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Impact of climatic change on vegetable

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ABSTRACT

When there is significant variation either in the state of climate or in its variability, persisting for an extended period, it is referred to as climate change. A significant change in climate on a global scale will impact agriculture and consequently affect world's food supply. Climate change *per se* is not necessarily harmful; the problems arise from extreme events that are difficult to predict (FAO, 2001). Unpredictable high temperature spells and more erratic rainfall patterns will consequently reduce crop productivity. Developing countries in the tropics will be particularly vulnerable. Vegetables are generally sensitive to environmental extremes, and thus high temperatures and limited soil moisture are the major causes of low yields in the tropics and will be further magnified by climate change. Climate changes will influence the severity of environmental stress imposed on vegetable crops. Moreover, increasing temperatures reduced irrigation water availability, flooding and salinity will be major limiting factors in sustaining and increasing vegetable productivity. Extreme climate conditions will also negatively impact soil fertility and increase soil erosion. Thus, additional fertilizer application or improved nutrient-use efficiency of crops will be needed to maintain productivity or harness the potential for enhanced crop growth due to increased atmospheric CO_2. The response of plants to environmental stresses depends on the plant developmental stage and the length and severity of the stress. Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms. Environmental interactions may make the stress response of plants more complex or influence the degree of impact of climate change.

Key words : Climate change, Effect on vegetables, Kashmir valley

According to United Nations Framework Convention on Climate Change (UNFCCC) climate change means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. A planet's climate is decided by its mass, its distance from the sun and the composition of its atmosphere. 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).

Greenhouse gases:

Naturally occurring greenhouse gases include water vapour, carbon dioxide, methane, nitrous oxide and ozone. Several classes of halogenated substances that contain flourine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are called bromofluorocarbons (*i.e.*,halons). The CFCs, HCFCs and halons are stratospheric ozone depleting substances.

Some other fluorine containing halogenated substances – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6), do not deplete stratospheric ozone but are potent greenhouse gases. There are also several gases that, although do not have a direct radiative forcing effect, do influence the global radiation budget. These tropospheric gases including carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and tropospheric (ground level) ozone (O_3) are referred to as ambient air pollutants. The tropospheric ozone is formed by two precursor pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NOx) in the presence of ultraviolet light (sunlight). The greenhouse gases listed in the Kyoto protocol include methane, nitrous oxide, HFCs, PFCs, SF_6 and those listed under the Montréal protocol and its amendments include CFCs, HCFCs and the halons. The reactive gases carbon monoxide, volatile organic compounds (VOC) and nitrogen oxides ($NOx= NO + NO_2$) are termed as indirect greenhouse gases because there pollutants are not significant direct greenhouse gases but they control the abundance of direct GHGs.

The GHGs act as partial blanket for thermal radiations

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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 green house effect. Without GHGs the earth's average temperature would be roughly -20^0C. Natural green house effect maintains a balance between absorbed solar radiations and outgoing terrestrial

Table 1 : Greenhouse gases and their brief description

Sr. No.	Greenhouse gases	Brief description
1.	Water vapour (H_2O)	Water vapour is the most abundant GHG. A warmer temperature caused by radiative forcing has an increased water holding capacity. The increased concentrations of water vapour affect cloud formation, which can both absorb and reflect solar and terrestrial radiation.
2.	Carbon dioxide (CO_2)	In the atmosphere, carbon predominantly exists in its oxidized form as CO_2. CO_2 follows water vapour with respect to abundance in atmosphere. The present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2, forest clearing, other biomass burning and some non-energy production processes.
3.	Methane (CH_4)	It is primarily produced through anaerobic decomposition of organic matter in biological systems like wetland rice cultivation, enteric fermentation in animals and decomposition of animal wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, as a by-product of coal mining and incomplete fossil fuel combustion.
4.	Nitrous oxide (N_2O)	Anthropogenic sources of N_2O emissions include agricultural soils, especially the use of synthetic and manure fertilizers, fossil fuel combustion, adipic (nylon) and nitric acid production, waste water treatment, waste combustion and biomass burning.
5.	Ozone (O_3)	In troposphere, ozone present at lower concentrations is the main component of anthropogenic photochemical "smog". Tropospheric ozone is produced from complex chemical reactions of volatile organic compounds mixing with nitrogen oxides in the presence of sunlight.
6.	Halocarbons, Perfluorocarbons and Sulphur hexafluoride	Halocarbons are mainly man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons containing chlorine - CFCs, HCFCs, methyl chloroform and carbon tetrachloride, and those containing bromine - halons, methyl bromide and hydrobromofluorocarbons result in stratospheric ozone depletion. HFCs, PFCs and SF_6 are not ozone depleting substances but are powerful greenhouse gases.PFCs and SF6 are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution and magnesium casting. CFCs are widely used refrigeration, aerosols, fire extinguishers, air conditioners and cleaners used in many industries.
7.	Carbon Monoxide (CO)	CO has an indirect radiative forcing effect by elevating concentrations of CH_4 and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g. hydroxyl radical, OH). CO is created when carbon –containing fuels are burnt incompletely.
8.	Nitrogen oxide (NOx)	Nitrogen oxides have indirect effect on climate change resulting from their role in promoting the formation of ozone in the troposphere. Nitrogen oxides are created from lightning, soil microbial activity, biomass burning, fuel combustion, aircraft emission, etc.
9.	Non-methane volatile organic compounds (NMVOCs)	NMVOCs include propane, butane and ethane and are emitted from transportation and industrial processes, biomass burning and non-industrial consumption of organic solvents.
10.	Aerosols	These are extremely small particles or liquid droplets often composed of sulphur compounds, carbonaceous combustion products, crustal materials and other human induced pollutants and can affect the absorption characteristics of the atmosphere and hence radiative forcing in both direct and indirect ways. Various categories of aerosols include - naturally produced aerosols like soil dust, dust storms, sea salt, biogenic aerosols, sulphates and volcanic aerosols, and - anthropogenically manufactured aerosols like industrial dust, carbonaceous aerosols (black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration and biomass burning

radiations emitted to the surface. The changes in the atmospheric concentration of these gases can alter the balance of energy transfers between atmosphere, space, land and oceans. A guage of these changes is called radiative forcing which is ultimately responsible for the climate changes. There are clear evidences that human activities have affected concentration, distribution and life cycle of these gases in past 200 years. In addition to GHGs, the hydroxyl radical (OH), highly reactive molecular fragment, also influences atmospheric activity even though it is much scarce (concentration < 0.00001ppb). It plays a different role and contributes to the cleansing of the atmosphere. But its abundance in atmosphere may diminish in the future. GHGs differ in their ability to absorb heat in the atmosphere. HFCs and PFCs are most heat absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 time more heat per molecule than CO2. GHG emissions are presented in units of millions metric tones of carbon equivalents (MMTCE) which weighs each gas by its global warming potential (GWP). The atmospheric concentration of greenhouse gases has increased tremendously mainly due to human activities, thereby leading to radiative forcing which is the driving force resulting in climate change (Table 2).

The warming due to green house effect has not been globally uniform. Some areas have in fact, cooled over the last century because an enhanced green house effect is expected to cause cooling in higher parts of the atmosphere because the increased "blanketing" effect in the lower atmosphere holds in more heat, allowing less to reach the upper atmosphere. Other consequences of increased GHE are increased cloud cover, cooling of lower stratosphere, changes in glacier length, extreme precipitation events, etc. Far reaching impacts will be caused by global warming which is becoming increasingly evident as a result of the continued growth in atmospheric concentrations of CO_2 (major factor) and other GHGs. In addition to GHGs, the hydroxyl radical (OH), highly reactive molecular fragment, also influences atmospheric activity even though it is much scarce (concentration < 0.00001ppb). It plays a different role and contributes to the cleansing of the atmosphere. But its abundance in atmosphere may diminish in the future. GHGs differ in their ability to absorb heat in the atmosphere. HFCs and PFCs are most heat absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 times more heat per molecule than CO_2. GHG emissions are presented in units of millions metric tones of carbon equivalents (MMTCE) which weighs each gas by its global warming potential (GWP).The atmospheric concentration of greenhouse gases has increased tremendously mainly due to human activities, thereby leading to radiative forcing which is the driving force resulting in climate change (Table 2).

Table 2 : Pre-industrial and present abundance of well-mixed greenhouse gasses and the radiative forcing due to the change in abundance (Gases relevant to radiative forcing only)

Gas	Abundance (Year 1750)	Abundance (Year 1998)	Radiate forcing (Wm^{-2})
CO_2	278	365	1.46
CH_4	700	1745	0.48
N_2O	270	314	0.15
CF_4	40	80	0.003
C_2F_6	0	3	0.001
SF_6	0	4.2	0.002
HFC-23	0	14	0.002
HFC-134a	0	7.5	0.001
HFC-12a	0	0.5	0.000

(Volume mixing ratios of CO_2 are in ppm, for CH_4 and N_2O in ppb and for the rest in ppt.)

Impact of climate change on vegetable production:

A significant change in climate on a global scale will impact agriculture and consequently affect world's food supply. Climate change *per se* is not necessarily harmful; the problems arise from extreme events that are difficult to predict (FAO, 2001). Unpredictable high temperature spells and more erratic rainfall patterns will consequently reduce crop productivity. Developing countries in the tropics will be particularly vulnerable. Latitudinal and altitudinal shifts in ecological and agro-economic zones, land degradation, extreme geophysical events, reduce water availability, and rise in sea level and salinization are postulated (FAO, 2004). Unless measures are undertaken to mitigate the affects of climate change, food security in developing countries will be under threat.

Vegetables are generally sensitive to environmental extremes, and thus high temperatures and limited soil moisture are the major causes of low yields in the tropics and will be further magnified by climate change. Climate changes will influence the severity of environmental stress imposed on vegetable crops. Moreover, increasing temperatures reduced irrigation water availability, flooding and salinity will be major limiting factors in sustaining and increasing vegetable productivity. Extreme climate conditions will also negatively impact soil fertility and increase soil erosion. Thus, additional fertilizer application or improved nutrient-use efficiency of crops will be needed to maintain productivity or harness the potential for enhanced crop growth due to increased atmospheric CO_2. The response of plants to environmental stresses depends on the plant developmental stage and the length and severity of the stress (Bray, 2002). Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms (Capiati *et al.,* 2006). Environmental interactions may make the stress response of plants more complex or influence the degree of impact of climate change. Measures are needed to adapt to these climate changes as the induced stresses are critical for sustainable tropical vegetable production. Until now, the scientific information on the effect of environmental stresses on vegetables is overwhelmingly on tomato. There is a need to do more research on other vegetable crops in this aspect.

Effect of high temperature:

Temperature limits the range and production of many crops. With a changing climate, crops will be subjected to increased temperature stress. Analysis of climate trends in vegetable growing locations suggests that temperatures are rising and the severity and frequency of above optimal temperature episodes will increase in the coming decades (Bell *et al.*, 2000). Vegetative and reproductive processes in plants are strongly modified by temperature alone or in conjunction with other environmental factors. High temperature stress disrupts the biochemical reactions fundamental for normal cell function in plants. It primarily affects the photosynthetic functions of higher plants (Weis and Berry, 1988). High temperatures can cause significant losses in tomato productivity due to reduced fruit set, and smaller and lower quality fruits (Stevens and Rudich, 1978). Pre-anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epidermis and endothecium, lack of opening of the stromium and poor pollen formation (Sato *et al.,* 2002). 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 (Erickson and Markhart, 2002). Hazra *et al.* (2007) summarized the symptoms causing fruit set failure at high temperatures in tomato including bud drop, abnormal flower development, poor pollen production, dehiscence, and viability, ovule abortion and poor viability, reduced carbohydrate availability and other reproductive abnormalities. In addition, significant inhibition of photosynthesis occurs at the temperatures above optimum, resulting in considerable loss of potential productivity. Physiological disorders caused by temperature have been given in Table 3.

Table 3: Physiological disorders of vegetables caused or exacerbated by high or low temperature

Sr. No.	Crop	Disorder	Aggravating factor
1.	Asparagus	High fiber in stalks	High Temperature
2.	Asparagus	Feathering and lateral branch growth	Temperature > 32ºC, especially if picking frequency is not increased
3.	Bean	High fiber in pods	High temperature
4.	Carrot	Low carotene content	Temperatures < 10 ºC or > 20 ºC
5.	Cauliflower	Blindness, buttoning, riciness	Low temperature
6.	Cauliflower, Broccoli	Hollow stem , leafy heads, no heads, bracting	High temperature
7.	Cole crops and lettuce	Tip burn	Drought, combined with high temperatures; high respiration
8.	Lettuce	Tip burn, bolting, loose and puffy heads	Temperature > 17-28ºC day and 3-12 ºC night
9.	Onion	Bulb splitting	High temperature
10.	Pepper	Low seed production and off-shaped fruit	Low temperature
11.	Pepper	Sun scald	High temperature
12.	Potato	Secondary growth and heat sprouting	High temperature
13.	Tomato	Fruit cracking, sunscald	High temperature
14.	Tomato, pepper, watermelon	Blossom end rot	High temperature; especially combined with drought, high transpiration

With global warming, the rate of germination may increase more than the total percentage germination (Fig.1) but rapid emergence makes the seedlings more competitive against diseases and insects and possibly against weeds. Warmer winter temperatures could allow the autumn crop to be grown farther into the winter, but higher summer temperatures could restrict the production of spring crops. For warm season crops, the temperature range for germination is much higher (13-25^{0}C) than for cool-season vegetables (3-17^{0}C). Any soil warming would be advantageous for cucurbits which are generally direct-seeded and have a high heat requirement. For most vegetables, growth is more rapid as temperatures increase, at least up to about 25^{0}C (Fig.1). Even at temperatures above 25^{0}C, plants sustain some growth through heat adaptation. In heat adapted plants, changes in the lipid composition of chloroplast membranes raise the temperature at which the photosynthetic electron transport systems are disrupted. Another protective mechanism in plants is the production of heat shock proteins after sudden exposure to high temperature. These proteins may help crops to acquire tolerance to temperature stress, maintain cell integrity, prevent protein denaturation and protect the photosystem II center.

A greater increase in winter temperatures may lead to lack of verbalization for some crops and hence flowering and thereafter seed quality may be affected as in brassica, celery, onion, etc. In bean, high temperatures delay flowering because they enhance the short day photoperiod requirement. In cucumber, sex expression is affected with low temperature leading to more female flowers and high temperatures leading to production of more male flowers. In lettuces and spinach, high temperature and long days induce flowering. Some seed production and perennial vegetable production locations may need to be moved farther north. In perennial crops, such as chive, asparagus and rhubarb, lower temperature being required before intitiation of new growth in spring, increase in winter temperature might decrease production.

High temperature actually shortens the seed filling period and the fruit maturation period. Generally, this results in lower individual seed and fruit weight and sometimes reduced concentrations of soluble solids in the fruit. In many crops reproductive events themselves are prevented at high temperatures e.g. in tomato high temperature causes reduced fruit set, yields and seed set. In pepper, high temperatures (27/21^{0}C) result into reduced fruit set and still higher temperature (38/32^{0}C) cause no fruit setting (Fig.2). Generally, pre-anthesis stress appears to be more injurious than stress applied after bloom. Temperature has potential impacts on plant disease through both the host crop plant and the pathogen. Generally, fungi that cause plant disease, grow best in moderate temperature ranges. Temperate climate zones that include seasons with cold average temperatures are likely to experience longer periods of temperatures suitable for pathogen growth and reproduction if climates warm. For example, predictive models for potato and tomato late blight (caused by *Phytophthora infestans*) show that the fungus infects and reproduces most successfully during periods of high moisture that occur when temperatures are between 45^0 F (7.2^{0}C) and 80^0 F (26.8^0 C) (Wallin and Waggoner, 1950). Earlier onset of warm temperatures could result in an earlier threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control. Increased temperatures can potentially affect insect survival, development, geographic range, and population

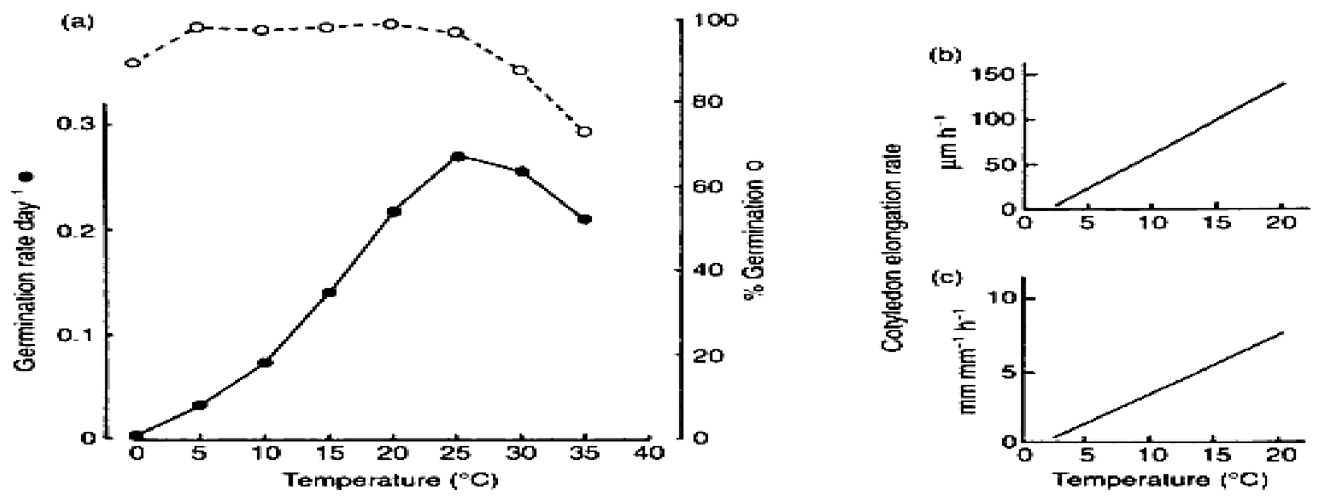

Fig. 1 : Effect of temperature on germination rate and cotyledon elongation rate in onion

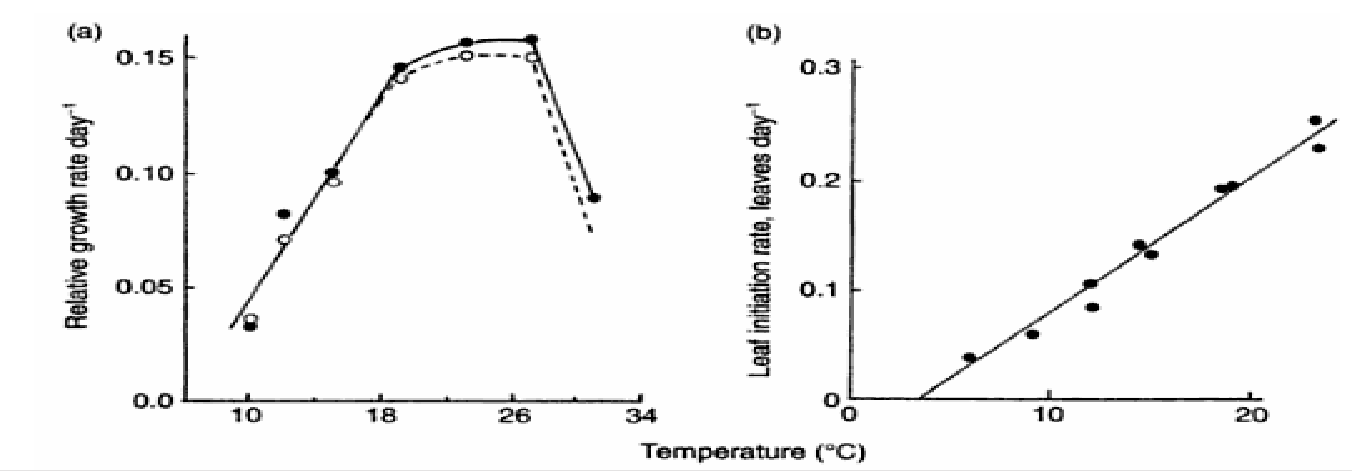

Fig. 2 : Effect of temperature on relative growth rate and leaf initiation rate in onion

size. Temperature can impact insect physiology and development directly or indirectly through the physiology or existence of hosts. Increased temperatures will accelerate the development of some types of insects like cabbage maggot, onion maggot, European corn borer, Colorado potato beetle – possibly resulting in more generations and crop damage per year. It has been estimated that with a 2^0 C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998).

Natural enemy and host insect populations may respond differently to changes in temperature. Parasitism could be reduced if host populations emerge and pass through vulnerable life stages before parasitoids emerge. Temperature may change gender ratios of some pest species such as thrips potentially affecting reproduction rates. Soil inhabiting insects may be more gradually affected by temperature changes than those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air. Lower winter mortality of insects due to warmer winter temperatures could be important in increasing insect populations. Rising temperatures could result in more diverse insect species attacking more hosts in temperate climates. Increased temperature could also decrease populations of pests like aphids.

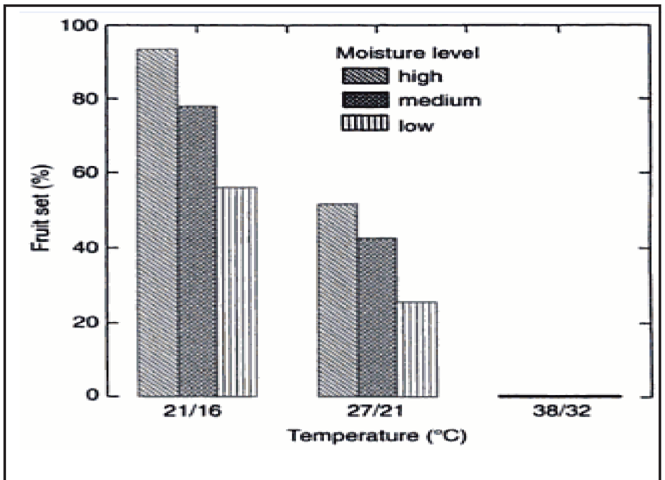

Fig. 3 : Influence of air temperature and soil moisture on percentage fruit set of 'World Beater' pepper grown in pots in glasshouse compartments

Effect of increased CO_2 emission:

Concentration of the atmospheric CO_2 has risen from close to 280 ppm in 1800, at first slowly and then progressively faster to a value of 367 ppm in 1999, echoing the increasing pace of global industrial and agricultural development. Increasing the concentration of CO_2 in the atmosphere has two effects on the reactions of rubisco (photosynthetic carbon fixing enzyme) increasing the rate of reaction with CO_2 (carboxylation) and decreasing the rate of oxygenation. Both effects increase the rate of photosynthesis, since oxygenation is followed by photorespiration which releases CO_2. With increased photosynthesis, plants can develop faster, attaining the same final size in less time, or can increase their final mass. The strength of the response of photosynthesis to an increase in CO_2 concentration depends on the photosynthetic pathway used by the plant. Plants with C3 photosynthetic pathway (all trees, nearly all plants of cold climates, and most agricultural crops) generally show an increased rate of photosynthesis in response to increases in CO_2 concentration above the present level. Plants with C4 photosynthetic pathway (tropical and many temperate grasses, some desert shrubs and some crops like maize and sugarcane) already have a mechanism to concentrate CO_2 and therefore, show either no direct photosynthetic response, or less response than C3 plants.

Increased CO_2 has also been reported to reduce plant respiration under some conditions.

Increased CO_2 concentration allows the partial closure of stomata, restricting water loss during transpiration and producing an increase in the ratio of carbon gain to water loss. This effect can lengthen the duration of growing season in seasonally dry ecosystems and can increase net primary production (NPP) in both C3 and C4 plants. Nitrogen–use efficiency also generally improves as carbon input increases, because plants can vary the ratio between carbon and nitrogen in tissues and require lower concentrations of photosynthetic enzymes in order to carry out photosynthesis at a given rate. For this reason, low nitrogen availability does not consistently limit plant responses to increased atmospheric CO_2. Increased CO_2 concentration may also stimulate nitrogen fixation. Changes in tissue nutrient concentration may affect herbivory and decomposition. The process of CO_2 "fertilization" involves direct effects on carbon assimilation and indirect effects such as those via water saving and interactions between the carbon and nitrogen cycles. Increasing CO_2 can, therefore, lead to structural and physiological changes in plants and can further affect plant competition and distribution patterns due to responses of different species. CO_2 improves water use efficiency because of decline in stomatal conductance, potentially decreasing drought susceptibility and reducing irrigation requirements. Incidence of such physiological disorders as tip burn in lettuce and cole crops and blossom-end rot in tomato, pepper and watermelon, being sometimes associated with excessive transpiration, may be reduced. Respiration of leaves and roots in the dark slows within minutes of an increase in ambient CO_2, so night-time respiration would be lower at high CO_2. This, direct short-term and readily reversible effect of CO_2 on respiration has been noted in tomatoes, lettuce, peppers and peas. The night time inhibition of respiration could slow growth. The effects of some stresses might exacerbate e.g. high temperature and ozone stress may require enhanced leaf respiration for repair and this repair might be impaired by elevated night-time CO_2. Elevated CO_2 is found to increase root dry weight and induces longer and numerous roots, enhanced rooting and establishment due to increased carbohydrate availability and from decreased stomatal conductance. By increasing plant size, elevated CO_2 increases total nutrient uptake and nutrient-use efficiency but nutrient uptake efficiency generally declines. Researchers have shown that higher growth rates of leaves and stems observed for plants grown under high CO_2 concentrations may result in denser canopies with higher humidity that favor pathogens. Lower plant decomposition rates observed in high CO_2 situations could increase the crop residue on which disease organisms can overwinter, resulting in higher inoculum levels at the beginning of the growing season, and earlier and faster disease epidemics. Pathogen growth can be affected by higher CO_2 concentrations resulting in greater fungal spore production. However, increased CO_2 can result in physiological changes to the host plant that can increase host resistance to pathogens. While physiological changes in host plants may result in higher disease resistance under climate change scenarios, host resistance to disease may be overcome more quickly by more rapid disease cycles, resulting in a greater chance of pathogens evolving to overcome host plant resistance. Fungicide and bactericide efficacy may change with increased CO_2, moisture, and temperature. The more frequent rainfall events predicted by climate change models could result in difficulty to keep residues of contact fungicides on plants, triggering more frequent applications. Systemic fungicides could be affected negatively by physiological changes that slow uptake rates, such as smaller stomatal opening or thicker epicuticular waxes in crop plants grown under higher temperatures. Exclusion of pathogens and quarantines through regulatory means may become more difficult for authorities as unexpected pathogens might appear more frequently on imported crops. Generally CO_2 impacts on insects are thought to be indirect resulting from changes in the host crop. e.g., population of pests like Japanese beetle, potato leafhopper, western corn rootworm, Mexican bean beetle has been found to increase due to measured increases in the levels of simple sugars in the host leaves that stimulate the additional insect feeding. Lowered nitrogen content induced by high CO_2 levels may increase damage by insect pests, which in order to obtain sufficient nitrogen for their metabolism, may increase their feeding rates. Increased carbon to nitrogen ratios in plant tissue resulting from increased CO_2 levels may slow development of some insects and increase the length of life stages vulnerable to attack by parasitoids. Entomologists expect that insects will expand their geographic ranges, and increase reproduction rates and overwintering success. Insecticides and their applications have significant economic costs for growers and environmental costs for society. Additionally, some classes of pesticides (pyrethroids and spinosad) have been shown to be less effective in controlling insects at higher temperatures. Entomologists predict additional generations of important pest insects in temperate climates as a result of increased temperatures, probably necessitating more insecticide applications to maintain populations below economic damage thresholds. With more insecticide applications required, the probability of applying a given mode of action insecticide more times in a season will increase, thus increasing the probability of insects developing resistance to insecticides.

Effectg of drought:

The Indian Meteorological Department in their annual summaries and monthly weather reports classify drought as slight, moderate and severe when the deficit of rainfall is -11 to -25 %, -26 to -50% and below 50%. Unpredicted drought is the single most important factor affecting world food security. Water availability is expected to be highly sensitive to such climate change and severe water stress conditions will affect crop productivity, particularly that of vegetables. In combination with elevated temperatures, decreased precipitation could cause reduction of irrigation water availability and increase in evapotranspiration, leading to severe crop water- stress conditions. Vegetables being succulent products by definition generally consist of greater than 90% water. Thus water greatly influences the yield and quality of vegetables, drought condition drastically reduces vegetable productivity. Drought stress causes an increase of solute concentration in the soil environment, leading to an osmotic flow of water out of plants cells. This leads to an increase in the solute concentration in plants cells, thereby lowering the water potential and disrupting membranes and cell processes such as photosynthesis. The timing, intensity, and duration of drought spells determine the magnitude of the effect of drought. Drought conditions are generally associated with narrow leaf orientation, leaf pubescence, increased spread and length of root system, delayed maturity, small and delayed flowers, decline in chlorophyll content, decreased chlorophyll stability index, reduced rate of transpiration, reduce uptake of nutrients, lesser germination. Water stress at critical stages of plant growth leads to severe reduction in yield. The effects of water stress on morphology and physiology of vegetables have been given in Table 4.

Salinity:

In hot and dry environments, high evapotranspiration results in substantial water loss, thus leaving salt around the plant roots which interferes with the plants' ability to uptake water. Salinity also affects agriculture in coastal regions which are impacted by low quality and high –saline irrigation water due to contamination of the ground water and intrusion of saline water due to natural or man-made events. Salinity fluctuates with seasons, being generally high in the dry season and low during rainy season when freshwater flushing is prevalent. Furthermore, coastal areas are threatened by specific saline natural disasters which can make agricultural lands unproductive, such as tsunamis which may inundate low lying areas with sea water. Although the seawater recedes rapidly, the ground water contamination and subsequent osmotic stress causes crop losses and affects soil fertility. In the inland areas, traditional water

Table 4 : Effect of water stress on morphological and physiological characters of vegetables

Sr. No.	Crop	Effect of water stress
1.	Brinjal	Reduced extension of main stem, reduced no. of branches per plant, reduction of leaf area, few flowers, delayed flowering, decreased per-plant yield, reduced ascorbic acid, protein and carbohydrate content, accumulation of free proline
2.	Beans	Few flowers, delayed flowering, empty seeds, seed reduction, decreased starch content, low seed protein, accumulation of free proline
3.	Potato	Yield loss, decreased starch content, increase in reducing sugars content.
4.	Watermelon	Short main root, numerous long roots.
5.	Cassava, Cauliflower, Winged bean	Reduction of leaf area
6.	Soybean	Reduced yield.
7.	Spinach beet	Quick bolting.
8.	Lettuce	Bitter taste, accelerated development of tip burn.
9.	Tomato	Blossom end rot, accumulation of free proline.
10.	Cauliflower Pumpkin, Chinese	Ricy, leafy, loose, yellow, small and hard curds.
11.	Cabbage	Accumulation of free proline.

wells are commonly used for irrigation water in many countries. The bedrock deposit contains salts and the water from these wells are becoming more saline, thus affecting irrigated vegetable production in these areas. Vegetable production is threatened by increasing soil salinity particularly in irrigated croplands which provide 40% of the world's food. Excessive soil salinity reduces productivity of many agricultural crops, including most vegetables which are particularly sensitive throughout the ontogeny of the plant. According to the United States Department of Agriculture (USDA), onions are sensitive to saline soils while cucumbers, eggplants, peppers and tomatoes, among the main crops of AVRDC- the world vegetables centre, are moderately sensitive. 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 build up in Na+ and Cl- concentrations that are detrimental to plants.Plant sensitivity to salt stress is reflected in loss of turgor, growth reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant.

Effect of flooding:

Vegetable production is often limited during the rainy season due to excessive moisture brought about by heavy rain. Most vegetables are highly sensitive to flooding and genetic variation with respect to this character is limited. 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 (Drew, 1979). Low oxygen levels stimulate an increased production of an ethylene precursor, 1- amino cyclopropane -1- carboxylic acid (ACC), in the roots. The rapid development of epinastic growth of leaves is a characteristic response of tomato to water-logged conditions and the role of ethylene accumulation has been implicated. Water logged condition prevailing for more then 24 hours leads to wilting in chilies. The severity of flooding symptoms increases with rising temperatures. Rapid wilting and death of plants (in tomato, chillies, etc.) is usually observed following a short period of flooding at high temperatures.Moisture can impact both host plants and pathogen organisms in various ways. Some pathogens such as late blight, and several vegetable root pathogens are more likely to infect plants with increased moisture. Other pathogens like the powdery mildew species tend to thrive in conditions with lower (but not low) moisture. More frequent and extreme precipitation events that are predicted by some climate change models could result in more and longer periods with favorable pathogen environments. Some climate change models predict higher atmospheric water vapor concentrations with increased temperature – this also would favor pathogen and disease development.Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains e.g., onion thrips. For some insects that overwinter in soil, flooding the soil has been used as a control measure. Fungal pathogens of insects are favored by high humidity and their incidence would be increased under high humidity and reduced in drier conditions.

Need for adaptation to climate change:

Potential impacts of climate change on agricultural production will depend not only on climate *per se*, but also on the internal dynamics of agricultural systems including their ability to adapt to the changes (FAO, 2001). Success in mitigating climate change depends on how well agricultural crops and systems adapt to the changes and concomitant environmental stresses of those changes on the current systems. Farmers need tools to adapt and mitigate the adverse effects of climate change on agricultural productivity, and particularly on vegetable production, quality and yield. One way is to change cropping patterns and make adjustment for available water resources. Another way might be to change farming practices by adjusting cultivation period, applying appropriate crop rotations and/or adopting new varieties that are resilient to future climate variability. The development in climate change forecast using global and regional climate models (GCM and RCM) has made it possible to provide more detailed information on regional precipitation and temperature changes in face of global warming. Current, and new, technologies being developed through plant stress physiology research can potentially contribute to mitigate threats from climate change on vegetable production. Technologies that are simple, affordable, and accessible must be used to increase the resilience of farms in less developed countries. Germplasm of the major vegetable crops which are tolerant of high temperatures, flooding and drought needs to be identified to develop advanced breeding lines. There is a need to identify nitrogen–use efficient germplasm. 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 top research and development priorities.

REFERENCES

Bell, G.D., Halpert, M.S., Schnell, R.C., Higgins, R.W., Lowrimore, J., Kousky, V.E., Tinker, R., Thiaw, W., Chelliah, M. and Artusa, A. (2000). Climate Assessment for 1999. *Bull Am. Meteorol Soc* 81.

Bray, E.A. (2002). Abscisic acid regulation of gene expression during water-deficit stress in the era of the *Arabidopsis* genome. *Plant Cell Environ.,* **25**:153-161.

Capiati, D.A., País, S.M. and Téllez-Iñón, M.T. (2006). Wounding increases salt tolerance in tomato plants: evidence on the participation of calmodulin-like activities in cross-tolerance signaling. *J. Exp. Bot.,* **57**:2391-2400.

Erickson, A.N. and Markhart, A.H. (2002). Flower developmental stage and organ sensitivity of bell pepper (*Capsicum annuum* L) to elevated temperature. *Plant Cell Environ.,* **25**:123-130.

FAO (2001). Climate variability and change: A challenge for sustainable agricultural production. Committee on Agriculture, Sixteenth Session Report, 26-30 March, 2001. Rome, Italy.

FAO (2004). Impact of climate change on agriculture in Asia and the Pacific. Twenty-seventh FAO Regional Conference for Asia and the Pacific. Beijing, China, 17-21 May 2004.

FAO (2003). *World Agriculture: Towards2015/2030. An FAO Perspective*. Bruinsma, Ed., FAO, Rome and Earthscan,London, 520 pp.

Hazra, P., Samsul, H.A., Sikder, D. and Peter, K.V. (2007). Breeding tomato (*Lycopersicon Esculentum* Mill) resistant to high temperature stress. *Internat. J. Plant Breed.,* **1**(1).

Sato, S., Peet, M.M. and Thomas, J.F. (2002). Determining critical pre- and post-anthesis periods and physiological process in *Lycopersicon esculentum* Mill. Exposed to moderately elevated temperatures. *J. Exp. Bot.,* **53** : 1187-1195.

Stevens, M.A. and Rudich, J. (1978). Genetic potential for overcoming physiological limitations on adaptability, yield, and quality in tomato. *Hort. Sci.,* **13**:673-678.

Wallin,J.R. and Waggoner, P.E. (1950). The influence of climate on the development and spread of *Phytophthora infestans* in artificially inoculated potato plots. *Plant Dis. Reptr. Suppl.,* **190** : 19-33.

Weis, E. and Berry, J.A. (1988). Plants and high temperature stress. *Soc. Expt. Biol.,* 329-346.

Yamamura, K. and Kiritani, K. (1998). A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. *Appl. Ent. & Zool*., **33** : 289-298.

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