiotic factor, genomics, phenomics, climate smart breeding.

Introduction

A shift in properties over a longer time span and a wider geographic area, as well as in the mean of the various climatic parameters including temperature, precipitation, relative humidity, and the composition of atmospheric gases, can be referred to as climate change. It can also apply to any gradual alteration in climate over time, whether brought on by human activity or natural variability. The production of vegetables in the tropical zone is facing significant risks from changing climatic parameters, such as rising air temperatures, altered precipitation patterns, excessive UV radiation, and an increase in the frequency of extreme weather events like floods and droughts. Vegetable crops are extremely vulnerable to weather fluctuations; abrupt temperature increases and erratic precipitation at any stage of crop growth can disrupt normal growth, flowering, pollination, and fruit development, which will ultimately reduce crop yield.

According to Schreinemachers *et al.* (2018), vegetables serve as the foundation for a healthy diet for everyone and present smallholder farmers with great economic prospects. Even with this potential, a major barrier remains the low output in some areas. There is a shortage of nutrient-rich vegetables in sub-Saharan Africa, Southeast Asia, and South Asia, where average vegetable yields are expected to be just 36%, 48%, and 64% of East Asia, respectively (FAOSTAT 2020). The low availability and productivity of vegetables, as well as the growth of their value chain, are caused by a number of socioeconomic and technological variables in these locations. Climate change makes this already dangerous situation worse by raising temperatures, altering precipitation patterns, and increasing the frequency of extreme weather events (IPCC 2019). According to a recent study on the production of vegetables and legumes worldwide, high temperatures, water scarcity, increased salt, and ozone might cause vegetable yields to decline by 35% by 2100 if greenhouse gas (GHG) emissions keep rising at the current rate (Scheelbeek *et al*., 2018). To modify this disastrous trajectory, there is an urgent need to increase the adaptive capacity of the vegetable value chain

In general, vegetables are susceptible to extremes in the environment. Low yields are primarily caused by extreme temperature variations and insufficient soil moisture, which have a significant impact on a number of physiological and biochemical processes, including decreased photosynthetic activity, changed metabolism and enzymatic activity, thermal injury to the tissues, decreased pollination and fruit set, etc. Climate change will amplify these effects even further, perhaps severely affecting vegetable production. Vegetable agriculture becomes unprofitable due to crop failures, low yields, declining quality, and an increase in pest and disease concerns under changing climatic conditions (Koundinya *et al.,* 2014). According to Sing *et al.* (2009), the effects of global warming and climate change could cause a 3.16% and 13.72% decrease in potato production in India in 2020 and 2050, respectively. Many climatic extremes, such as the development of high temperatures, low temperatures (chilling & freezing) in the atmosphere, the occurrence of floods, droughts, salinity, soil erosion, storms, wind, hail damage, volcanic eruptions, tsunamis, etc., have a significant impact on the yield potential of the majority of crops in this group. An overview of these extremes' effects on vegetable cultivation is provided below.

Carbon dioxide (CO_2)

The creation of carbohydrates in crops, which is necessary for crop development and yield, is mostly dependent on carbon dioxide. Vegetable crop productivity will probably increase overall when CO_2 levels rise (Bisbis *et al.,* 2018). However, any yield increases could be completely or partially offset by losses from weeds, plant diseases, other abiotic stressors, and phytophagous insects. Accurate forecasts for vegetable production at high CO_2 concentrations are further complicated by the likelihood of changes in temperature and water availability as CO_2 concentration rises.

Elevated temperature

Temperature events that beyond the typical growth ranges are anticipated to impact the growth and development of vegetable crops, ultimately determining their potential yields and quality. However, the way that different species and varieties react to high temperatures also relies on the age and growth stage of the plants. Temperatures above 35°C are generally thought to hinder the germination of seeds and the emergence of seedlings, interfere with regular photosynthetic processes, and increase respiration during the night, which reduces the amount of biomass produced for plant development and yield. Furthermore, according to Wheeler *et al.* (2000), high temperatures inhibit the modification of edible organs such as the leafy head, bulb, tuber, fleshy stem, fleshy root, and curd. They also interfere with normal reproductive processes, which reduce the amount of cruciferous vegetable flowering as well as the amount of fruit and seed set on annual crops like cucurbitous, leguminous, and solanaceous vegetables. In vegetable crops, high temperatures cause flower abortion, which impedes the development of floral buds (Gazala *et al*., 2020). According to Wheeler *et al.* (1998), high temperatures can also lower the postharvest quality of vegetable products.

It has been observed that harvested organ temperatures are 8–10°C higher than ambient temperatures when there is high insolation and high humidity. Under such circumstances, harvested vegetables from field crops frequently have unfavorable qualities like blotchy ripening, sunburn, sun scald, etc. For all these reasons, crop adaptation strategies tailored to a given region will be needed to adjust vegetable crops and cropping systems to temperature regimes. On the other hand, given the anticipated rise in global temperatures, it is crucial for breeders to comprehend the molecular underpinnings of the pertinent horticultural characteristics of priority vegetables in order to create new ideotypes in silico and eventually create new varieties that can withstand a variety of heat stress situations.

Waterlogging

Soils with inadequate drainage might become flooded as a result of excessive rainfall and improper irrigation. Vegetable crops may be harmed by waterlogging because it reduces the oxygen content and gas exchange rates in the soil, which limits root respiration (Patel *et al*., 2014). Waterlogging sensitivity or tolerance among vegetable species, genotypes, and rootstocks is greatly influenced by plant age, the length of the waterlogging period, ambient temperature, the state of the floodwater, and site features. Herbaceous veggies quickly wilt and die when they are wet and the temperature is high. The majority of vegetables grown worldwide, particularly those with shallow root systems, are susceptible to waterlogging, which can lead to sharp drops in output. This trait has relatively little genetic diversity.

Plants experience drought stress when there is insufficient rainfall and no additional irrigation for a longer length of time. This causes the soil to become dehydrated. A third of the world's population lives in regions experiencing water stress, a situation that could worsen as atmospheric carbon dioxide concentrations rise. Therefore, it is more likely that future climate changes may result in severe droughts (Khursheed Hussain *et al.*, 2022). Reduced germination, decreased turgor, decreased net photosynthesis, lower nutrient uptake, and stunted growth are the main effects on vegetable crops, which reduces vegetable output. High temperatures are frequently associated with drought stress, which increases evapotranspiration and modifies photosynthetic kinetics. These effects exacerbate the effects of drought and further decrease vegetable output. Due to their succulent nature (their edible parts containing more than 85% water, with the exception of dry legume seeds), vegetable crops are vulnerable to drought stress, especially when developing edible components like bulbs, leafy heads, tubers, and curds as well as during the blooming and seed development stages (Nakanwagi *et al.*, 2020).

Salinity

In regions that are arid due to increased rates of shallow groundwater evapotranspiration, and in coastal areas due to saltwater intrusion, soil salinity rises under climate change scenarios. Many vegetable crops suffer from reduced yield due to excessively salinized soil, as these crops are especially sensitive during the plant's developmental stages.

Biotic stresses on vegetable crops

The interactions between weeds, pathogens, insect pests, their natural enemies, hosts, and competitors can be altered by changes in temperature, moisture content, and greenhouse gas concentrations brought on by climate change. These changes can also accelerate the growth and generation rates of weeds, pathogens, and their vectors. As a result, they open up fresh ecological niches where some plant diseases, insect pests, and weeds can arise, reappear, and spread. Numerous factors could be affected, including an increase in the frequency of outbreaks, the spread of weeds, insect pests, and plant diseases into new areas, the emergence of new, more aggressive strains and types of pathogens and pests, and a heightened susceptibility of normally tolerant or resistant plant defense mechanisms.

Climate smart breeding of vegetable crops

New plant breeding technologies as a revolutionary toolkit for smart agriculture

Genomics-Assisted Breeding

In conventional breeding projects of WorldVeg's priority global and traditional vegetables, phenotypic selection is a hard and time-consuming process that combines desirable features in a step-by-step way. This is especially true for complex traits with polygenic control and substantial environmental variation. The ensuing lead time may be ten to fifteen years before the promising cultivars are available for release. At a cost that is constantly decreasing, recent developments in genomics-assisted breeding techniques employing next generation sequencing (NGS) technologies have made it possible to identify adapted traits that are represented by genes or gene groups that contribute to resistance or tolerance to abiotic and biotic stresses (Manivannan *et al.*, 2018). By employing NGS technologies, WorldVeg breeders can more rapidly introgress desirable genes from landraces and wild relatives of priority vegetables, and identify breeding lines with enhanced productivity even in the presence of drought, heat, waterlogging, and disease and pest pressures relative to the current varieties available.

As the cost of genome sequencing declines, researchers will also be able to employ these technologies on germplasm collections and breeding populations. This will enable them to identify regions on the genome where breeders have most successfully selected and bred for adaptive traits in the past, providing additional knowledge to improve vegetable yield. They will also be able to uncover the genomic basis of resistance/tolerance to abiotic and biotic stresses in vegetable crops. Furthermore, because breeders can more accurately predict the results of breeding decisions made by forward breeding, genome-wide prediction, sometimes referred to as genomic selection, and breeding simulations are assisting breeders in making better selections in their programs.

Conventional breeding methods are typically expensive, time-consuming, and labour-intensive. However, new tools, methods, and strategies that potentially improve plant breeding programs have also been developed and implemented in tandem with recent advances in genetics and genomics. For numerous crop species, including several vegetables, whole-genome sequences, genetic linkage maps, marker assays, and molecular markers have been created and published (Singh, 2007). Marker-assisted selection (MAS) (Collard and Mackill, 2008), marker-assisted backcrossing (MABC) (Collard and Mackill, 2008), marker-assisted recurrent selection (MARS) (Charmet *et al.,* 1999), and genomic selection (GS) (Heffner *et al.,* 2009) that can be used for precision breeding are in various stages of development for each vegetable crop, depending on available resources and the complexity of the species genetics and breeding

High Throughput Phenotyping.

Recent developments in field-based high-throughput phenotyping platforms allow for the non-destructive screening of a greater number of samples for various traits at lower costs and with higher accuracy. These platforms also offer automated environmental data collection and a high capacity for data recording, processing, and interpretation (Chawade *et al*., 2019). It may be possible to unlock genetic potential and improve the prediction of complex traits, such as yield and resistance/tolerance to abiotic and biotic stresses, which are characterized by strong environmental context dependencies, i.e., genotype by environment interactions, using the obtained phenotyping data processed through an open-source data management system like Phenotyping Hybrid Information System (PHIS).

According to D'Agostino and Tripodi (2017), combining genotyping data with whole plant phenotyping data will speed up the pyramiding of desirable genes suitable for particular environments and enable the identification of alleles linked to target traits and accessions that can serve as parents for breeding programs.

Imaging Techniques

There is more to imaging plants than just "taking pictures." The objective of imaging is to quantify a phenotypic by means of photons that interact with plants, such as transmitted, absorbed, or reflected photons. Each constituent of plant tissues and cells has characteristics related to wavelength-specific transmittance, reflectance, and absorbance. For instance, the principal absorption properties of water are in the near and short wavelengths, while cellulose absorbs photons in a wide range between 2200 and 2500 nm. Chlorophyll, on the other hand, typically absorbs photons in the blue and red spectral region of visible light. Different wavelengths of imaging are employed for various elements of plant phenotyping.

Measurements of plant architecture such as image-based projected biomass, leaf area, color, growth dynamics, seedling vigor, seed morphology, root architecture, assessments of leaf disease severity, yield, and fruit number and distribution are the main applications of visible imaging. For the purpose of detecting genetic disease resistance, fluorescence imaging was employed. In order to identify variations in stomatal conductance, which serve as a gauge of the plant's reaction to water status and transpiration rate for abiotic stress adaptation, thermal infrared imaging could be used to assess the temperature of the plant. By measuring spatiotemporal growth patterns during experiments and collecting plant spectroscopy data to quantify vegetation indices, water contents, seed composition parameters, and pigment composition in yield potential, imaging spectroscopy can shed light on the factors driving growth dynamics. At present, imaging techniques for plant phenotyping primarily include fluorescence imaging, thermal infrared imaging, visible imaging, imaging spectroscopy and other techniques (MRI, PET and CT).

Table 1 : The applications of imaging techniques for plant phenotyping under different growing environments (Deery, 2014)

Imaging Techniques	Growing Environment	Applications
Visible imaging	Field	Imaging canopy cover and canopy colour; colour information can be used for green indices; the use of 3D stereo reconstruction from multiple cameras or viewpoints allows the estimation of canopy architecture parameters
Fluorescence imaging	Field	Photosynthetic status, indirect measurement of biotic or abiotic stress
Thermal imaging	Field	Stomatal conductance; water stress induced by biotic or abiotic factors
Imaging spectroscopy	Field	Biochemical composition of the leaf or canopy; pigment concentration; water content; indirect measurement of biotic or abiotic stress; canopy architecture
LIDAR	Field	Canopy height and canopy architecture; estimation of LAI; volume and biomass; reflectance from the laser can be used for retrieving spectral information

Speed Breeding

The world has taken notice of the most fascinating technique, known as fast breeding. A University of Queensland scientist was inspired by NASA to cultivate wheat seedlings in space. A useful strategy for shortening crop-generation times and expediting breeding initiatives for crop enhancement is speed breeding. In agriculture, speed breeding has been a game-changer. It can expedite processes including fast gene identification, crossing, population mapping, backcrossing, and trait pyramiding for crop breeding (Bhatta *et al.,* 2021). In vitro/embryo culture, double haploid technology, and off-season nursery/shuttle breeding have all been employed to shorten the generational interval in a variety of crops. By adjusting the primary factors that plants need, such as temperature, length of day, and light intensity, speed breeding allows for the rapid development of generations. This results in a generation time decrease from 2.5 to 5 compared to regular greenhouse and field settings.

Speed-breeding components

Light

Photosynthesis and plant growth are powered by light. Plant growth and development can be impacted by light features such as direction, wavelengths, intensity, and duration (Bayat *et al.,* 2018). Photosynthesis, stem length, leaf color, and flowering are all influenced by light intensity. Artificial light is used as a photoperiodic light to regulate flowering and as a supplemental light to speed up plant development and increase yield and quality of the produce.

Because of its great radiant efficiency, long lifespan, low heat emission, narrow spectrum, and ability to match the light intensity and wavelength requirements of many plant species, LED lighting has grown in popularity in recent years for use in horticulture systems.

Temperature

One of the main factors influencing how quickly plants develop is temperature. The way that different plant species respond to temperature depends on their phenological stage. Plants develop more vegetatively when the temperature rises, as long as it stays within the necessary ideal range. For the majority of plant species, the ideal temperature for the vegetative phase is often greater than for the reproductive period. Fruits and nuts from the temperate zone normally emerge from dormancy when exposed to prolonged low winter temperatures and high moisture levels. For regulating flowering in many plants, temperature and photoperiod interact strongly.

Humidity

In addition to having an indirect effect on pollination, photosynthesis, and leaf growth, relative humidity has a direct effect on plants' water relations. The atmospheric humidity and the vapor pressure deficit determine the motions of plant stomata. Even with their stomates open, plants' water-usage efficiency decreases in high air humidity. Low humidity causes too much transpiration, so plants close their stomatal openings to prevent water loss. This causes wilting, which slows down photosynthesis and stunts the growth of the plants (Georgii *et al.,* 2017). In controlled-environment chambers, humidity is the most challenging environmental component to regulate, but a suitable range of 60%–70% is ideal (Ghosh *et al.,* 2018). Lower humidity levels might be preferable for crops that are more suited to drier circumstances (Ghosh *et al*., 2018).

Abiotic stresses: where speed breeding can be implemented

The genetic and molecular mechanisms behind the resistance to abiotic stressors such as salt, cold, drought, ion toxicity, and mineral shortage have only partially been understood (Bechtold and Field 2018). The development of crop-improvement techniques for stress tolerance heavily depends on an understanding of the tolerance process to abiotic stress, from the perception of environmental signals through cellular response to putting out the adaptive response. Speed breeding can be more effectively integrated into abiotic-stress experiments, generation advancement, and phenotypic evaluation investigations since it necessitates glasshouse conditions for regulated growth.

The complexity of the interactions between genetic and environmental impacts on phenotypic (G × E interaction) can be minimized and experimental error reduced in a controlled setting (Roy *et al.,* 2011). In a controlled setting, it is possible to monitor the onset of certain stresses, such as water restriction during a drought, saline addition to hydroponics, and overwatering. However, because plants are cultivated in pots as opposed to fields, control settings do not accurately reflect the natural environment and the less expensive reality. Preliminary abiotic stress tests, such as those involving water deficiency stress (drought), excess water, temperature extremes, and salinity, are typically carried out in glasshouse conditions. Regular breeding programs can benefit from the inclusion of speed breeding as a dependable method.

Table 2 : Speed breeding protocols optimized for shortening the breeding cycle of various vegetable crops

Crop	Photoperiod	Temperature	Humidity (%)	Field condition (Days)	Speed breeding (Days)	Refrences
B. rapa	22h	22/17C (light/dark)	70	171	98	Watson *et al.* (2018)
B. oleracea	22h	20/15C (light/dark	70	112	91	Ghosh *et al.* (2018)
B. napus	22h	20/15C (light/dark	70	109	91	Ghosh *et al.* (2018)
Pea	22h	22/17C (light/dark)	70	84	51	Watson *et al.* (2018)
Amaranthus	16h	35/30C (light/dark)	70	180	60	Stetter *et al.* (2016)
Tomato	16h	35/30C (light/dark)	70	80	60	Velez-Ramirez *et al.* (2014)
Potato	11h	30/25C (light/dark	70	135	100	Velez-Ramirez *et al.* (2014)

Genome editing

Genome editing can be used to revive plant breeding techniques. Genome editing appears to be opening up new avenues for precise and expedited agricultural modification in order to boost yields and protect crops from abiotic stressors, diseases, and pests. Genome editing techniques hold significant potential for speeding up, improving, and lowering the cost of crop breeding. The genome editing technique known as CRISPR allows for novel, transgene-free applications. The idea that genome editing may be repurposed for agricultural improvement has been stifled by the advent of next-generation CRISPR-associated (CRISPR/Cas) methods, such as base editing, prime editing, and de novo domestication.

In order to produce double-stranded breaks (DSBs) at or near the target site, genome editing uses site-specific nucleases (SSNs) that are specifically designed to bind and break a specific nucleic acid site (Pickar-Oliver and Gersbach, 2019). Then, homologous recombination (HR) or error-prone non-homologous end joining (NHEJ) naturally repair the DNA DSBs (Jun *et al.,* 2019). To achieve the optimum changes in a sequence, such as the insertions or deletions of sizable transgene arrays, these DSB repairs can be controlled. These SSNs have significant potential for plant breeding because they offer multimodal methods for modifying the host's genome structure and function, including opportunities for stacking, knock-in, translation modulation, targeted mutagenesis, and gene knock-out to engineer disease resistance traits.

Major crop improvement difficulties are anticipated to be resolved by CRISPR through precision genome engineering. A major food crop in many nations, potatoes struggle with issues such heat, drought, low nitrogen, bacterial infections, insect pests, and viruses that they are mediated by (Tiwari *et al.*, 2022). Conventional potato breeding has explored the genetic diversity of the Solanum genus and can further enrich it with the latest NGS-based transcriptomics studies (Tiwari *et al.,* 2020). These studies will ultimately lead to the identification of specific gene targets for CRISPR-based genome editing (Tiwari *et al.,* 2022), offering new insights in crop improvement.

Table 3 : Application of the CRISPR-based genome editing approach in plants for improvement of various stress tolerance.

Stress Tolerance	Plant Species	Target Gene	Method of Delivery	References
Drought tolerance	*Solanum lycopersicum*	SlNPR1	Agrobacterium-Mediated	Li *et al.* (2019)
Drought tolerance	*Solanum lycopersicum*	SlMAPK3	Agrobacterium-Mediated	Wang *et al.* (2018)
Drought tolerance	*Solanum lycopersicum*	SlLBD40	Agrobacterium-Mediated	Liu *et al.* (2020)
Drought tolerance	*Solanum lycopersicum*	SlARF4	Agrobacterium-Mediated	Chen *et al.* (2021)
Salt tolerance	*S. tuberosum*	StCoilin	PEG-mediated	Makhotenko *et al.* (2019)
Salt tolerance	*S. lycopersicum*	SlHyPRP1	PEG-mediated	Tran *et al.* (2021)
Heat tolerance	*Lactuca sativa*	LsNCED4	Agrobacterium-Mediated	Bertier *et al.* (2018)
Heat tolerance	*S. lycopersicum*	SlCPK28	Agrobacterium-Mediated	Hu *et al.* (2021)
Heat tolerance	*S. lycopersicum*	SlMAPK3	Agrobacterium-Mediated	Yu *et al.* (2019)
Cold tolerance	*S. lycopersicum*	SlCBF1	Agrobacterium-Mediate	Li *et al.*(2018)

Improved Stress Tolerance Through Grafting

One of the potentially useful methods for altering a plant's root structure and increasing its resistance to different abiotic challenges is vegetable grafting. Grafted plants are currently utilized in vegetable crops, provided suitable tolerant rootstocks are employed, to increase resistance against abiotic stresses such as high and low temperatures, drought, salinity, and flooding. Yetisir *et al.,* observed that melons grafted onto hybrid squash rootstocks were more salt tolerant than the non-grafted melons

It has mostly been used to control soil-borne diseases that are associated with vegetable grafting procedures, which were first introduced to East Asia in the 1900s and are currently extensively practiced in Korea, Japan, and numerous European countries. The technique of grafting involves uniting the scion and the rootstock of two live plants to form a single living plant. Diseases can impair the productivity of fruits and vegetables, including cucumber, tomatoes, and eggplant. However, if appropriate tolerant rootstocks are employed, it can provide tolerance to soil-related environmental issues such salinity, drought, low soil temperature, and flooding. Melons grafted onto hybrid squash rootstocks shown greater resistance to salt than non-grafted melons, according to Romero *et al.*'s 1997 study. The resistance of rootstocks to salt varies greatly among species. For instance, Cucurbita spp. rootstocks are more salt-resistant than Lagenaria siceraria rootstocks (Matsubara, 1989). Furthermore, plants that were grafted exhibited increased resilience to low soil temperatures. *Solanum lycopersicum* x *S. habrochaites* rootstocks enable their grafted tomato scions to endure low soil temperatures (10°C to 13°C), even while grafted eggplants on S. *integrifolium x S. melongena* rootstocks fared better than ungrafted plants at lower temperatures (18°C to 21°C) (Okimura, 1986). Many eggplant accessions are highly resistant to floods, according to research done by the World Vegetable Center (AVRDC) (Midmore, 1997).

Table 3 : Examples of top-performing rootstock and scion combinations in vegetable crops under induced stresses

S. No	Type of stress	Root stock	Scion	Key improved characteristics	References
	Drought	Tomato (*Solanum lycopersicum* L.) cv. Unifort	Tomato (*Solanum lycopersicum* L.) cv. Farida	Increased WUE, growth, and yield were observed in grafted plants	Wahb-Allah (2014)
	Drought	Sweet pepper (*Capsicum annum*) rootstock lines Atlante, Terrano and Creonte	Sweet pepper (*Capsicum annum*) cv. Herminio	High photosynthetic activity, leaf water content, and more stable leaf area and the maintenance of high reproductive/ vegetative ratio	López-Marín *et al.* (2017)
		Tomato (*Solanum lycopersicum*) cv. Beaufort and cv. Maxifort	Tomato (*Solanum lycopersicum*) cv. Amelia	Improved photosynthesis and stomatal conductance were observed	Chaudhari *et al.* (2017)
	Salinity	Pumpkin (*Cucurbita moschata* Duch.) cv. Chaojiquanwang	Cucumber (*Cucumis sativus* L.) cv. Jinchun No. 2	Relatively higher activities of dehydroascorbate reductase, ascorbate peroxidase, and glutathione reductase were observed in the chloroplasts of grafted plants providing better H_2O_2-scavenging capacity	Zhen *et al.* (2011)
		Capsicum chinense Jacq. 'ECU-973' Capsicum baccatum L. var. pendulum 'BOL-58'	Pepper (*Capsicum annum*) cv. Adige	Lesser negative impact on the nitrate reductase activity, photosynthetic rate, and lipid peroxidation	Penella *et al.* (2014)
	Thermal	Tomato (*Solanum lycopersicum*) cv. Summerset and Eggplant (Solanum melongena) cv. Black Beauty	Tomato (*Solanum lycopersicum*) cv. UC 82-B	Larger leaf area, more leaf fresh and dry weight, Higher chlorophyll fluorescence	Abdelmageed & Gruda (2009)
		Figleaf Guard (*Cucurbita ficifolia*) and Luffa (*Luffa cylindrica*) cv. Xiangfei	Cucumber (*Cucumis sativus*) cv. Jinyan No. 4	Higher biomass production and CO_2 assimilation capacity, Decrease in lipid peroxidation and protein oxidation	Li *et al.* (2014)

Climate Smart Villages

Communities are collaborating with the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) to create "Climate-Smart Villages." These are the locations where scientists, regional partners, and farmers work together to assess and optimize the synergies across a variety of climate-smart agriculture initiatives.

The Climate-Smart Village approach's ability to bring together farmers, policy makers, scientists, and local organizations to collaborate on a portfolio of policies to adapt agriculture to climate change is one of its greatest strengths.

According to farmers' initial testimonies, there are great prospects to expand the Climate-Smart Village model across several villages in several locations. Millions of farmers in areas susceptible to natural disasters can have the security of their food and means of subsistence guaranteed by incorporating the model into current or prospective government policy.

Conclusion

Changes in climate is a continual process, it has become apparent in agricultural field from the previous few years resulting in permanent effect on crop productivity. Vegetable crops are particularly vulnerable to the effects of climate change because of their highly varied growing seasons, when crop yields and production are greatly impacted by harsh weather. The first step in creating effective adaptation methods to mitigate the negative effects of climate change is understanding how temperature changes affect vegetable crops. However, in addition to creating such technologies that fully utilize and mitigate climate change, greater attention should be placed on the development of heat- and drought-resistant crops, where crop design and physiology may be genetically modified to adapt to warmer environmental circumstances.

Future prospects

Global food security depends on the breeding of crop plants with higher yield potential and more resilience to such settings in the face of ongoing and expected climate change, which will bring forth higher temperatures and more unpredictable climate events across large portions of the world. environment resilient agriculture can only be achieved with the support of improved plant types that can tolerate diseases and pests while efficiently using fewer resources and displaying stable yields in a harsh environment in the near future. Research attention is essential for currently underutilized agricultural species if they are to contribute to climatic resilience. The concept of smart breeding largely depends upon generating large breeding populations, efficient high throughput phenotyping, big data management tools and downstream molecular techniques to tackle the vulnerability of crop plants to changing climate.

Climate smart breeding also requires the effective protection and preservation of plant genetic resources. Using cutting edge technologies like gene editing to directly insert novel alleles from wild plants into domesticated crop types is one strategy for capturing the unique variety. Growing knowledge of their underlying physiological and genetic processes can be used to create new crop cultivars that are tolerant of various conditions. Climate smart variety development and implementation may be facilitated by advances in phenotypic and genotypic analysis technology, the biotechnology revolution, and the digital revolution.

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