Effects of Climate Change on Vegetable Cultivation - A Review

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INTRODUCTION

The importance of vegetables in providing food and nutritional security and amelioration of nutrient deficiencies has been realised world over (Prasad et al. 2014). They also provide opportunities for higher farm income apart from livelihood security through employment generation. The worldwide production of vegetables has gone up tremendously during the last two decades and the value of global trade in vegetables now exceeds that of cereals (Dhiman 2012). It is a challenging issue to the most of nations to feed hunger-laden people. IFAD (International Fund for Agricultural Development) (2009) has reported that climate change is expected to put 49 million additional people at risk of hunger by 2020, and 132 million by 2050 (Devendra 2012). Hence, more emphasis is being given in the developing countries like India to promote cultivation of vegetables. World geographical areas comprise of mountains, coastal regions, deltas and different climatic conditions like temperate, tropical, sub-tropical, arid and humid zones etc. which are vulnerable to climate change. Little change in the climate will disturb the whole ecology and in-turn the traditional pattern of growing vegetables in these regions (Bhardwaj 2012). Degradation of land, extreme geophysical events and reduced water availability, are the factors which affect the vegetable production. Climate change refers to a change in the state of climate that can be identified by (e.g., by using statistical tests) changes in the mean of the various climatic parameters, such as temperature, precipitation, relative humidity and atmospheric gases composition, etc. and/or the variability of its properties, and that persists for an extended period, typically decades or longer in larger geographical areas (Cubasch et al. 2013). UNFCC defined climate change as a change of climate which is attributed directly or indirectly to human activity or due to natural variability. Vegetables are generally sensitive to environmental extremes. Extreme variation in temperature 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. These will further be magnified by climate change which can exact a heavy toll on the vegetable production. Under changing climatic situations, crop failures, shortage of yields, reduction in quality and increasing pest and disease problems are common, which render the vegetable cultivation unprofitable (Koundinya...
et al., 2014). In India, potato production under the impact of climate change and global warming may decline by 3.16% and 13.72% in the year 2020 and 2050, respectively (Singh et al. 2009). Yield potential of majority crops in this group are seriously affected by various climatic vagaries like development of high temperature, low temperature (chilling & freezing) in the atmosphere, occurrence flood, drought, salinity, soil erosion, storm, wind, hail damage, volcanic eruption and tsunamis etc., the summarized impact of these environmental extremes on vegetable cultivation is given below.

**IMPACTS OF CLIMATE CHANGE ON VEGETABLES PRODUCTION**

**High temperature:** High temperatures can cause significant losses in tomato productivity due to reduced fruit set and smaller and lower quality fruits. Pre-anthesis temperature stress is associated with developmental changes in the anthers, particularly irregularities in the epithesium and endothesium, lack of opening of the stromium, and poor pollen formation (Peet et al. 1988, 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 & Markhart 2002). The cell membrane permeability and proline (heat tolerance index) content increased slightly under high temperature stress in Chinese cabbage cultivars (Datta 2013). Increased temperatures also reduce yield by affecting factors such as the sprouting of seed tubers, growth rates and tuberization, and each of these factors may be controlled by different genes (Peet & Wolfe 2000). Sudden development of high temperatures during the growing phase of lettuce and celery cause bolting (premature seed head production), resulting in poor quality heads, and reduced yields. In warm climate, survivability of DBM (Diamond Back Moth) increases. Due to climate change they can affect the brassica growing regions, particularly the sub-tropical regions, and increasingly so in temperate regions. Under arid conditions, in the future, thrips will reproduce and survive more easily. Higher temperatures will have negative effects on survivability and reproduction of some important parasites and predators, e.g. Trichogramma in vegetables (Peter Puglis, Dennis Decoteau 1998). It was observed that flooded tomato plants accumulate endogenous ethylene (Table 2) that causes damage to the plants (Drew 1979). Low oxygen levels stimulate an increased production of an ethylene precursor, 1-aminocyclopropane-1-carboxylic acid (ACC), in the roots. The rapid development of epinastic growth of leaves is a characteristic response of tomatoes to waterlogged conditions and the role of ethylene accumulation has been implicated (Kawase 1981). Further reports (Barclay & Crawford 1981, Patel et al. 2014) indicated that an internal ethanol concentration of 60 m mol/L appeared to be the threshold value for the survival of pea seedlings, and that anoxic death occurred when this concentration was exceeded. 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). ABA concentrations were found to increase in the roots of pea plants during the 2nd, 3rd and 4th days of flooding, causing stomata to partially close due to accumulation of ABA in the leaves (Zhang & Davies 1987). CO₂ used during photosynthesis first must pass through stomata into internal spaces within the leaf, then it diffuses into mesophyll cells where it becomes available for photosyn-
thesis. When the stomata close, CO₂ levels drop rapidly within the leaf, inhibiting the light-independent reactions. This then causes photosynthesis to stop. Flooded soils of sweet potato (Ipomoea batatas L.) caused losses due to rotting at harvest and increased shrinkage in storage (Thompson et al. 1992, Ton & Her-nandez 1978) besides losses in carotenoid pigments, dry matter content, and baking quality (Constantin et al. 1974). A study by Igwilo & Udeh (1987) on water logging effects on yam (Dioscorea spp.) vines for 24, 48, and 72 h indicated a progressive degeneration of the leaf starting with the development of fresh lesions on the lower leaves, through necrotic spots, to complete leaf necrosis. The degree of damage increased with the duration of water logging and damage was more severe in younger plants compared to the older plants. Pepper (Capsicum annuum L.) is sensitive to prolonged flooding. Continuous flooding of pepper plants for 4 weeks resulted in poor growth, yellowing of leaves, blackening of the root tips, and a distinct swelling at the junction of the shoot and the roots (Hasnain & Sheik 1976) caused by decreased O₂ supply, decreased N uptake by roots, and the development of cortical cells. Flooding asparagus (Asparagus officinalis L.) plants continuously for 48 h after 2 and 3 weeks after transplanting, delayed the growth and reduced the survival of the transplanted seedlings when compared to two 8-h flooding separated by a 16-h period of drainage (Falloon et al. 1991).

**Drought:** Drought is defined as a long period of abnormally low rainfall, especially one that adversely affects growing or living conditions (Allaby 1989). Unpredictable drought is the single most important factor affecting world food security and the catalyst of the great famines of the past (CGIAR 2003). Vegetables, being succulent products by definition, generally consist of greater than 90% water (AVRDC 1990). Thus, water greatly influences the yield and quality of vegetables; drought conditions drastically reduce vegetable productivity. Drought stress causes an increase of solute concentration in the environment (soil), leading to an osmotic flow of water out of the plant cells. This leads to an increase of the solute concentration in plant 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 (Peña & Hughes 2007). (Kirnak et al. 2001) found that water stress results in significant decrease in chlorophyll content, electrolyte leakage, leaf relative water content and vegetative growth; and plants grown under high water stress have less fruit yield and quality. The prevalence of drought conditions adversely affects the germination of seeds in vegetable crops like onion and okra and sprouting of tubers in potato (Arora et al. 1987). Potato is highly sensitive to drought; a moderate level of water stress can also cause reductions in tuber yield (Jefferies & Mackerron 1993). Tomatoes are very sensitive to water deficits during immediately after transplanting, at flowering and fruit development (Nuruddin 2001). Root and bulb crops like potato, carrot, and onion crop yields depend on the production and translocation of carbohydrates from the leaf to the root or bulb (storage organ). Occurrence of drought stress during enlargement of storage organs reduces yield and quality. Cucumbers, melons, pumpkins and squashes, lima beans, snap beans, peas, peppers, sweet corn, and tomatoes are most sensitive to drought stress at flowering and as fruits and seeds develop. Fruit set on these crops can be seriously reduced if water becomes limited (Anonymous). Leafy vegetables like amaranthus, palak and spinach are succulent in nature; the drought condition reduces the water content in produce, which leads to poor quantity and quality (AVRDC 1990).

**Salinity:** Vegetable production is threatened by increasing soil salinity particularly in irrigated croplands which supply 40% demand of the food in the world (FAO 2001). In hot and dry environments, high evapotranspiration results in substantial water loss from soil, thus leaving salt around the plant roots which interferes with the plant’s ability to uptake water. 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 (Yamaguchi & Blumwald 2005). Plant sensitivity to salt stress is reflected in the loss of turgor, reduction in growth, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, change in respiration, loss of cellular integrity, tissue necrosis, impaired seed germination, reduced nodule formation, retardation in plant development and a reduction in crop yield and even death of the plant (Jones 1986, Cheeseman 1988). According to the United States Department of Agriculture (USDA), onions are sensitive to saline soils, while cucumbers, eggplants, peppers, and tomatoes, amongst the main crops are moderately sensitive (Bharadwaj 2012). Under the influence of salt stress, growth of many species of vegetables is reduced, such as tomato (Romero-Aranda et al. 2001, Maggio et al. 2004), pepper (De Pascale et al. 2003b), celery (De Pascale et al. 2003a) and peas (Maksimovic et al. 2008, Maksimovic et al. 2010). Salt stress causes anatomical modifications in many vegetables, the epidermis and mesophyll cells of bean leaves become thick (Longstreth & Nobel 1979, reviewed Ivana Maksimovic & Žarko Ilin 2012). The adverse effect of salt stress causes a reduction in intercellular spaces in spinach leaves due to the presence of salt (Delfine et al. 1998) and increased stomatal density in pea (Maksimoviæ et al. 2010).
Increase in uptake and accumulation of Cl\(^{-}\) is accompanied by a reduction in the concentration of NO\(_3\) in eggplant (Savvas & Lenz 2000). High salt concentration causes a reduction in fresh and dry weight, relative water and total chlorophyll content (Baysal et al. 2004) of all cucurbits.

**Frost:** Frost injury occurs when ice forms inside the protoplasm of cells (intracellular freezing) and injures the plant cells. It can occur in annuals (legumes of forage and root crops) multi-annuals and perennials (deciduous and evergreen perennial vegetable trees). Frost damage may have a drastic effect upon the entire plant or affect only a small part of the plant tissue, which reduces yield, or merely product quality. Resulted of frost damage on different vegetables indicated in Table 3.

**SOIL EROSION, STORM, WIND, HAIL DAMAGE, VOLCANIC ERUPTION AND TSUNAMI**

Soil erosion causes negative effects that cannot be quantified easily. Erosion of soil from the root zone causes lodging of plants which is more harmful to most of the vegetables (tomato, egg plant, chilli, etc.). Damage of vegetable crops due to storm and further recovery of the crop will depend on a number of factors including the type of vegetable, stage of growth, weather conditions immediately after storms, and prevalence of disease organisms. Continued hot and moist condition after the storm is very detrimental which increases disease incidence, particularly bacterial diseases (Gordon Johnson 2013). Fruit bruising or wounding often causes the most severe losses in crops such as tomatoes. Fruits may be rendered unmarketable or of reduced grade. Wounds can also increase the incidence of some fruit diseases and storage rots. A report from Netherlands indicated that by 2050 annual hailstorm damage to outdoor farming could increase by between 25% and 50%, with considerable larger impacts on greenhouse horticulture in summer (more than 200%) (Sing et al. 2009). Sweet corn is more susceptible to loss of leaf area from the hail at tasseling and silking stage than any other in its life cycle. In general, complete loss of leaf area at this stage results in nearly 100% yield loss (Ritchie et al. 1997). Volcanic eruption generates numerous pollutants like SO\(_2\) and other nitrogenous oxides which can destroy the plants nearby. Both of them are highly toxic to the vegetation. Tsunamis are natural disasters and its occurrence cause inundation of low lying areas with saline water near the shoreline which eventually suffers from severe salinization, harmful for salt sensitive vegetables like (potato, sweet potato, brinjal, radish and peas).

**IMPACT OF CLIMATE CHANGE ON POLLINATING AGENTS AND POLLINATION BEHAVIOUR**

Pollination is a crucial stage in the reproduction of most flowering plants, including vegetable crops (Kearns et al. 1998). Change in the climate may be threatening to pollination activities due to altered behaviour of pollinating agents (Memmott et al. 2007, Hegland et al. 2009, Schweiger et al. 2010). Among all the climatic factors, an increase in temperature has the highest adverse effect on pollinator interactions. Warming may actually enhance the performance of insects living at higher altitudes, thereby resulting in increased seed setting and yields in the temperate crops growing in these areas. But, rise in temperature in low lying hills adversely affects the activity of pollinating agents and hence lower seed yield. Climatic change, including global warming and increased variability of environmental hazards require improved analyses that can be used to assess the risk of the existing and the newly developed pollinators management strategies and techniques, and to define the impact of these techniques on environment, productivity and
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Table 2: Summary of the influence of flooding duration and growth stage on tomato crop response (Renuka Rao & Yuncong Li 2003).

<table>
<thead>
<tr>
<th>Duration (hours)</th>
<th>Stage</th>
<th>Response</th>
</tr>
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<tbody>
<tr>
<td>24 h</td>
<td>6-7 leaf stage</td>
<td>Increase in ethylene production rate; leaf water potentials increased, stomatal closure and reduced transpiration, leaf epinasty.</td>
</tr>
<tr>
<td>24 h</td>
<td>9 week stage</td>
<td>Pronounced epinastic curvature of the petioles due to ethylene accumulation and production.</td>
</tr>
<tr>
<td>3d</td>
<td>1 month</td>
<td>Reduced Stem growth and leaf chlorophyll content; increase in epinastic curvature of leaf petiole and adventitious roots. Greatest sensitivity was at the flowering stage. Overall, reduced plant height, leaf area, chlorophyll, respiration rate, percent survival, fruit set, total yield, seed set and dry weight of the plants.</td>
</tr>
<tr>
<td>36 h</td>
<td>1 month</td>
<td>Reduced flow of nitrate, hydrogen ions, most protein amino acids, glutamine, and abscisic acid to the shoots.</td>
</tr>
<tr>
<td>72 h</td>
<td>Flowering</td>
<td>Decrease in leaf water potentials and increase in adventitious roots.</td>
</tr>
<tr>
<td>8d</td>
<td>Fruiting</td>
<td>Induced stomatal closure, hastened fruit maturation, reduced internal fruit firmness and subsequently reduced the storage quality of fruit.</td>
</tr>
<tr>
<td>24 h</td>
<td>Flowering</td>
<td>Wilting of 15% of tomato plants (versus 4% for no waterlogged plants) and 40% yield reductions.</td>
</tr>
</tbody>
</table>

Table 3: Frost damage symptoms for vegetable crops (Caplan 1988).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artichoke</td>
<td>Epidermis becomes detached and forms whitish to light tan blisters. When blisters are broken, underlying tissue turns brown.</td>
</tr>
<tr>
<td>Asparagus</td>
<td>Tip becomes limp and dark and the rest of the spear is water soaked. Thawed spears become mushy.</td>
</tr>
<tr>
<td>Beet</td>
<td>External and internal water soaking and sometimes blackening of conductive tissue.</td>
</tr>
<tr>
<td>Broccoli</td>
<td>The youngest florets in the centre of the curd are most sensitive to freezing injury. They turn brown and give off strong odour.</td>
</tr>
<tr>
<td>Cabbage</td>
<td>Leaves become water soaked, translucent and limp. Upon thawing the epidermis separates.</td>
</tr>
<tr>
<td>Carrot</td>
<td>Blistered appearance, jagged length-wise cracks. Interior becomes water soaked and darkens upon thawing.</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>Curds turn brown and have a strong off-odour when cooked.</td>
</tr>
<tr>
<td>Celery</td>
<td>Leaves and petioles appear wilted and water soaked upon thawing. Petioles freeze more readily than leaves.</td>
</tr>
<tr>
<td>Garlic</td>
<td>Thawed cloves appear greyish yellow and water soaked.</td>
</tr>
<tr>
<td>Lettuce</td>
<td>Blistering of dead cells of the separated epidermis on outer leaves, and become tan with increased susceptibility to physical damage and decay.</td>
</tr>
<tr>
<td>Onion</td>
<td>Thawed bulbs are soft, greyish yellow and water soaked in cross-section. Damage is often limited to individual scales.</td>
</tr>
<tr>
<td>Bell Pepper</td>
<td>Dead, water-soaked tissue in part or all of pericarp surface with pitting, shriveling and decay.</td>
</tr>
<tr>
<td>Potato</td>
<td>Freezing injury may not be externally evident, but shows as grey or bluish-grey patches beneath the skin. Thawed tubers become soft.</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>A yellowish-brown discoloration of the vascular ring and a yellowish green, water-soaked appearance of other tissues. Roots soften and become susceptible to decay.</td>
</tr>
<tr>
<td>Tomato</td>
<td>In partially frozen fruits, the margin between healthy and dead tissue is distinct, especially in green fruits.</td>
</tr>
</tbody>
</table>

Many bee species are able to control the temperatures in their flight muscles before, during and after the flight, by physiological and behavioural means (Willmer & Stone 1997). With respect to the potential effects of future global warming, behavioural responses of pollinator to avoid extreme temperatures have the potential effect on significant reduction of pollination services (Corbet et al. 1993). Examples of behavioural strategies for thermal regulation include long periods of basking in the sun to warm up and shade seeking or nest returning to cool down, which reduces the floral visiting time of pollinators, thereby subsequent pollination and fruit or seed set (Willmer & Stone 2004).

CONCLUSION

Climate change is a continuous process. An overall idea on the effects of climate change will provide better diagnosis and this is the primary tool to take further steps for mitigation. It is high time to realise the sensitivity of climate, which is adversely effected either environmentally (naturally) or through human intervention. According to previous studies, it was revealed that magnitude of climate change is most sensitive to anthropogens which directly or indirectly induce environmental aberrations like floods, drought, salinity, high temperature, etc., apart from shifting of cropping seasons, growth and yield patterns, pest and disease scenario and pollinating behaviour of insects. It is clearly indicated that, severe threat is ahead generating cautions for crises of food and nutrition, employment and livelihood security, leading to poverty in future. Complete eradication of climatic change effects is not possible, but minimization of it is evitable through sincere intervention. There must be a
goal of nations to formulate global strategy to take a missionary approach. According to authors opinion, it is high time to take small but sincere efforts by each individual or group for reduction of the climate change so that the nature God can take care of its living entities on the earth.

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