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Review Article

Impact of Climate Change on Vegetable Crops and its Mitigation

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A B S T R A C T

Agriculture sector is the most sensitive sector to the climate changes because the climate of a region/country determines the nature and characteristics of vegetation and crops. A significant change in climate on global scale will impact agriculture and consequently affect the world's food supply. Vegetable crops are very sensitive to climatic vagaries and sudden rise in temperature as well as irregular precipitation at any phase of crop growth can affect the normal growth, flowering, pollination, fruit development and subsequently decrease the crop yield. Under changing climatic situations crop failures, shortage of yields, reduction in quality and increase in pest and disease problems are common and they render the vegetable cultivation unprofitable. In India diverse climatic conditions available across the country provide ample opportunity to grow almost all type of vegetable crops, thus making our country the second largest producer of vegetables. Vegetables play a crucial role in ensuring food and nutritional security, but they are highly perishable and their prices rise fast under climate change putting them out of reach of the poor. To mitigate the adverse impact of climate change on productivity and quality of vegetable crops there is need to develop sound adaptation strategies. The emphasis should be on development of production systems for improved water use efficiency adoptable to the hot and dry conditions. The crop management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. Excessive soil moisture due to heavy rain becomes a major problem which can be overcome by growing crops on raised beds. Breeding techniques and biotechnology are essentially required to meet these challenges.

Keywords

Climate change, Vegetable, Yields, Management and breeding techniques

Introduction

Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or variability of its properties, and that persist for an extended period, typically decades or longer (IPCC, 2007). Climatic change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of global atmosphere and that is in addition to natural climate variability observed over comparable time period (UNFCC). The earth's atmosphere consists of 78% Nitrogen, 21% Oxygen and 0.93% Argon. These gases have limited interaction with incoming solar radiation and outgoing infra-red radiations. Carbon dioxide accounts for just 0.03%-0.04%, water vapour varying from 0-2%. Carbon dioxide and some other minor gases (methane, CH_4, nitrous oxide, N_2O and ozone, O_3) present in the atmosphere absorb some of the thermal radiation leaving the surface (infra-red) and emit these radiations upward and downward, which tends to raise the temperature near the earth's surface.

These radiatively active gases are known as greenhouse gases (GHGs). The GHGs act as partial blanket for thermal radiations from the surface and enable it to be warmer than it would otherwise be, analogous to the effect of a green house. This is known as natural greenhouse effect. Without GHGs the earth's average temperature would be roughly -20ºC.

Natural greenhouse effect maintains a balance between absorbed solar radiations and outgoing terrestrial radiations emitted to the surface.

Human activities released very few gases into the atmosphere before the industrial revolution. The long-term climatic variations and sudden fluctuation in weather parameters raised doubts for investment in fruit industry. In order to sustain farm income and provide nutritional security, it becomes imperative to understand the possible impacts of climate change on various Agricultural crops.

The ever increase in greenhouse gasses emission resulted in warming of climate by 0.74 °C over the last 100 years. However, it is uncertain to comment on future, but according to IPCC 2001 the increase in global temperature and other weather events will continue with higher frequency in twenty-first century due to emission of greenhouse gases. The phenology of Agricultural plants is greatly affected by maximum, minimum and mean temperatures. Increased global temperature would require demand for more high temperature adaptable varieties. The climatic change will affect suitability and adaptability of current cultivars by altering the growing period (Dhillon and Gill, 2015). The broad impacts can be summarized as:

Early melting of glaciers and floods.

Warmer and extended winters – erratic changes.

Erratic and reduced winter precipitation and snowfall.

Depletion of ground water and water scarcity.

Shift in apple cultivation towards higher altitude and cold arid areas.

Shift in ecological zone.

Incidence and resurgence of insect and diseases in horticulture.

Hail storms and low temperature during spring – common phenomenon now.

Crop failure in high chill fruit crops under low altitudes.

Effect on fruit quality.

Early blooming.

Effect on fruit quality as the high temperature and moisture stress increases sun burn and cracking in tomato, capsicum etc. Tomato fail to attain deep red colour if temperature is high.

Effect on chilling requirement.

Elevated requirements of irrigation.

Impact of climate change on vegetable production

Vegetable crops are very sensitive to climatic vagaries like sudden rise in temperature as well as irregular precipitation at any phase of crop growth (Afroza *et al.,* 2010). Vegetables play a crucial role in ensuring food and nutritional security, but they are highly perishable and their prices rise fast under situations like droughts or floods, putting them out of reach of the poor. Climate change may have more effect on small and marginal farmers, particularly who are mainly dependent on vegetables. Under changing climatic situations crop failures, shortage of yields, reduction in quality and increase in pest and disease problems are common and they render the vegetable cultivation unprofitable (Lal *et al.,* 2014). Moreover, the winter season vegetables are more sensitive to harsh weather than the summer season vegetables. Abiotic stresses like extreme temperatures (low/high), soil salinity, droughts and floods are detrimental to vegetable production. Thus, high temperature and limited soil moisture are the major causes of low yields in vegetables. The different development phases like vegetative growth, flowering and fruiting are significantly influenced by the vagaries of climate. The effects of elevated temperature and unpredictable and irregular precipitation can disrupt the normal growth and development of plants which ultimately affect crop productivity. Environmental stresses severely affect the soil organic matter decomposition, nutrient recycling, nutrient and water availability to the plant. However, the intensity and duration of environmental extremes determine the magnitude of impact on crop growth cycle, biomass accumulation and ultimately, the economic return. Crop yields in Asia are expected to decline by 2.5 - 10% from 2020 onwards and by 5- 30% after 2050, with worst declines in South and Central Asia (Cruz *et al.,* 2007). The estimated potential yield losses are 17 % due to drought, 20 % due to salinity, 40 % due to high temperature and 15 % due to low temperature (Ashraf *et al.,* 2008).

Environmental constraints limiting vegetable productivity

High temperature

A constantly high temperature causes an array of morpho-anatomical changes in plant which affect the seed germination, plant growth, flower shedding, pollen viability, gametic fertilization, fruit setting, fruit size, fruit weight, fruit quality. There are different types of morphological traits which help in heat tolerance in the conventional breeding approaches, these are long root length as it has a good ability to uptake water and nutrients from the soil, short life-span which help to minimize the temperature effect on plant, hairiness which provides partial shade to cell wall and cell membrane repels sun rays and insects, small size of leaf which resists evaporation due to reduction of stomata, leaf orientation enhances the photosynthetic activity and produces tolerance against heat stress, leaf glossiness and waxiness which repel sunlight and insects.

Vegetative and reproductive processes in tomatoes are strongly modified by temperature alone or in conjunction with other environmental factors. The reproductive development in tomato is more sensitive to high temperatures than vegetative development. The optimum temperatures for tomato cultivation are between 25ºC and 30ºC during the photoperiod and 20ºC during the dark period. However, only 2-4ºC increase in optimal temperature adversely affected gamete development and inhibited the ability of pollinated flowers into seeded fruits and thus, reduced crops yields (Firon *et al.,* 2006). High temperatures also interfere with floral bud development due to flower abortion. High temperatures can cause significant losses in tomato productivity due to reduced fruit set, and smaller and lower quality fruits. In addition, significant inhibition of photosynthesis occurs at temperatures above optimum, resulting in considerable loss of potential productivity. Fruit colour is having significant importance in assessing the marketable quality of tomato. The optimum temperature for development of lycopene pigment in tomato is 21-24^0 C. Degradation of lycopene starts at above 27^0 C and it is completely destroyed at 40^{0}C. Similarly high temperatures above 25^{0}C affect pollination and fruit set in tomato (Kalloo *et al.,* 2001). Due to increase in temperature the potato breeding area is shifting towards the further more high altitudes. Potato is very strict to its temperature requirement for tuber formation. Optimum tuber formation takes place at 20^0 C. An increase in temperature of above 21^0 C cause sharp reduction in the potato tuber yield, at 30^0 C complete inhibition of tuber formation occurs (Sekhawat, 2001).

Low temperature

Low temperature like chilling and freezing injury can occur in all plants, but the mechanism and types of damage vary considerably. Damage due to exposure of the plant above 0°C (0°C-10°C) is chilling injury and slight exposure to less than 0°C is freeze injury. Freeze injury occurs in all plants due to rupture of the cell wall and destruction of cytoplasmic constituents as ice crystals are formed from cytoplasmic water. Crop plants that develop in tropical climates, may experience serious freezing injury, even occurrence of small freezing conditions, whereas most of the crops that develop in colder climates often survive with little freezing if the freezing condition is not too severe. Exposure to chilling temperature in temperate climate may lead to a severe reduction of yield or complete crop failure due to either direct damage or delayed maturation. Even a small drop in temperature, causing no visible damage to chilling sensitive plants, may cause up to 50% reduction in their productivity. Low temperatures (decreases to 8-12°C.) have been reported to reduce seed germination and growth speed of pollen tube and the percent of fruit set of tomato. Growth reduction of muskmelon (reticulates group) and watermelon. Seeds are especially (beans) sensitive to low temperatures during imbibition and may not germinate at low temperatures.

Flooding

Most of the vegetables are highly sensitive to flooding, especially those which are shallow rooted. Water logging is a serious problem which affects crop growth and yield in low lying rain fed areas. The main cause of damage under water logging is oxygen deprivation which affect nutrient and water uptake so the plants show wilting even when surrounded by excess of water. Lack of oxygen shifts the energy metabolism from aerobic mode to anaerobic mode (Sairam *et al.,* 2008). Most of the vegetable crops are highly sensitive to flooding and genetic variation with respect to this character is limited. Flooded crops especially in tomato plants accumulate endogenous ethylene that causes damage to the plants (Drew 1979).Under low oxygen levels stimulate an increased production of an ethylene precursor 1-aminocyclopropane-1-carboxylic acid (ACC) in the roots. The rapid development of epinastic growth of leaves is a characteristic response of tomatoes to water-logged conditions and the role of ethylene accumulation has been implicated. The severity of flooding symptoms increases with rising temperatures; rapid wilting and death of tomato plants is usually observed following a short period of flooding at high temperatures (Kuo *et al.,* 1982).

Drought

Drought is a meteorological term and is commonly defined as a period without significant rainfall. Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Drought stress tolerance is seen in almost all plants but its extent varies from species to species and even within species. Drought stress is characterized by reduction of water content diminished leaf water potential and turgor loss closure of stomata and decrease in cell enlargement and growth. Severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of plant (Jaleel *et al.,* 2008).It has been established that drought stress is a very important limiting factor at the initial phase of plant growth and establishment. It affects both elongation and expansion growth (Anjum *et al.,* 2003). Drought stress produced changes in the ratio of chlorophyll 'a' and 'b' and carotenoids. The prevalence of drought conditions adversely affects the germination of seeds in vegetable crops like onion and okra and sprouting of tubers in potato (Arora *et al.,* 1987). Potato is highly sensitive to drought. A moderate level of water stress can also cause reductions in tuber yield (Jefferies and Mackerron 1993). As succulent leaves are commercial products in leafy vegetables like amaranthus, palak and spinach the drought conditions reduce their water content thereby reduces their quality(AVRDC).Stem length was significantly affected under water stress in potato (Heuer and Nadler 1995) *Abelmoschus esculentus* (Sankar *et al.,* 2007) parsley (*Petroselinum crispum*) (Petropoulos *et al.,* 2008). The reduction in plant height was associated with a decline in the cell enlargement and more leaf senescence in A. esculentus under water stress (Bhatt and Rao 2005). Bahadur *et al.,* 2009 observed significant reduction in photosynthesis rate and stomatal conductance in spring-summer okra when water stress was imposed for 10 or 12 days.

Salinity

Excessive amounts of soluble salts in soil in many regions of the world particularly in arid and semi-arid areas limit production of most crops including vegetables (FAO 2002).Salt stress causes loss of turgor reduction in growth wilting leaf abscission decreased photosynthesis and respiration loss of cellular integrity, tissue necrosis and finally death of the plant (Cheeseman,1988).Salinity causes a significant reduction in germination percentage germination rate and root and shoots length and fresh root and shoot weight in cabbage (Jamil and Rha, 2004). Salinity stress has been reported to cause alteration in a variety of morphological attributes and to decrease almost all growth parameters including shoot and root fresh and dry weights plant height total leaf area and yield and some yield quality attributes in tomato (Eraslan *et al.,* 2008). Salt stress also causes changes in a range of metabolic processes. For example protein contents and activities of ascorbate peroxidase and catalase decreased proline contents increased and superoxide dismutase activity remained unchanged under saline conditions (Chookhampaeng *et al.,* 2008).In mature tomato fruit the amount of sucrose and the activity of sucrose phosphate synthase increased while fruit yield decreased under saline conditions (Chookhampaeng *et al.,* 2008). High salt concentration also causes an ionic imbalance and osmotic shock to tomato plants (Ciobanu and Sumalan, 2009).

Yield loss up to 50% was observed in eggplant at 8.5 dS m"1 of soil salinity (Shalhevet *et al.*, 1983). As well as appraising overall response of various varieties of eggplant to soil stress their response to salinity stress at various growth stages has also been examined (Chartzoulakis and Loupassiki, 1997). However Chartzoulakis and Loupassiki 1997 concluded that initial growth stages i.e. germination and seedling stages are the most sensitive to salinity stress. For example salt (NaCl) stress caused considerable reduction in germination percentage and rate radicle and hypocotyl fresh and dry weights and their length seedling length, seedling root and shoot fresh and dry biomass and leaf area (*Akinci et al.*, 2004). Under saline conditions seedling leaf Na^+ concentration increased while that of K^+ and K^+ /Na^+ ratios decreased in eggplant (Akinci *et al.*, 2004). Salt stress also adversely affects the plants at later stages including shoot and root fresh and dry weights shoot and root lengths (Hamdy *et al.*, 2002). Salinity also markedly reduces both fruit weight and number of fruits per plant in eggplant (Abbas *et al.*, 2010). Salinity induced suppression in shoot and root fresh and dry biomass of pepper due to reduction in total leaf area per plant as well as net CO_2 assimilation rate and stomatal conductance (Cabanero *et al.*, 2004).

In addition, the salinized areas are increasing at a rate of 10% annually; low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor cultural practices are the major contributors to the increasing soil salinity. Young seedlings and plants at anthesis appear to be more sensitive to salinity stress than at the mature stages. Onions are sensitive to saline soils, while cucumbers, eggplants, peppers, beet palak and tomatoes are moderately sensitive. The response of plants to increasing salt application may differ significantly among plant species as a function of their genetic tolerance.

Mitigation strategies

Climate resilient technologies

To mitigate the possible impact of climatic change on vegetable production as well as on national economy, several initiatives have been undertaken. These include Proper management practices, measures to improve water and nutrient-use efficiency and biological nitrogen fixation, selection of better adaptable genotypes and genetic manipulation to overcome extreme climatic stresses.

Management practices for enhancing vegetable production

Various management practices have the potential to raise the yield of vegetables grown under hot and wet conditions. Several technologies have also been developed to alleviate production challenges.

Agronomical adaptation

Improved agronomic practices that reduce net Greenhouse gas emissions, increase yields and generate higher inputs of carbon residue leading to increased soil carbon storage, include using improved crop varieties, extending crop rotations, notably those with perennial crops that allocate more carbon below ground, avoiding or reducing use of bare fallow, adding more nutrients when deficit, adopting cropping systems with reduced reliance on fertilizers, pesticides and other inputs e.g., rotation with legumes, providing temporary vegetative cover (catch/cover crops) between successive agricultural crops or between rows of tree or vine crops which add carbon to soils and may also extract plant available nitrogen unused by the preceding crop and hence reduce N_2O emission.

Nutrient management

Practices that improve nitrogen use efficiency include: adjusting application rates based on precise estimation of crop needs (e.g., precision farming); using slow- or controlled-release fertilizer forms or nitrification inhibitors (which slow the microbial processes leading to N_2O formation); applying N when least susceptible to loss, often just prior to plant uptake (improved timing); placing the N more precisely into the soil to make it more accessible to crops roots (Monteny *et al.,* 2006).

Tillage/residue management

Soil disturbances usually done for sowing, planting, weed control, etc., tend to stimulate soil carbon losses through enhanced decomposition and erosion. Advances in weed control methods and farm machinery now allow crop production with minimal/zero tillage which, most often, results into reduced CO_2 and N_2O emissions. Systems that retain crop residues also tend to increase soil carbon because these residues are the precursors for soil organic matter (main source of carbon store in soil). Avoiding burning of residues also avoids emissions of aerosols and GHGs generated from fire.

Organic agriculture

Organic agriculture has a greater potential for mitigating climate change, largely due to its greater ability in reducing emissions of greenhouse gases (GHGs) including carbon dioxide, nitrous oxide (N_2O) and methane (CH_4). It also increases carbon sequestration in soils compared with that of conventional agriculture. In addition, many farming practices commonly adopted in organic agriculture such as rotation with leguminous crops, minimum or no tillage and the return of crop residues favour the reduction of GHGs and the enhancement of soil carbon sequestration. Furthermore, organic agriculture is highly adaptable to climate change compared with conventional agriculture. However, greater recognition of the potential of organic agriculture for mitigating climate change is needed.

At present, this recognition depends on the ability of organic yields to out-perform conventional yields, which has been shown to occur in developing countries. More research is needed to improve organic yields in developed countries and to improve the potential of mitigating climate change by organic agriculture.

Water management

Since vegetables contain a very high amount of water and many vegetables are eaten raw, therefore use of quality water remains a major concern. The quality and efficiency of water management determine the yield and quality of vegetable products. Too much or too little water causes abnormal plant growth, predisposes plants to infection by pathogens, and causes nutritional disorders. If water is scarce and supplies are erratic or variable, then timely irrigation and conservation of soil moisture reserves are the most important agronomic interventions to maintain yields during drought stress. There are several methods of applying irrigation water and the choice depends on the crop, water supply, soil characteristics and topography. Surface irrigation methods are utilized in more than 80% of the world's irrigated lands, yet its field level application efficiency is often 40 - 50% (Von and Chieng, 2004). To generate income and alleviate poverty of the small farmers, promotion of affordable, small-scale drip irrigation technologies are essential.

Drip irrigation

It is also known as trickle irrigation or micro irrigation. It is an irrigation method that allows a grower to control the application of water and fertilizer by allowing water to drip slowly near the plant roots through a network of valves, pipes, tubing, and emitters. It minimizes water losses due to run-off and deep percolation and water savings of 50-80% are achieved when compared to most traditional surface irrigation methods. Crop production per unit of water consumed by plant evapotranspiration is typically increased by 10-50%. Thus, more plants can be irrigated per unit of water by drip irrigation, and with less labour. For drought-tolerant crops like watermelon, yield differences between furrow and drip irrigated crops were not significantly different; however, the incidence of Fusarium wilt was reduced when a lower drip irrigation rate was used. In general, the use of low-cost drip irrigation is cost-effective, labour-saving and allows more plants to be grown per unit of water, thereby both saving water and increasing farmer's incomes at the same time.

Water harvesting

Water harvesting for dry land is a traditional water management technology to ease future water scarcity in many arid and semi-arid regions of the world. Rainwater and flood water harvesting have the potential to increase the productivity of arable land by increasing the yields and reducing the risk of crop failure under climate change situation.

Cultural management practices that conserve water and protect crops

Various crop management practices such as mulching and the use of shelters and raised beds help to conserve soil moisture, prevent soil degradation, and protect vegetables from heavy rains, high temperatures and flooding. The use of organic and inorganic mulches is common in high-value vegetable production systems. These protective coverings help reduce evaporation, moderate the soil temperature and reduce soil run-off and erosion. Protect fruits from direct contact with soil and minimize weed growth. It can save 20-25% of irrigation water. Use of organic materials as mulch can help enhance soil fertility, structure and other soil properties. Rice straw is abundant in rice growing areas of the tropics and generally recommended for summer tomato production. Mulching improved the growth of eggplant, okra, bottle gourd, round melon, ridge gourd and sponge gourd compared to the non-mulched controls under diverse climatic conditions of India. Yields were the highest when polythene and sarkanda (*Saccharum* spp. and *Canna* spp.) were used as mulch material. In the lowland tropics where temperatures are high, dark-colored plastic mulch is recommended in combination with rice straw (AVRDC, 1990).

Dark plastic mulch prevents sunlight from reaching the soil surface and the rice straw insulates the plastic from direct sunlight thereby preventing the soil temperature rising too high during the day. During the hot rainy season, vegetables such as tomatoes suffer from yield losses caused by heavy rains. Simple clear plastic rain shelters prevent water logging (due to flooding) and direct rain impact damage on developing fruits, with consequent improvement in tomato yields (Midmore *et al.*, 1992). Fruits cracking and the number of unmarketable fruits are also reduced. Another form of shelter using shade cloth can be used to reduce temperature stress. Shade shelters also prevent damage from direct rain impact and intense sunlight. Planting vegetables on raised beds can ameliorate the effects of flooding during the rainy season (AVRDC, 1981).

Table.1 Effect of high temperature on vegetable crops

Parameters	Effect	Observed in	Reference
Fruit colour	Decrease	Tomato	(Kalloo *et al.*, 2001).
Tuber formation	Decrease	Potato	(Sekhawat, 2001)
Bud and flower abscission	Increase	Bean	(Yoldas and Esiyok, 2009)
Male flowers	Increase	Cucumber	(Singh *et al.*, 2010)
Flower bud size	Decrease	Broccoli	(Kałuzewiczet *al.*, 2012)

Table.2 Physiological disorders of vegetable crops caused by high temperatures

S.No.	Crop	Disorder	Aggravating factor
01	Asparagus	High fiber in stalks and spheres	High Temperature
02	Asparagus	Feathering and lateral branch growth	Temperature > 32ºC, especially if picking frequency is not increased
03	Bean	High fiber in pods	High temperature
04	Carrot	Low carotene content	Temperatures < 10 ºC or > 20 ºC
05	Cauliflower	Blindness, buttoning, riceyness	Temperature fluctuations
06	Cauliflower, Broccoli	Hollow stem, leafy heads, no heads, bracting	High temperature

Table.3 The list of the vegetables, sensitive to chilling temperatures, the lowest safe storage/handling temperature and the symptoms of chilling injury (Deell, 2004).

Crop	Lowest safe temperature °C	Chilling injury symptoms
Asparagus	0-2	dull, gray-green, limp tips
Bean(snap)	7	pitting and russeting
Cucumber	7	pitting, water-soaked lesions, decay
Eggplant	7	Surface scald, *Alternaria* rot, seed blackening
Okra	7	discoloration, water soaked areas, pitting,
Pepper	7	pitting, *Alternaria* rot, seed blackening
Potato	7	mahogany browning, sweetening
Pumpkin	10	decay, especially *Alternaria* rot
Squash	10	decay, especially *Alternaria* rot
Sweet potato	10	decay, pitting, internal discoloration

Table.4 Effect of flooding on various vegetable crops

Crop	Effect of flooding	Reference
Sweet potato	Losses due to rotting at harvesting, Losses in carotenoid pigments and dry matter content	(Thompson *et al.*, 2009)
Yam	Degradation of leaves	(Udeh, 2015)
Chilli	Poor growth, yellowing of leaves, Wilting	(Prasad *et al.*, 2015)

Table.5 Tolerant varieties

Crop	Variety	Tolerance
Tomato	Pusa Sadabahar,	Tolerant to high and low temperatures
	Pusa Sheetal	Low temperature
Radish	Pusa Chetki	Better root formation under high temperature regime.
Carrot	Pusa Vrishti	Form root at high temperature and high Humidity
Cauliflower	Pusa Meghna	Can form curd at high temperature
Bottle gourd	Pusa Santushti	Heat and cold tolerant
Bitter gourd	Pusa Do Mausami	Suitable for spring and rainy season

Yields of tomatoes and chilies can increase with bed height, most likely due to improved drainage and reduction of anoxic stress. Additive effects on yield have also been observed when in addition to raised beds, rain shelters were also used.

Protected cultivation

Protected structures can play important role to minimize the impact of temperature fluctuation, over/under precipitation, fluctuating sun shine hour and infestation of disease and pest (Singh and Satpathy, 2005). Protected structures can play important role to minimize the impact of climatic change effect.

Farmers are gradually adopting different protected structures to combat the climatic vagaries and emerging challenges in vegetable production. Poly-tunnel was the most used structure utilized for raising vegetable seedling during rainy season. Seedling rising in pro-trays and crop production inside agro-shade net is also gaining popularity among the farmers. Although poly-tunnel was the most adopted structure but the performance of poly-house was emerged as best structure in field condition. In Ladakh region many Solanaceous vegetable crops do not perform well in the open conditions and those surviving produce poor yields, so they are grown under greenhouses.

Improved pest management

Changes in temperature and variability in rainfall would affect incidence of pests and disease and virulence of major crops. It is because climate change will potentially affect the pest/weed-host relationship by affecting the pest/ weed population, the host population and the pest/weed-host interactions. Some of the potential adaptation strategies could be:

Adoption of integrated pest management with more emphasis on biological control.

Developing cultivars resistant to pests and diseases.

Pest forecasting using recent tools such as simulation modeling.

Management of pests and diseases with use of resistant varieties and breeds, alternative natural pesticides, bacterial and viral pesticides, pheromones for disrupting pest reproduction, etc. could be adopted for sustainability of agricultural production process.

Bio-agents have a crucial role in pest management, hence practices to promote natural enemies like release of predators and parasites; improving the habitat for natural enemies.

Crop rotation and multiple cropping should be integrated in pest management practices. Reduction in use of pesticides will also help in reducing carbon emissions.

Grafting of vegetables for stress management

Grafting vegetables originated in East Asia during the 20th century and is currently common practice in Japan, Korea and some European countries. Grafting, in this context, involves uniting of two living plant parts (rootstock and scion) to produce a single growing plant. It has been used primarily to control soil-borne diseases affecting the production of fruit vegetables such as tomato, eggplant, and cucurbits. However, it can provide tolerance to soil-related environmental stresses such as drought, salinity, low soil temperature and flooding if appropriate tolerant rootstocks are used. Grafting of eggplants was started in the 1950s, followed by grafting of cucumbers and tomatoes in the 1960s and 1970s (Edelstein 2004). Romero *et al.,* (1997) reported that melons grafted onto hybrid squash rootstocks were more salt tolerant than the non-grafted melons. However, tolerance to salt by rootstocks varies greatly among species, such that rootstocks from *Cucurbita* spp. are more tolerant of salt than rootstocks from *Lagenaria siceraria* (Matsubara 1989). Grafted plants were also more able to tolerate low soil temperatures. *Solanum lycopersicum* x *S. habrochaites* rootstocks provide tolerance of low soil temperatures (10^{o} C to 13^{o} C) for their grafted tomato scions, while eggplants grafted onto *S. integrifolium* x *S. melongena* rootstocks grew better at lower temperatures (18^{o} C to 21^{o} C) than non-grafted plants (Okimura *et al.*, 1986). Vegetables generally are unable to tolerate excessive soil moisture. Tomatoes in particular are considered to be one of the vegetable crops most sensitive to excess water. In the tropics, heavy rainfall with poor drainage induces water-logged conditions that reduce oxygen availability in the soil thereby causing wilting, chlorosis, leaf epinasty, and ultimately death of the tomato plants. Genetic variability for tolerance of excess soil moisture is limited or inadequate to prevent losses. Research at AVRDC - The World Vegetable Center has shown that many accessions of eggplant are highly tolerant of flooding (Midmore *et al.*, 1997). Thus, the Center developed grafting techniques to improve the flood tolerance of tomato using eggplant rootstocks which were identified with good grafting compatibility with tomato and high tolerance to excess soil moisture. Tomato scions grafted onto eggplant rootstock grow well and produce acceptable yields during the rainy season (Midmore *et al.,* 1997). In addition to protection against flooding, some eggplant genotypes are drought tolerant and eggplant rootstocks can therefore provide protection against limited soil moisture stress.

Developing climate-resilient vegetables

Improved, adapted vegetable germplasm is the most cost-effective option for farmers to meet the challenges of a changing climate. However, most modern cultivars represent a limited sampling of available genetic variability including tolerance to environmental stresses. Breeding new varieties, particularly for intensive, high input production systems in developed countries, under optimal growth conditions may have counter-selected for traits which would contribute to adaptation or tolerance to low input and less favorable environments.

Tolerance to high temperatures

AVRDC - The World Vegetable Center has developed tomatoes and Chinese cabbage with general adaptation to hot and humid tropical environments and low-input cropping systems since the early 1970s. This has been achieved by developing heat-tolerant and disease-resistant breeding lines. The Center has made significant contributions to the development of heat-tolerant tomato and Chinese cabbage lines and the subsequent release of adapted, tropical varieties worldwide. Indeed, AVRDC - The World Vegetable Center's heat tolerant hybrids have resulted in the successful cultivation of Chinese cabbage in the lowland tropics. The key to achieving high yields with heat tolerant cultivars is the broadening of their genetic base through crosses between heat tolerant tropical lines and disease resistant temperate or winter varieties (Opena & Lo 1981). The heat tolerant tomato lines were developed using heat tolerant breeding lines and landraces from the Philippines (e.g. VC11-3-1-8, VC 11-2-5, Divisoria-2) and the United States (e.g. Tamu Chico III, PI289309) (Opena *et al.,* 1989). However, lower yields in the heat tolerant lines are still a concern. More heat tolerant varieties are required to meet the needs of a changing climate, and these must be able to match the yields of conventional, non-heat tolerant varieties under non-stress conditions. A wider range of genotypic variation must be explored to identify additional sources of heat tolerance. An AVRDC - The World Vegetable Center breeding line, CL5915, has demonstrated high levels of heat tolerance in Southeast Asia and the Pacific. The fruit set of CL5915 ranges from 15% - 30% while there is complete absence of fruit set in heat-sensitive lines in mean field temperatures of 35^{o} C.

Drought tolerance and water-use efficiency

Plants resist water or drought stress in many ways. In slowly developing water deficit, plants may escape drought stress by shortening their life cycle (Chaves & Oliveira 2004). However, the oxidative stress of rapid dehydration is very damaging to the photosynthetic processes, and the capacity for energy dissipation and metabolic protection against reactive oxygen species is the key to survival under drought conditions (Ort 2001, Chaves & Oliveira 2004). Tissue tolerance to severe dehydration is not common in crop plants but is found in species native to extremely dry environments (Ingram & Bartels 1996). Genetic variability for drought tolerance in *S. lycopersicum* is limited and inadequate.

The best source of resistance is from other species in the genus *Solanum*. The Tomato Genetics Resource Center (TGRC) at the University of California, Davis has assembled a set of the putatively stress tolerant tomato germplasm that includes accessions of *S. cheesmanii, S. chilense, S. lycopersicum, S. lycopersicum* var. cerasiforme, *S. pennelli, S. peruvianum and S. pimpinellifolium. S. chilense and S. pennelli* are indigenous to arid and semi-arid environments of South America. Both species produce small green fruit and have an indeterminate growth habit. *S chilense* is adapted to desert areas of northern Chile and often found in areas where no other vegetation grows (Rick 1973, Maldonado *et al.,* 2003).

Tolerance to saline soils

Attempts to improve the salt tolerance of crops through conventional breeding programs have very limited success due to the genetic and physiologic complexity of this trait (Flowers, 2004). In addition, tolerance to saline conditions is a developmentally regulated, stage specific phenomenon; tolerance at one stage of plant development does not always correlate with tolerance at other stages (Foolad, 2004). Success in breeding for salt tolerance requires effective screening methods, existence of genetic variability, and ability to transfer the genes to the species of interest. Screening for salt tolerance in the field is not a recommended practice because of the variable levels of salinity in field soils. Screening should be done in soil-less culture with nutrient solutions of known salt concentrations. Most commercial tomato cultivars are moderately sensitive to increased salinity and only limited variation exists in cultivated species.

Use of biotechnological tools in stress management

Use of molecular technologies has revolutionized the process of traditional plant breeding. The use of molecular markers as a selection tool provides the potential for increasing the efficiency of breeding programmes by reducing environmental variability, facilitating earlier selection, and reducing subsequent population sizes for field testing. Molecular markers facilitate efficient introgression of superior alleles from wild species into the breeding programmes and enable the pyramiding of genes controlling quantitative traits; thus, enhancing and accelerating the development of stress tolerant and higher-yielding cultivars for farmers in developing countries. Several QTLs have been identified to stress tolerance in tomato, i.e. for water-use efficiency in *S. pennellii* and *S. pimpinellifolium* as source of salt tolerance. Only a few major QTLs account for the majority of phenotypic variation, indicating the potential for marker-assisted selection (MAS) for salt tolerance.

Changes in climate is a continuous process, it has become recognizable in agricultural field from the past few years resulting in lasting effect on crop production. The effects of climate change on vegetable crops are due to variable climatic factors and the extreme weather conditions at critical periods of growth play a vital role in the yields and productivity of these crops. Understanding, the impact of change in temperature on vegetable crops is the first step in developing sound adaptation strategies to address the adverse impact of climate change. However, more emphasis on development of heat and drought resistant crops where crop architecture and physiology may be genetically altered to adopt to warmer environmental conditions besides developing such technologies which mitigates and makes full use of the effects of changing climate.

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