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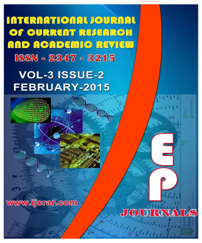

Climate resilient technologies to meet the challenges in vegetable production

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ABSTRACT

The changing patterns of climatic parameters like rise in atmospheric temperature, changes in precipitation patterns, excess UV radiation and higher incidence of extreme weather events like droughts and floods are emerging major threats for vegetable production in the tropical zone (Tirado *et al*., 2010). 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 (Afroza *et al*., 2010). To mitigate the adverse impact of climatic 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 condition. 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 major problem which can be overcome by growing crops on raised beds (Singh *et al*., 2010). Development of genotypes tolerant to high temperature, moisture stress, salinity and climate proofing through conventional, non conventional, breeding techniques, genomics and biotechnology etc. are essentially required to meet these challenges.

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 the variability of its properties and that persists for an extended period, typically decades or longer. CO_2 concentration in the atmosphere has increased drastically from 280 ppm to 370 ppm and is likely to be doubled in 21st century (IPCC, 2007).

The Indian climate has undergone significant changes showing increasing trends in annual temperature with an average of 0.56°C rise over last 100 years (Rao *et al.* 2009; IMD, 2010).The changing patterns of climatic parameters like rise in atmospheric temperature, changes in precipitation patterns, excess UV radiation and higher incidence of extreme weather events like droughts and floods are emerging major threats for vegetable production in the tropical zone (Tirado *et al.*, 2010). Climate change, which includes increase in temperature, changes in rainfall pattern, sea level rise, salt-water intrusion, generation of floods and droughts is recognized as a global issue (Bates *et al.*, 2008). Climate change poses a serious impact on agriculture, environment and health over the world. It is predicted that by 2080 the cereal production could be reduces down as 2–4% meanwhile the price will increase up to 13–45%, and about 36–50% of population being affected by hunger. Despite several negative impacts, there are a few beneficial aspects of enhanced green house gas effects e.g. higher atmospheric concentration of CO_2 may enhance the crop production of rice, wheat and soybean.

Implications of climate change in horticulture

A study conducted at IISR, Calicut using GIS models have shown that many areas presently suitable for spices would become unsuitable in another 25 years. There would be new areas which are presently unsuitable, become highly suitable for cultivation of spices. This will be applicable in other horticultural crops.

- Production timing will change due to rise in temperature and photoperiods may not show much variation. As a result, photosensitive crop will mature faster.
- The winter regime and chilling duration will reduce in temperate regions affecting the temperate crops and their seed production.
- Pollination will be affected adversely because of higher temperature. Floral abortions flower and fruit drop will be occurred frequently.
- The requirement of annual irrigation will increase and heat unit requirement will be achieved in much lesser time.
- Higher temperatures will reduce tuber initiation process in potato, reduced quality in tomatoes and pollination in many crops. In case of crucifers, it may lead to bolting; anthocyanin production may be affected in apples and capsicum. Tip burn and blossom end rot will be the common phenomenon in tomatoes.
- Yield of vegetable can be reduced by 5–15 percent when daily ozone concentrations reach to greater than 50 ppb (Raj Narayan, 2009).
- Coastal regions can expect much faster percolation of sea water in inland water tables causing more salinity.
- Heavier rainfall, in some locations, will increase field flooding, problems with field operations, soil compaction and crop losses due to anoxic conditions for roots, and disease problems associated with wet conditions.
- Impaired stomatal conductance due to ozone exposure can reduce root growth, affecting crops such as carrots, sweet potatoes and beet roots.
- Pathogens, pests and weed problems will change due to the temperature changes. They will survive more in high temperature and as a result crops will need more insecticides and pesticides application. The

effectiveness of pesticides will reduce at higher temperature.

- If temperature continues to rise then the decomposition process of soil will also increase which in turn will affect soil fertility.

Impact of climate change on vegetable production

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 (FAO, 2009). 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 and 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). To mitigate the possible impact of climatic change on vegetable production as well as on national economy, several initiatives have been undertaken. These include selection of better adaptable genotypes, genetic manipulation to overcome extreme climatic stresses, measures to improve water and nutrient-use efficiency and biological nitrogen fixation as well as exploiting the beneficial effects of CO_2 enhancement on crop growth. In this chapter, the impact of global climate change on vegetable crop growth and yield is discussed and strategies to overcome the harmful consequences are outlined. The effect of climate on different quality aspects of vegetable crops that may occur under the changed climate is reviewed.

Environmental constraints limiting vegetable productivity

Environmental stress is the primary cause of low production of most of the vegetables worldwide; reducing average yields for most of the major vegetables. Under optimum climatic conditions, the productivity of vegetables is three to four folds higher. Climatic changes will influence the severity of environmental stress on the vegetable crops. Moreover, increasing temperatures, reduced irrigation-water availability, flooding, and salinity will be the major limiting factors in sustaining and increasing vegetable productivity. Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms (Capiati *et al.*, 2006). Environmental interactions may cause stress response of plants more complex or influence the degree of impact of climate change. Measures to adapt to these climate change-induced stresses are critical for sustainable vegetable production. There is a need to do more research on how vegetable crops are likely to be affected by the increased abiotic stresses as there is a direct potential threat from the climate change. Some of the important environmental stresses which affect vegetable production have been reviewed below.

• 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 etc. These problems can be minimized by improvement in the cultural practices and breeding approaches. There are different types of morphological traits which help in heat tolerance in the conventional breeding approaches, these are:

- Long root length 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 (Abdalla and Verkerk, 1968). 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 (Stevens and Rudich, 1978). In addition, significant inhibition of photosynthesis occurs at temperatures above optimum, resulting in considerable loss of potential productivity.

• Chilling Tolerance in Tomato

The cultivated tomato genotype (*Solanum lycopersicum*, earlier known as *Lycopersicon esculentum* L.) displays limited growth and development at temperatures under 12ºC (Hu *et al.*, 2006). At temperatures between 0 and 12ºC, plants are damaged by the chilling stress. The severity of damage is proportional to the length of time spent in this temperature range. Due to their sensitivity to cold, commercial cultivated tomatoes are planted in the field at later dates to avoid excessively low temperatures and minimize the risk of chilling damage. Cold-resistant cultivars could be planted earlier in the season, leading to an early harvest. Unlike cultivated tomatoes, wild tomato species such as *S. habrochaites* S. Knapp & D.M. Spooner, *S. chilense* (Dunal) Reiche and *S. peruvianum*

L., recover rapidly after exposure to sub-optimal temperatures. These genotypes can be grown at high elevations where temperature remains low, below 10°C. Wild species have been used for constructing genetic maps and identifying genes of agronomic importance. Through backcrosses and selection assisted by molecular markers, cold-resistant genes from wild species can be bred into cultivated tomato varieties (Goodstal *et al*., 2005).

Following strategies can be adopted

- The wild genotypes can be introgressed in cultivated tomatoes by somatic and sexual hybridization as well as by chloroplast exchange. The cultivated tomato (*L. esculentum)* is used as a female in crosses due to inability of *L. esculentum* to fertilize ovules of most of the wild species (unilateral incongruity).
- Evaluate the off spring for chilling tolerance.
- Identify the chromosomal regions which may be associated with chilling tolerance in the wild species. With development of chilling-tolerant tomato, the tomato cultivating season can be extended and it can be produced round the year. The area of adaptation may get broadened for glass house production, cold-tolerant genotype may reduce the energy consumption in horticulture and may cause a reduction in CO_2 emissions and greenhouse effect on global warming. In general, the cold-tolerant genotypes have earliness, water-use efficiency, adaptability and high yield when grown under suboptimal temperature.

Physiological Traits of Chilling Tolerance in Tomato

- Thin stem, short dense glandular hairs and narrow leaflets (*L. peruvianum*)
- Densely hairy stem, leaves and fruits (*L. hirsutum*), high photosynthetic rate and seedling can survive at 0°C temperature.
- *L. chilense* can survive on rock as it has a deep root system and can tolerate moisture stress.

Drought tolerance

Water availability is highly sensitive to climate change and severe water-stress conditions will affect crop productivity, particularly of vegetables. In combination with elevated temperatures, decreased precipitation could cause reduction in availability of irrigation water and increase in evapotranspiration, leading to severe crop water-stress conditions (IPCC, 2001). Vegetables, being succulent products by definition, generally consist of more than 90% water (AVRDC, 1990). Thus, water greatly influences the yield and quality of vegetables; and drought conditions drastically reduce vegetables productivity. Drought-stress causes an increase in solute concentration in the environment (soil), leading to an osmotic flow of water out of plant cells. This leads to an increase in the solute concentration in plant cells, thereby lowering the water potential and disrupting membranes and cell processes such as photosynthesis. The water requirements of vegetable crop range from about 6 inches of water per season for radishes to 24 inches for tomatoes and watermelons. Precise irrigation requirements can be predicted based on crop water-use and effective precipitation values. Lack of water influences the crop growth in many ways and the effect depends on the severity, duration, and time of stress in relation to the stage of growth. Nearly all vegetable crops are sensitive to drought during two periods: flowering and two-to-three weeks before harvesting at fruiting stage.

- **Salinity**

Salinity is also a serious problem that reduces growth and productivity of vegetable crops in many salt-affected areas. It is estimated that about 20% of cultivated lands and 33% of irrigated agricultural lands worldwide are afflicted by high salinity (Foolad, 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. In spite of the physiological cause ion toxicity, water deficit, and/or nutritional imbalance, high salinity in the root area sternly inhibits normal plant growth and development, resulting in reduced crop productivity or total crop failure (Ghassemi *et al*., 1995). Young seedlings and plants at anthesis appear to be more sensitive to salinity stress than at the mature stages (Lutts *et al*., 1995). Onions are sensitive to saline soils, while cucumbers, eggplants, peppers, beet palak and tomatoes are moderately sensitive. One of the most effective ways to overcome salinity problems is the use of tolerant species and varieties (Yilmaz *et al*., 2004). The response of plants to increasing salt application may differ significantly among plant species as a function of their genetic tolerance.

- **Flooding**

When there is excess amount of water than its optimum requirement is known as flooding/ water logging. It leads to replacement of gaseous phase by liquid phase. The cultivation of vegetables starts at commercial level in many areas on the onset of monsoon, but production occurs in both dry and wet seasons. However, production is often limited during the rainy season due to excessive moisture brought about by heavy rains. Most vegetables are highly sensitive to flooding and genetic variation with respect to this character is limited, particularly in tomato and early cauliflower. In general, the damage to vegetables by flooding is due to reduction of oxygen in the root zone, which inhibits aerobic processes. Flooded tomato plants accumulate endogenous ethylene that causes damage to the plants (Drew, 1979). The rapid development of epinastic growth of leaves is a characteristic response of tomatoes to waterlogged conditions and the role of ethylene accumulation has been implicated (Kawase, 1981). 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).

The need for adaptation to climate change

The impacts of climate change on vegetable production will depend not only on climate, but also on the internal dynamics of agricultural systems, including their ability to adapt to the changes (FAO, 2001). Adoption of effective and efficient measures is required to mitigate the adverse effects of climate change on vegetable production, and particularly on their productivity, quality and yield. New technologies being developed through plant stress physiology research can potentially contribute to mitigate threats from the climate change on vegetable production. As most of the farmers in developing countries are small holders, have fewer options and must rely heavily on resources available in their farms or within their communities. Thus, technologies that are simple, affordable, and accessible must be disseminated to increase the resilience of farms in less-developed countries. Many institutes have been working on addressing the effect of environmental stress on vegetable production. Germplasm of major vegetable crops, which are tolerant to high temperatures, flooding and drought have been identified and advanced breeding lines are being developed in many institutions. Efforts are also underway to identify nitrogen-use efficient germplasm. In addition, development of production systems geared towards improved water-use efficiency and expected to mitigate the effects of hot and dry conditions in vegetable production systems are the top research and development priorities.

- **Climate resilient technologies**

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 GHG 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. Improved agronomic practices that increase yields and generate higher inputs of carbon residue can lead to increased soil carbon storage (Follett, 2001).

a. **Nutrient Management**: Practices that improve N 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; or avoiding N applications in excess of immediate plant requirements (Monteny *et al*., 2006).

b. **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.

To reduce the rapid mineralization of vegetable crop residues with low C:N ratios, Rahn *et al*. (2003) used several amendments (molasses, paper waste, green compost, etc.) and found that the amounts of N mineralized decreased when the concentration of cellulose and lignin in the amendment materials increased. These amendments had a variable effect on nitrous oxide emissions. In a similar study, Chaves *et al*. (2005) found that the addition of several organic biological waste materials to the soil significantly reduced N_20 emissions from celery crop residues.

Organic Agriculture: Mitigation of Climate Change

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. The water-use efficiency by pepper chilli was significantly higher in drip irrigation compared to furrow irrigation, with higher efficiencies observed with high delivery rate drip irrigation regimes (AVRDC, 2005). Melon crop under drip irrigation, N_2O losses were reduced by 70% (Sanchez-Guerrero *et al*., 2009). 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 farmers' 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 that conserve water and protect crops

- Mulching
- Use of shelter
- Raised bed

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 (Pandita and Singh, 1992). 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 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). 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 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 vegetable valuable crops like Tomato, Brinjal, Okra do not perform well in the open conditions and those surviving produce poor yields. Capsicum cultivation during summer season seems a profitable alternative for farmer of Ladakh region of Jammu and Kashmir state if the crop is grown under greenhouses as compared to open field conditions (Kanwar and Sharma, 2010).

Cucurbits production in cold desert

- Commercial production of cucurbits in cold desert of India is now possible through protected cultivation. Sarda melon imported in large quantity in the country can be produced in these areas with ease. Production of off season (August and September) muskmelon, watermelon etc in open fields has also become possible. An early crop of cucurbits like squash and long melon can also be taken in poly houses.

Plastic Low Tunnel Technology

- Plastic low tunnels provide a cheap and better way for off- season cultivation of vegetable production. Low tunnels also offer several advantages like protection of the crop from adverse climate along with crop advancement from 20~30 days over their normal season of cultivation. Healthy and early nursery raising can be obtained under low tunnels. Technology for cucurbits production has been extended to the farming community successfully

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:

- Developing cultivars resistant to pests and diseases.

- Adoption of integrated pest management with more emphasis on biological control a changes in cultural practices.
- Pest forecasting using recent tools such as simulation modeling.
- Developing alternative production techniques and crops, as well as locations, that are resistant to infestations and other risks.

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. Bioagents 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; facilitating beetle banks and flowering strips; 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 of susceptible plant (scion) on tolerant plant (rootstock) helps to grow plant successfully under stress conditions, especially under salt and drought stress conditions. Grafting of vegetables was originated in East Asia during the 20th century and it has been used primarily to control soil-borne diseases affecting the production of 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 during 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 are also able to tolerate low soil temperatures. *Solanum lycopersicum* x *S. habrochaites* rootstocks provide tolerance to low soil temperatures (10°C to 13°C) for their grafted tomato scions, while eggplants can be grafted on wild brinjal (*S. integrifolium)* as rootstocks to overcome low temperatures (18°C to 21°C).

Most of the vegetables are unable to tolerate excessive soil moisture. Tomatoes in particular are considered to be one of the vegetable crops most sensitive to excess water. Until now, genetic variability for tolerance of excess soil moisture is limited or inadequate to prevent losses. Many accessions of eggplant are highly tolerant to flooding (Midmore *et al.*, 1997), thus, can be grafted 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. In addition to protection against flooding, some eggplant genotypes are drought tolerant and eggplant rootstocks can, therefore, provide protection against limited soil moisture stress.

Role of agroforestry in adapting to climate change

Agroforestry, the integration of trees and shrubs with annual crops production is an age old management system practiced by farmers to provide shade, a steady supply of food /or income throughout the year, arrest degradation and maintain soil fertility, diversify income sources, increase and stabilize income, enhance use efficiency of soil nutrients, water and radiation, and provide regular employment. Agroforestry play a significant role in mitigating the atmospheric accumulation of green house gases (DeFries and Rosenweig, 2010).

The IPCC Third Assessment Report on Climate Change (IPCC, 2001) states that "Agroforestry can both sequester carbon and produce a range of economic, environmental, and socioeconomic benefits. It can improve soil fertility through control of erosion, maintenance of soil organic matter and physical properties, increased N, extraction of nutrients from deep soil horizons, and promotion of more closed nutrient cycling.

The greatest role of agroforestry in relation to climate change is perhaps in mitigating the emissions of CO_2 by productively sequestering carbon from the atmosphere .The tree component of the agroforestry systems can be a significant sink for carbon in lands devoted to agriculture. The three major paths through which tree can help reduce atmospheric carbon are: conservation of existing carbon pools through practices such as avoided deforestation and alternatives to slash and burn; sequestration through improved fallows and integration with trees, and substitution through biofuel and bioenergy plantations to replace fossil fuel use.

Breeding approaches

- Tolerance to high and low temperature
- Drought tolerant crop varieties
- Tolerance to water logging and saline soils

Use of Heat - and Cold-Tolerant Genotypes

Several heat-tolerant genotypes have been developed in vegetables, particularly in tomato**.** AVRDC, Taiwan, has made significant contributions to the development of heat-tolerant tomato and Chinese cabbage lines (*Brassica rapa* subsp. *Pekinensis* and *chinenesis*) adapted to hot and humid climate. 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 and Lo, 1981). The heat-tolerant tomato lines were developed using heat-tolerant breeding lines and landraces from the Philippines (viz., VC11-3-1-8, VC 11-2-5, Divisoria-2) and the United States (viz., Tamu Chico III, PI289309) (Opena *et al.*, 1992). 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 the additional sources of heat tolerance, for example AVRDC's breeding line, CL5915, has demonstrated high levels of heat ranges from 15% to 30%, while there is complete absence of fruit set in heat-sensitive lines in mean field temperatures of 35^0C. Now, new breeding lines have been developed from CL5915 and other sources that exhibit increased heat tolerance.

A CL5915 line is considered best combiners for percentage fruit set and total yield in hybrids developed for heat-tolerance (Metwally *et al.*, 1996). Similarly for cold tolerance, several genotypes have shown very good tolerance like, PI-120256, a primitive tomato from Turkey; LA-1777 (*Solanum habrochaites*) from AVRDC, Taiwan, and *Lycopersicon hirsutum* LA3921 and LA3925, both *Solanum habrochaites* from AVRDC, Taiwan, have also shown chilling tolerance. Similarly, EC-520061 (*Solanum habrochaites*) can set fruits under both high (40±2°C) and low (10±2°C) temperatures. These lines can be used for the development of cold tolerance in various backgrounds.

- **Drought tolerance**

Most of the vegetables are sensitive to drought; however brinjal, cowpea, amaranthus, and tomato can tolerate drought to a certain extent. Genetic variability for drought tolerance found in the cultivated tomato (*S. lycopersicum)* is limited and inadequate. The best source of resistance is from other species in the genus *Solanum*. Wild accessions of tomato, viz. *S. cheesmanii*, *S. chilense*, *S. lycopersicum*, *S. lycopersicum* var. *cerasiforme*, *S. pennellii*, *S. peruvianum* and *S. pimpinellifolium* possess stress tolerance. *S. chilense* and *S. pennellii* produce small green fruit and have an indeterminate growth habit. *S chilense* is adapted to desert areas and often found in areas where no other vegetation grows (Rick, 1973; Maldonado *et al.*, 2003).

S. chilense has finely divided leaves and a well-developed root system (Sánchez Peña, 1999). It has a longer primary root and more extensive secondary root system than cultivated tomato .Drought tests show that *S. chilense* is five-times more tolerant to wilting than cultivated tomato. *S. pennellii* has the ability to increase its water-use efficiency under drought conditions, unlike the cultivated *S. lycopersicum* (O'Connell *et al.*, 2007). It has thick, round waxy leaves, is known to produce acyl-sugars in its trichomes, and its leaves are able to take up dew (Rick, 1973). Transfer and utilization of genes from these drought-tolerant species will enhance tolerance of tomato cultivars to dry conditions, although wide crosses with *S. pennellii* produce fertile progenies. *S. chilense* is cross-incompatible with *S. lycopersicum* and embryo rescue through tissue culture is required to produce progeny plants.

- **Salt Tolerance**

Conventional breeding programmes have shown very limited success in the improvement of salt tolerance due to the genetic and physiologic complexity of this trait (Flowers, 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 (Cuartero and Fernandez-Munoz, 1999).

A few vegetables like, beet palak, tomato, etc. can tolerate salt to some extent. Most commercial tomato cultivars are moderately sensitive to increased salinity and only limited variation exists in the cultivated species. Genetic variation for salt tolerance during seed germination in tomato has been identified within the cultivated and wild species. Yildirim and Guvenc (2006) have reported that pepper genotypes Demre, Ilica 250, 11-B-14, Bagci Carliston, Mini Aci Sivri, Yalova Carliston, and Yaglik 28 can be useful as sources of genes to develop pepper cultivars with improved germination under salt-stress. In Tunisia, pepper cultivar 'Beldi' significantly out yielded than other test cultivars at high salt treatments. *S. esculentum* accession (PI174263) showed that the ability of tomato seed to germinate rapidly under the salt-stress (Foolad and Jones, 1991). The tomato genotypes, LA1579 and LA1606, (*S. pimpinellifolium*) and LA4133 (*S. lycopersicum* var *cerasiforme*) from AVRDC, Taiwan, have shown salt tolerance. Wild tomato species, *S. cheesmani*, *S. peruvianum*, *S. pennellii*, *S. pimpinellifolium*, and *S. habrochaites* are the potential source of salt tolerance (Flowers, 2004; Foolad, 2004; Cuartero *et al.*, 2006). Attempts to transfer quantitative trait loci (QTLs) and elucidate the genetics of salt tolerance have been conducted using populations involving wild species. Elucidation of mechanism of salt tolerance at different growth periods and the introgression of salinity tolerance genes into vegetables would accelerate development of varieties that are able to withstand high or variable levels of salinity compatible with different production environments.

- **Use of biotechnological tools in stress management**

Use of molecular technologies has revolutionized the process of traditional plant breeding. Combining of new knowledge from genomic research with traditional breeding methods has enhanced our ability to improve crop plants. 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. Integration of QTL analysis with gene discovery and modelling of genetic networks will facilitate a comprehensive understanding of stress tolerance, permit the development of useful and effective markers for marker-assisted selection, and identify candidate genes for genetic engineering.

Conclusion

A holistic approach is required to over stress tolerance rather than a single method. A systems approach, where all available options are considered in an integrated manner, will be the most effective and ultimately the most sustainable measure under a variable climate. For this to succeed, adequate and long-term funding is necessary, scientific results have to be delivered, best approaches utilized and effective methods sustained to deliver global public goods for impact involving public and private sector together.

For reducing malnutrition and alleviating poverty in developing countries through improved production and consumption of safe vegetables will involve adaptation of current vegetable systems to the potential impact of climate change. To mitigate the adverse impact of climatic 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 condition. 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 major problem which can be overcome by growing crops on raised beds. Vegetable germplasm with tolerance to drought, high temperatures and other environmental stresses, and ability to maintain yield in marginal soils must be identified to serve as sources of these traits for both public and private vegetable breeding programmes. These germplasms will include both cultivated and wild accessions possessing genetic variation unavailable in current, widely-grown cultivars. Genetic populations are being developed to introgress and identify genes conferring tolerance to stresses and at the same time generate tools for gene isolation, characterization, and genetic engineering. Furthermore, agronomic practices that conserve water and protect vegetable crops from sub-optimal environmental conditions must be continuously enhanced and made easily accessible to farmers in the developing world. An effective extension strategy must be in place that includes technical, socioeconomic, and political considerations. Finally, capacity building and education are the key components of a sustainable adaptation strategy to climate change.

Table.1 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 strem , leafy heads, no heads, bracting	High temperature
07	Cole crops and lettuce	Tip burn	Drought, combined with high temperatures; high respiration
08	Tomato , pepper, watermelon	Blossom end rot	High temperature , especially if combined with drought and high transpiration.

Table.2 Effect of water stress on morphological/ physiological characters of vegetables

S.No	**vegetable**	**Symptoms**
1	Brinjal	Reduced extension of main stem, reduced no. of branches per plant
2	Beans	Few flowers, delayed flowering, seed yield reduction, decreased starch content, low seed protein, accumulation of free proline.
3	Potato	Yield loss, decreased starch content, increase in reducing sugars
4	Cauliflower	Ricey, leafy, loose, yellow, small and hard curds
5	Tomato	Blossom end rot, accumulation of free proline.
6	Cassava	Reduction of leaf area
7	Lettuce	Bitter taste, accelerated development of tip burn
8	Spinach beet	Quick bolting.

(Source: Yadav *et al*., 2012)

Table.3 Some varieties of vegetables to mitigate the harmful effect of heat and cold

S.No	**crop**	**varieties**	**Tolerance**
1	Tomato	PusaSadabahar, Pusa Sheetal Pusa Hybrid-1	Tolerant to high and low temperatures
2	Radish	Pusa Chetki	Better root formation under high temperature regime, i.e. April-August
3	Carrot	Pusa Vrishti	Form root at high temperature and high humidity i.e. March-August
4	Early cauliflower	Pusa Meghna	can form curd at high temperature

Table.4 List of some variety and advanced line tolerant to abiotic stress

S.No	**Tolerant**	**Crop**	**Variety**	**Advanced line**
1	Drought/ rain fed	Tomato	Arka Vikas	RF- 4A
		Onion	Arka kalyan	MST-42 and MST-46
		chilli	Arka Lohit	IIHR Sel.-132
2	Photo insensitive	Dolichos	Arka Jay, Arka Vijay, Arka Sambram, Arka Amogh, Arka Soumya	IIHR Sel.-16-2
		Cowpea	Arka Garima, Arka Suman, Arka Samrudhi	
3	High temperature	Capsicum		IIHR Sel.-3
		French bean		IIHR-19-1
		Peas		IIHR-1 and IIHR-8
		Cauliflower		IIHR 316-1 and IIHR-371-1

(Source: Rai and Yadav, 2005).

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