

## Review on Impacts of Climate Change on Vegetable Production and its Management Practices

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Received date: December 01, 2017; Accepted date: January 12, 2018; Published date: January 19, 2018

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### Abstract

Climate change is the primary cause of low production of most of the vegetables worldwide; reducing average yields for most of the major vegetables. Moreover, increasing temperatures, reduced irrigation-water availability, flooding, and salinity will be the major limiting factors in sustaining and increasing vegetable productivity. Under changing climatic situations crop failures, shortage of yields, reduction in quality and increasing pest and disease problems are common and they render the vegetable production unprofitable. As many physiological processes and enzymatic activities are temperature dependent, they are going to be largely effected. Drought and salinity are the two important consequences of increase in temperature worsening vegetable production. These effects of climate change also influence the pest and disease occurrences, host-pathogen interactions, distribution and ecology of insects, time of appearance, migration to new places and their overwintering capacity, there by becoming major setback to vegetable cultivation. 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 that can be overcome by growing crops on raised beds. 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. Therefore, the objective of this paper is to review the effects of climate change on vegetable production and its management practices.

**Keywords:** Abiotic factors; Adaptation; Climate change; Productivity; Vegetable crops

### Introduction

According to Ward [1], the term 'vegetable' in its broadest sense refers to any kind of plant life or plant product. In the narrower sense, it refers to the fresh, edible portion of herbaceous plant consumed in either raw or cooked form. Vegetable crops can be classified as fruit vegetables such as tomato, cucumber, watermelon, peas; root and tuber/root vegetables such as carrot, potato, sweet potato, radish, elephant foot yam; green leafy vegetables such as Amaranthus, celery, cabbage, curry leaf and bulb vegetables such as onion and garlic. Vegetables are a rich source of vitamins, carbohydrate, salts and protein. They are the best resources for overcoming micronutrient deficiencies and provide smallholder farmers with much higher income and more jobs per hectare than staple crops. Yields in Asia are highest in the east where the climate is mainly temperate and sub-temperate. India is the second largest producer of vegetables (17.3 t/ha) after China (22.5 t/ha) [2]. Among vegetable crops, tomato is the most important vegetable crop worldwide and is grown over four million hectares of land area [3]. Increasing the production and consumption of vegetables is an obvious pathway to improve dietary diversity and quality, especially in diets dominated by high-energy foods that are poor in micronutrients. However, vegetables are generally sensitive to environmental extremes, and thus high temperatures and limited soil moisture are the major causes of low yields as they greatly affect several physiological and biochemical processes like reduced photosynthetic

activity, altered metabolism and enzymatic activity, thermal injury to the tissues, reduced pollination and fruit set etc., which will be further magnified by climate change.

Climate change may be a change in the mean of the various climatic parameters such as temperature, precipitation, relative humidity and atmospheric gases composition etc. and in properties over a longer period and a larger geographical area. It can also be referred as any change in climate over time, whether due to natural variability or because of human activity. According to Schneider et al. vulnerability of any system to climate change is the degree to which these systems are susceptible and unable to survive with the adverse impacts of climate change. They also explained the concept of risk as which combines the magnitude of the impact with the probability of its occurrence, captures uncertainty in the underlying processes of climate change, exposure, impacts and adaptation. 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 [4]. 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 [5].

Shifting weather patterns resulting in changing climate, has threatened agricultural productivity through high and low temperature regimes and increased rainfall variability [6,7]. Climate change and its

variability are posing the major challenges influencing the performance of agriculture including vegetable crops. Reduction in production of fruits and vegetables is likely to be caused by short growing period, which will have negative impact on growth and development particularly due to terminal heat stress and decreased water availability. Rainfed agriculture will be primarily impacted due to rainfall variability and reduction in number of rainy days [8]. The issue of climate change and climate variability has thrown up greater uncertainties and risks, further imposing constraints on vegetable production systems. Climate change might result in price hike of vegetable crops. Moreover, climate change is fostering the spread of pathogens and the evolution of new strains of insect pests and fungal, bacterial and virus diseases. Challenges ahead are to have sustainability and competitiveness, to achieve the targeted production to meet the growing demands in the environment of declining land, water and threat of climate change, which needs climate-smart vegetable interventions, which are highly location-specific and knowledge-intensive for improving production in the challenged environment [7,9]. Therefore, the objective of this paper is to review the impacts of climate change on vegetable production and its management practices.

## Impact of Climate Change on Vegetable Production and Its Management Practices

### Impact of climatic changes on vegetable production

Vegetables crops, like other agricultural crops, are sensitive to climate variability. According to Bhardwaj [3] vegetables are generally sensitive to environmental extremes, and thus high temperature are the major causes of low yields and will be further magnified by climate change. The author also noted that increasing temperature, reduced irrigation water availability, flooding and salinity would be major limiting factors in sustaining and increasing vegetable productivity. Global climatic change, especially erratic rainfall pattern and unpredictable high temperature spells, will reduce the productivity of vegetable crops. Yusuf [10] also reported that environmental factors have negative effects on tomato production. Thakur and Jahn stated that continuous declining weather conditions and changes in climate due to the escalating temperature, erratic rainfall, more demand for water and enhanced incidence of diseases are all set to affect the production of various vegetable crops. Adeniyi [11] reported that rainfall is one of the most important factors affecting crop production. Bhardwaj [3] also observed that water greatly influence the yield and quality of vegetables; drought conditions drastically reduced vegetable productivity and tomatoes in particular are considered to be one of the vegetable crops most sensitive to excess water. Some of the important environmental stresses that affect vegetable crop production will be reviewed below.

**Temperature:** Fluctuations in daily mean maximum and minimum temperature is the primary effect of climate change that adversely affects vegetable production, as many plant physiological, bio-chemical and metabolic activities are temperature dependent. The occurrence of high temperature influences the vegetable production in tropical and arid areas [12]. High temperature causes a significant alteration in morphological, physiological, biochemical and molecular response of the plant and in turn affects the plant growth, development and yield. Hazra et al. [13] summarized the symptoms causing fruit set failure at high temperatures in tomato; this includes bud drop, abnormal flower development, poor pollen production, dehiscence, and viability, ovule abortion and poor viability, reduced carbohydrate availability, and

other reproductive abnormalities. Similarly high temperatures above 25°C affect pollination and fruit set in tomato [14]. Moreover, high temperature can cause significant loss in tomato productivity due to reduced fruit set, and smaller and lower quality fruits [3]. In pepper, high temperature exposure at the pre-anthesis stage did not affect pistil or stamen viability, but high post-pollination temperatures inhibited fruit set, suggesting that fertilization is sensitive to high temperature stress [15]. High temperature affects red colour development in ripen chilli fruits and also causes flower drop, ovule abortion, poor fruit set and fruit drop in chilli [16].

Germination of cucumber and melon seeds is greatly suppressed at 42 and 45°C, respectively besides germination will not occur at 42°C in watermelon, summer squash, winter squash and pumpkin seeds [17]. The temperature fluctuations delay the ripening of fruits and reduce the sweetness in melons. Warm humid climate increase the vegetative growth and result in poor production of female flowers in cucurbitaceous vegetables like ash gourd, bottle gourd, pumpkin that causes low yield [18]. The author also added that high temperatures would cause enhanced abscission of flower buds, flowers and young pods and reduce pod production, mature pod size and seeds per pod. (High temperature causes bolting in cole crops, which is not desirable when they are grown for vegetable purpose [14].

**Drought:** Water availability is expected to be highly sensitive to climate change and severe water stress conditions will affect crop productivity, particularly that of vegetables. Drought is a major problem in arid and semi-arid regions, which is the primary cause of crop loss worldwide, reducing average yields for most of the crop plants by more than 50% [19]. Drought stress because of insufficient rainfall or deficient soil moisture might induce various biochemical, physiological and genetic responses in plants, which severely restricted crop growth [20]. The prevalence of drought conditions adversely affects the germination of seeds in vegetable crops like onion and okra and sprouting of tubers in potato [16]. The drought condition induces flower abscission in tomato [21]. More than 50% yield reduction was reported in tomato because of water stress during reproductive stage [22]. It has been suggested that water stress at flowering stage reduces photosynthesis and the amount of photosynthetic assimilates allocated to floral organs and might thereby increase the rate of abscission. Drought stress causes an increase of solute concentration in the environment (soil), leading to an osmotic flow of water out of plant cells. This leads to an increased water loss in plant cells and inhibition of several physiological and biochemical processes such as photosynthesis, respiration etc., thereby reduces productivity of most vegetables [23].

Apart from inhibiting the photosynthetic rate through reducing stomatal conductance [24], drought stress also induces metabolic impairment [25]. The photosynthesis and photosynthetic capacity are reduced during limited water conditions. Further, the biochemical capacity was also affected by the water stress as indicated by a decrease in sucrose phosphate synthase (SPS) and invertase activities, which affect the availability and utilization of sucrose. The SPS is considered to play a major role in the resynthesis of sucrose and sustain the assimilatory carbon flux from source to developing sink [26]. The decreased invertase activity might affect the ability to utilize sucrose and result in reduced ovary growth and reduced concentration of hexoses [27].

**Salinity:** Salinity is a serious problem that reduces growth and productivity of vegetable crops in many salt-affected areas. Excessive soil salinity reduces productivity of many agricultural crops, including

most vegetables, which are particularly sensitive throughout the ontogeny of the plant. Physiologically, salinity imposes an initial water deficit that results from the relatively high solute concentrations in the soil, causes ion-specific stresses resulting from altered  $K^+/Na^+$  ratios, and leads to a buildup in  $Na^+$  and  $Cl^-$  concentrations that are detrimental to plants. 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 [28]. Onions are susceptible to saline soils, while cucumber, eggplant, pepper, and tomato are moderately sensitive to saline soils [23]. Salinity causes a significant reduction in germination percentage, germination rate, and root and shoots length and fresh root and shoot weight in cabbage [29].

The combined stress of salinity and heat results in failure of vegetative growth recovery and a consequent reduction in the leaf area index and canopy functioning due to the damage of salt accumulation avoiding mechanism in young expanding leaves of potato [30]. According to Lopez et al. [31], salinity reduces dry matter production, leaf area, relative growth rate and net assimilation rate in chilli. The author also added that number of fruits per plant is more affected by salinity than the individual fruit weight. High salt concentration causes a reduction in fresh and dry weight of all cucurbits. These changes are associated with a decrease in relative water content and total chlorophyll content. Salt stress causes suppression of growth and photosynthesis activity and changes in stomata conductivity, number and size in bean plants. It reduces transpiration and the cell water potential in salt-affected bean plants [32]. The high salinity levels of soil and irrigation water are known to affect many physiological and metabolic processes, leading to cell growth reduction.

**Flooding:** Flooding is another important abiotic stress and cause serious problems for the growth and yield of vegetable crops, which are generally considered flood-susceptible crops [33]. The occurrence of flooding conditions normally cause oxygen ( $O_2$ ) deficiency which arises from a slow diffusion of gases in water and  $O_2$  consumption by microorganisms and plant roots. Most vegetables are highly sensitive to flooding and genetic variation with respect to this character is limited, particularly in tomato. In general, damage to vegetables by flooding is due to the reduction of oxygen in the root zone, which inhibits aerobic processes. Flooded tomato plants accumulate endogenous ethylene that causes damage to the plants [34]. 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 [35]. 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 [36]. Onion is also sensitive to flooding during bulb development with yield loss up to 30-40%. These stresses are the primary cause of yield losses worldwide by more than 50% plant and the response of plants to environmental stresses depends on the developmental stage and the length and severity of the stresses [37].

Flooding affects the physiology of the vegetable plants. One of the earliest plant physiological responses to soil flooding is the reduction in stomatal conductance [38]. It causes an increase in leaf water potential, decrease in stomatal conductance resulting in significant reduction in carbon exchange rate and elevation of internal  $CO_2$  ( $C_i$ ) concentration [39]. The vegetative and reproductive growth of plants is negatively affected by flooding due to detrimental impacts on physiological functioning [40]. In sensitive crop plants, flooding causes

leaf chlorosis and reduces shoot and root growth, dry matter accumulation and total plant yield [41]. Floods can make the spread of water-borne pathogens easier, droughts and heat waves can predispose plants to infection, and storms can enhance wind-borne dispersal of spores [42].

### Pests and diseases responses to climatic change

Climate change also influences the ecology and biology of insect pests [43]. Increased temperature, in some group of insects with short life cycles such as aphids and diamond back moth, increases fecundity, earlier completion of life cycle. Hence, these can produce more generations per year than their usual rate [44]. Contrary to it, some insects may take several years to complete their life cycle. Some insect species that reside in soil for the whole or some stages of life cycle tend to suffer more than insects present above the soil surface, because soil provides an insulating medium that will tend to buffer temperature changes more than the air [45]. Increased temperature causes migration of insect species towards higher latitudes, while in the tropics higher temperatures might adversely affect specific pest species. High atmospheric temperature increases insect developmental and oviposition rates, insect outbreaks and invasive species introductions, whereas it decreases the effectiveness of insect bio-control by fungi, reliability of economic threshold levels, insect diversity in ecosystems and parasitism [46].

Insects are particularly sensitive to temperature because they are stenotherms (cold-blooded). In general, insects respond to higher temperature with increased rates of development and with less time between generations. Increased temperatures will accelerate the development of cabbage maggot, onion maggot, European corn borer, Colorado potato beetle [47]. Rising temperatures will lengthen the breeding season and increase the reproductive rate. Studies on aphids and moths have shown that increasing temperatures can allow insects to reach their minimum flight temperature sooner, aiding in increased dispersal capabilities [48]. Accelerated metabolic rates at higher temperatures shorten the duration of insect diapauses due to faster depletion of stored nutrient resources [49]. Warming in winter may cause delay in onset and early summer may lead to faster termination of diapauses in insects, which can then resume their active growth and development. This gives an important implication that increase in temperature in the range of  $1^\circ C$  to  $5^\circ C$  would increase insect survival due to low winter mortality, increased population build-up, early infestations and resultant crop damage by insect-pests under global warming scenario [50].

Changes in temperature and precipitation regimes due to climate variation may alter the growth stage, development rate and pathogenicity of infectious agents, and the physiology and resistance of the host plant [51]. The large population size and short generation time of plant pathogens are expected to make them the first organisms to show effects of climate change. In northern latitudes, the impacts of plant pathogens are expected to increase with warming, because low temperatures and long winters currently reduce the survival, generations per year, reproduction rate, and activity of most pathogens attacking crops during the growing season [52]. Temperature and frost sensitivity effect the distribution of pathogen species as irrespective of their huge host range the soil borne pathogens such as *Sclerotium rolfsii* and *Macrophomina phaseolina* do not occur in temperate climates due to their high temperature optimum and frost Sensitivity [53]. Higher temperatures cause faster disease cycles in air borne pathogens and increase their survival due to reduction in frost [54].

The earlier appearance and increase in number of insect vectors of viral diseases due to rise in temperature during winter, results in increasing viral diseases of crops like potato and sugarbeet [47]. Reduction in frost due to increased average minimum temperatures implies the removal of a limiting factor for pathogens such as *Fusarium* [42].

### Management practices for adapting climate change

**Cultural management practices:** The emphasis should be on use of recommended production systems for improved water-use efficiency and to adapt to the hot and dry conditions. According to Welbaum [55], strategies like changing sowing or planting dates in order to combat the likely increase in temperature and water stress periods during the crop-growing season should be adopted. Modifying fertilizer application to enhance nutrient availability and use of soil amendments to improve soil fertility and enhance nutrient uptake [9,56]. Providing irrigation during critical stages of the crop growth and conservation of soil moisture reserves are the most important interventions [57]. The crop management practices like mulching with crop residues and plastic mulches help in conserving soil moisture. In some instances excessive soil moisture due to heavy rain becomes a major problem and it could be overcome by growing crops on raised beds [58]. The authors also added that production of vegetables could be taken up using clear plastic rain shelters, which can reduce the direct impact on developing fruits and also reduce the field water logging during rainy season. Planting of vegetables on raised beds during rainy season will increase the yield due to improved drainage that reduced anoxic stress to the root system [55].

**Improved stress tolerance through grafting:** Grafting vegetables originated in East Asia during the 20th century with the objective of reducing the effects of soilborne diseases like fusarium wilt, which affects the production of vegetables such as tomato, eggplant, and cucurbits [59]. Nowadays, Grafting is considered as a common practice in vegetable production in Asian countries such as Japan, Korea and some European countries which is an efficient rapid alternative tool to the relatively slow breeding methodology aimed at enhancing environmental-stress tolerance of horticultural crops in general and vegetables in particular [60]. Grafting is one of the promising tools for modifying the root system of the plant for enhancing its tolerance to various abiotic stresses [61]. In vegetable crops, grafted plants are now being used to improve resistance against abiotic stresses like low and high temperatures, drought, salinity and flooding if appropriate tolerant rootstocks are used [60,62,63]. Because of these beneficial effects of grafting, the cultivation of grafted plants in crops like tomato, eggplant and pepper and cucurbits (melon, cucumber, watermelon and pumpkin) has increased in recent years [64,65].

Grafting of eggplants was started in the 1950s, followed by grafting of cucumbers and tomatoes in the 1960s and 1970s [66]. Yetisir et al., [67] 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* [68]. In addition to protection against flooding, some eggplant genotypes are drought tolerant and eggplant rootstocks can therefore provide protection against limited soil moisture stress. Grafting temperature-sensitive tomato onto more resistant rootstock cultivars improves plant adaptation to heat-stress conditions [12]. It is reported that grafted plants found to develop better under heat-stress conditions than the ungrafted plants of tomato. Moreover, the

eggplants (*S. melongena* cv. Yuanqie) grafted onto a heat-tolerant rootstock (cv. Nianmaoqie) resulted in a 10% increase in fruit yield.

**Developing climate resilient vegetables:** Improved, adapted vegetable germplasm is the most cost-effective option for farmers to meet the challenges of a changing climate [69]. 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 that would contribute to adaptation or tolerance to low input and less favorable environments. Superior varieties adapted to a wider range of climatic conditions could result from the discovery of novel genetic variation for tolerance to different biotic and abiotic stresses. Genotypes with improved attributes conditioned by superior combinations of alleles at multiple loci could be identified and advanced. Improved selection techniques are needed to identify these superior genotypes and associated traits, especially from wild, related species that grow in environments, which do not support the growth of their domesticated relatives that are cultivated varieties. Plants native to climates with marked seasonality are able to acclimatize more easily to variable environmental conditions [70] and provide opportunities to identify genes or gene combinations that confer such resilience.

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 [71]. 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. 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. Most commercial tomato cultivars are moderately sensitive to increased salinity and only limited variation exists in cultivated species [72].

Genetic variation for salt tolerance during seed germination in tomato has been identified within cultivated and wild species. A cross between a salt-sensitive tomato line (UCT5) and a salt-tolerant *S. esculentum* accession (PI174263) showed that the ability of tomato seed to germinate rapidly under salt stress is genetically controlled with narrow-sense heritability ( $h^2$ ) of 0.75 [73]. Several studies indicate that salt tolerance during seed germination in tomato is controlled by genes with additive effects and could be improved by directional phenotypic selection [72]. 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.

**Biotechnology:** Increasing crop productivity in unfavorable environments will require advanced technologies to complement traditional methods, which are often unable to prevent yield losses due to environmental stresses. Genes have been discovered and gene functions understood. This has opened the way to genetic manipulation of genes associated with tolerance to environmental stresses. These tools promise more rapid, and potentially spectacular, returns but require high levels of investment. Many activities using these genetic and molecular tools are in place, with some successes. Molecular marker analysis of stress tolerance in vegetables is limited but efforts are underway to identify QTLs underlying tolerance to stresses. QTLs for drought tolerance have been identified in tomato. Martin et al., identified three QTLs linked to water use efficiency in *S.*

*pennellii* based on 13C composition. Three independent yield-promoting regions were identified in *S. pennellii* when grown in both wet and dry field conditions in Israel [74], while Foolad et al., [75] identified four QTLs associated with seed germination drought tolerance, two of which were contributed by *S. pimpinellifolium*. *S. pimpinellifolium* is also commonly investigated as source of salt tolerance. QTL mapping indicates that salt tolerance is quantitatively inherited [72]. Lin et al., identified random amplified polymorphic DNA (RAPD) markers linked to heat tolerance in AVRDC-The World Vegetable Center's tomato line CL5915. A follow-up study is currently underway at the Center to fully understand the genetic mechanism of heat tolerance of CL5915. Studies indicate that stress tolerance is quantitatively inherited and in some cases, tolerance is dependent on the developmental stage of the plant.

Environmental stress tolerance is a complex trait and involves many genes [76]. In response to stresses, both RNA and protein expression profiles change. The genes are involved with transcription modulation, ion transport, transpiration control and carbohydrate metabolism. *DREB1A* and *CBF*, and *HSF* genes are transcription factors implicated in drought and heat response, respectively [77]. Cell wall invertase (INV) and sucrose synthase (SUSY) play key roles in carbohydrate partitioning in plants and this regulation of carbohydrate metabolism in leaves may represent part of the general cellular response to acclimation and contribute to osmotic adjustment under stress. The engineered tomato has a stronger, larger root system that allows the roots to make better use of limited water. The control plants suffered irreversible damage after five days without water as opposed to transgenic tomatoes which began to show water-stress damage only after 13 days but recovered completely as soon as water was supplied. The *CBF/DREB1* genes have been used successfully to engineer drought tolerance in tomato and other crops [78].

## Prospects of Work

Depending on the vulnerability of individual crop and the agro-ecological region, the crop-based adaptation strategies need to be developed, integrating all available options to sustain the productivity. Developing strategies and tools to comprehensively understand the impact of climate change and evolve possible adaptation measures in vegetable crops is less understood. To enhance our preparedness for climate change and to formulate a sound action plan, we need to identify gaps in vital information and prioritize research issues from point of view of farmers, policy planners, scientists, trade and industry. It is imperative to deliberate upon the likely changes, which can happen in next year's; how these changes could affect growth, development and quality of vegetable crops; what are the technologies, which shall help to mitigate the problem; and what kind of innovative research should be done to overcome the challenges of climate change. Thus, policy issues, adaptation strategies and mitigation technologies could be worked out, and challenges could be converted into opportunity with the updating of following:

Priority of education, research and development and policy implications for enhancing adaptive capacity of vegetable crops to climate change

Appropriate short-and long-term action plan to mitigate the impact of climate change in vegetables

Identification and development of stress resistant vegetable crop varieties

Water harvesting through pond, and its judicious utilization in the form of drip, mist and sprinkler to deal with the drought conditions including adoption of soil moisture conservation practices like mulching

Cultivation of parthenocarpic cultivars, use of auxin for parthenocarpic fruits set in tomato, eggplant and cucumber.

Grafting of the scion on root stock with high drought, heat and salt stress tolerance can increase the growth and yield of the crops

Awareness and educational programmes for the growers, modification of present vegetable production practices and greater use of greenhouse technology are some of the solutions to minimize the effect of climate change.

## Summary and Conclusions

Currently, the world agriculture especially the vegetable production is passing through a difficult situation and faced with the challenge of food/nutritional security to meet the requirement for ever growing population. We have to produce more and more food from less and less land. The problem is aggravated because of the growing biotic and abiotic stresses and decline in the quality of environment and along with the menace of increasing global warming caused by the greenhouse gases. The succulent vegetable crops are highly sensitive to climatic conditions of heat, drought and flooding. Therefore, there is an urgent need to focus attention on studying the impacts of climate change on growth, development, yield and quality of crops. The focus should also be on development of adaptation technologies and quantify the mitigation potential of the crops. Rise in temperature affects crop duration, flowering, fruiting, fruit size and ripening of vegetable crops with reduced productivity and economic yield.

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 that 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, 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.

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