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Horticulture

Impact of Climate Change on Vegetable Cultivation - A Review

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Abstract

Vegetables are an important component of human diet as they are the only source of nutrients, vitamins and minerals. They are also good remunerative to the farmer as they fetch higher price in the market. Likewise other crops, they are also being hit by the consequences of climate change such as global warming, changes in seasonal and monsoon pattern and biotic and abiotic factors. 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 cultivation 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 cultivation. Increase in CO_2 may increase crop yields due to increased CO_2 fertilization, but decreases after some extent. Anthropogenic air pollutants such as CO_2, CH_4 and CFC's are contributing to the global warming and dioxides of nitrogen and sulphur are causing depletion of ozone layer and permitting the entry of harmful UV rays. These affects 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. Potato, among the all vegetables, is most vulnerable to climate change due to its exact climatic requirement for various physiological processes.

Highlights

- The mean annual temperature of India is increased by 0.46^0c over a period of last 111 years due to the increased amount of green house gases like CO_2 and CH_4 in atmosphere.
- Potato productivity is expected to decline in all potato growing states of India and is highest for Karnataka with a reduction of 18.68% by 2020.
- Over the next 50 years, aphids will appear at least eight days earlier in the spring spreading viral diseases.
- Fecundity of several *Lepidopteron* pests is increasing and they are migrating towards north due to increase in temperature.
- Limited availability of literature indicates that research on changing climatic conditions in respect to vegetable crops has been lacking, which has to be taken up as a missionary approach.

Keywords: Climate change, Vegetables, Pest and diseases and Production problems

Introduction

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 of time and a larger geographical area. It can also be referred as any change in climate over time, whether due to natural variability or as a result of human activity. According to Schneider *et al.* (2007) 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. At present due to anthropogenic activities like industrialization, deforestation and automobiles etc. changes in the climate are being taken place, which will again turn detrimental to life (Rakshit *et al.*, 2009). The changes in climate may include fluctuations in temperature, increase in soil salinity, water logging, high atmospheric CO_2 concentration and UV radiation. High temperature is due to the increased amount of green house gases like CO_2 and CH_4 in atmosphere (Table 1), which is commonly known as global warming or green house effect. The mean annual temperature of India is increased by 0.46^0 C over a period of last 111 years since 1901 (24.23^0 C) to 2012 (24.69^0 C) (Data Portal India, 2013). Global combined surface temperatures over land and sea have been increased from 13.68^0 C in 1881-90 to 14.47^0 C in 2001-10 (WMO, 2013). Globally averaged surface temperature is expected to rise by between 1.1°C up to 6.4°C by the last decade of the 21st century (Minaxi *et al.*, 2011). The change in the mean decadal temperature of India and world is presented in Fig 1 and 2 respectively. This temperature increase will alter the timing and amount of rainfall, availability of water, wind patterns and causes incidence of weather extremes, such as droughts, heat waves, floods or storms, changes in ocean currents, acidification, forest fires and hastens rate of ozone depletion (Minaxi *et al.*, 2011; Kumar, 2012). Higher average temperatures will also stimulate the emergence and re-emergence of pests and diseases and increase the vectors that carry disease. Increase in temperature will cause the melting of polar ice, which in turn causes increase in sea level and protruding of sea water into the coastal areas resulting in water logging and increased salinity levels. Higher sea levels will have disastrous allegations for small Pacific states and low-lying countries such as Bangladesh, and also for all major coastal cities. Ozone depletion in the stratosphere, caused by trace gases such as chlorofluorocarbons (CFCs) and nitrogen oxides results in increased levels of ultraviolet-B radiation (UV-B, 280-315 nm) reaching the earth's surface, which is harmful to life (Zajac and Kubis, 2010). Agriculture is a climate dependent activity. So, it is going to be effected by climate change largely. Being a victim of climate change, agriculture contributes to it by significant consumption of fossil fuels and methane emissions through rice production and livestock raising (Ahmed *et al.*, 2011). The Indira Gandhi Institute of Development Research has reported that if the predictions relating to global warming made by the inter-governmental panel on climate change comes to fruition, climate related factors could cause India's GDP to decline by up to 9 per cent (Priyadarshini, 2009).

Table 1: Increase in atmospheric concentration of green house gases since pre industrial times (WMO, 2013; Permission obtained)

Green house gas	Conc. in 2010	Increase since pre industrial time
Carbon dioxide	389 ppm	39%
Methane	1808 ppb	158%
Nitrous oxide	323.2 ppb	20%

Climate change vs Vegetables

Vegetables are known as protective food as they supply essential nutrients, vitamins and minerals to the human body and are the best resource for overcoming micronutrient deficiencies. The worldwide production of vegetables has doubled over the past quarter century and the value of global trade in vegetables now exceeds that of cereals. 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). In the past two decades, the vegetable production in India has been increased 2.5 times from 58.5 mt in 1991-92 to 146.5 mt in 2010-11(Kumar *et al.*, 2011). 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 photo synthetic 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.

The consequences of the climate change badly hit the vegetable production. Under changing climatic situations

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crop failures, shortage of yields, reduction in quality and increasing pest and disease problems are common and they render the vegetable cultivation unprofitable. This ultimately questions the availability of nutrient source in human diet. South Asian summer monsoon will be delayed and become less certain and that temperature increases will be most intense during the winter season (Lal *et al.*, 2001). The failure of the monsoons results in water shortages, resulting in below-average crop yields. This is particularly true of major drought-prone regions such as southern and eastern Maharashtra, northern Karnataka, Andhra Pradesh, Orissa, Gujarat, and Rajasthan. High temperatures and inadequate rainfall at the time of sowing and heavy rainfall at the time harvesting cause severe crop losses in Andhra Pradesh, Tamilnadu and Karnataka. According to Network Project on Climate Change (Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change), the maximum and minimum temperature (1960-2003) analysis for northwest region of India showed that the minimum temperature is increasing at annual, *kharif* and *rabi* season time scales. The rate of increase of minimum temperature during *rabi* is much higher than during *kharif*. The maximum temperature showed increasing in annual, *kharif* and *rabi* time scales but very sharp rise was observed from the year 2000 onwards and significant negative rainfall trends were observed in the Eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of NW and NE India and also a small pocket in Tamil Nadu (http://www.crida.in/Climate%20change/network.htm).

Despite of having a direct effect on rainfed vegetable cultivation, climate change affects water storage and availability of water for irrigation. Since availability of water is limited, drought will become the major stress factor to vegetable production, further stressing farming systems (Verchot *et al.*, 2007). Climate change will be the most important cause of biodiversity loss over the next 100 years, which causes changes in species distributions, phenology and ecological interactions. For example, many vegetable crops like cole crops, onion and root crops are pollinated by insects as changes in insect species distribution will affect the pollination. Invasions of agricultural systems by weeds can be another problem (Vermeulen *et al.*, 2010). Climatic fluctuations are known to affect post-harvest quality of vegetables and cause severe losses and affect food safety during storage, for example by causing changes in populations of aflatoxin-producing fungi (Cotty and Jaime-Garcia, 2007). The more frequent extreme weather events under climate change may damage infrastructure, with damaging impacts on storage and distribution of vegetables (Costello *et al.*, 2009).

In addition to the physiological and biochemical changes, climate change influences the pest and disease incidence, host-pathogen interactions, distribution and ecology of insects, time of appearance, migration to new places and their overwintering capacity. Development of plant diseases depends largely on environment prevailing around the host and pathogen, and a change in the constituents may influence host susceptibility and consequently host-parasite relationship (Khan, 2012). In general, climate change has the potential to modify host physiology and resistance and to alter stages and rates of development of the pathogen (Coakley *et al.*, 1999). Neumeister (2010) reviewed that temperature, rainfall, humidity, radiation or dew can affect the growth and spread of fungi and bacteria. Other important factors influencing plant diseases are air pollution, particularly ozone and UV-B radiation as well as nutrient availability. Boonekamp (2012) summarized the effects of climate change on plant-disease interactions as follows:

1. Higher temperatures will hasten the life cycle of many pathogenic fungi, multiplying rate and consequently increasing the infection pressure.
2. Prolonged generations of diseases will be able to infect crops at a later growth stage then at present.
3. The expression of resistance genes in the host plant and the efficacy may decrease dramatically with climate change. Due to increase in number of generations or multiplication rates of pathogen, selection for more aggressive race or strain occur within pathogen population and when such selected race or strain find a host with compromised resistance, become virulent and eventually it will lead to unprecedented opportunities for disease epidemics.
4. When over a large cropping area, the genetic variation of the crop is low and a new or adapted strain is becoming dominant in the pathogen population, the effects can be dramatic.

Some important effect of various climatic factors on vegetable growth and development and incidence of pest and diseases has been summarized 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. Potato is the fourth most important and non-cereal staple food of the mankind. Potato is well known for its exact temperature and day length requirement for tuber formation as well as flowering, so it becomes the most vulnerable crop for climate change. The effect of climate change on potato production in India has previously been studied by Singh *et al.*, (2009). Potato productivity is expected to decline in all potato growing states of India (Table 2). Luck *et al.*, (2010) expected 16% decline in tuber yield of potato by 2050 for West Bengal if any special strategies are not adapted. However, they suggested planting of potato crop at a new optimal date of mid November in order to minimize the yield losses up to 8%. Increase in temperature favours the potato cultivation by prolonging the crop growing season in high altitudes and temperate regions of the world like Europe, Russia and in India, Himalayan and other mountain regions and frost prone states like Haryana and Punjab (Table 2) whereas, it disfavours the potato production by shortening the growing period in subtropical plains such as West Bengal and Bihar during winter season (Singh, 2010). Potato requires long days and low temperatures for its flowering. It makes possible the hybridization or heterosis breeding of potato in high altitudes of Himachal Pradesh. Due to increase in temperature the potato breeding area is shifting towards the further more high altitudes. Potato is very strict to its temperature requirement for tuber formation. Optimum tuber formation takes place at 20^0 C. An increase in temperature of above 21^0 C cause sharp reduction in the potato tuber yield, at 30^0 C complete inhibition of tuber formation occurs (Sekhawat, 2001). In potato high harvesting index (HI) of 0.8 is recorded at 15^0 C night temperatures of and zero at 28^0 C in Northern Indian Punjab, Haryana, Uttar Pradesh, Bihar and Northern hills. A moderate HI of 0.4-0.6 is recorded at 20^0 C night temperatures in Central Indian states like Gujarat, Chattisgarh, some parts of Maharashtra and West Bengal indicating temperature stress limiting the partitioning of photosynthates to the tubers. A low HI of 0.2 is recorded at more than 20^0 C night temperatures in South India (Pandey *et al.*, 2009; Singh, 2010). Potato tubers with high starch content are favored by the processing industry. At low temperatures starch is converted into the sugar, which causes browning due to charring of sugar while chips making there by reduces their preference by the processing industry. This ultimately results in increased post harvest losses more than the present level, which is figured as 40-50%. This is most common problem in areas where night temperatures fell below optimum during winter season (Singh, 2010).

Fruit colour is having significant importance in assessing the marketable quality of tomato. The optimum temperature for development of lycopene pigment in tomato is 25-30^0 C. Degradation of lycopene starts at above 27^0 C and it is completely destroyed at 40^0 C. Similarly high temperatures above 25^0 C affect pollination and fruit set in tomato (Kalloo *et al.*, 2001). Abnormal pollen production, abnormal development of the female reproductive tissues, hormonal imbalances and lower levels of carbohydrates and lack of pollination are responsible for the poor reproductive performance of tomatoes at high temperatures (Peet *et al.*, 1997). Lurie *et al*., (1996) reported high temperature inhibits ripening by inhibiting the accumulation of ripening related m-RNAs, thereby inhibits continuous protein synthesis including ethylene production, lycopene accumulation and cell-wall dissolution. In pepper, exposure to high temperature at post-pollination stage inhibits fruit set (Erickson and Markhart 2002). 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 (Arora *et al.*, 1987). Flynn *et al.* (2002) found high percentage (90%) seed germination of chilli at 20^0 C and complete inhibition at 10^0 C indicating that fall in minimum temperatures affect seed germination in chilli.

Table 2: Predicted impact of climate change on tuber yield productivity in major potato growing states of India under optimal management without adaptations (Singh *et al.*, 2009).

States	Change (%) from current productivity		States	Change (%) from current productivity	
	By 2020	By 2050		By 2020	By 2050
Uttar Pradesh	-1.61	9.08	Madhya Pradesh	-6.64	-20.63
West Bengal	-4.86	-16.11	Gujarat	-16.75	-55.10
Bihar	-3.01	-11.50	Maharashtra	-8.82	-35.29
Punjab & Haryana	+7.31	+3.66	Karnataka	-18.68	-45.73

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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 (Kurtar, 2010). The temperature fluctuations delay the ripening of fruits and reduce the sweetness in melons. Low moisture content in the soil effects fruit quality and development in melons and gourds (Arora *et al.*, 1987). Warm humid climate increase the vegetative growth and result in poor production of female flowers in cucurbitaceous vegetables like ash gourd, bottle gourd, pumpkin which causes low yield (Singh, 2010). High temperatures will cause enhanced abscission of flower buds, flowers and young pods and reduce pod production, mature pod size and seeds per pod. Onsets of anthesis and pod development stages are most sensitive to high night temperature. Pods larger than 3 cm do not abscise but usually abort and shrivel under high night temperatures (Konsens *et al.*, 1991). Moisture stress in the months of April and May and intense rain during flowering and fruiting stage (Jun-Jul) reduces the productivity of french bean (Singh, 2010). In okra, high temperatures cause poor germination of seed during spring summer season Flower drop in okra is recorded at high temperatures above 42^0 C (Dhankhar and Mishra, 2001), whereas flower abscission and ovule abortion in french bean occurs at temperature above 35^0 C (Prabhakara *et al.*, 2001). High temperature causes bolting in cole crops, which is not desirable when they are grown for vegetable purpose.

Climate change resulting in increased temperature could show impact on insect pest populations in several complex ways. Although some climate change effects might tend to depress insect populations, the warmer temperature in temperate climate will result in more types and higher populations of insects. Climate change also influences the ecology and biology of insect pests (Jat, 2012). Anticipated effect of climate change on some insect pests of vegetables is presented in Table 3. 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 (FAO, 2008). Contrary to it, some insects may take several years to complete their life cycle. Temperature may change gender ratios of some pest species such as thrips (Lewis, 1997) potentially affecting reproduction rates. Some insect species which 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 (Bale *et al.*, 2002).

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

Table 3: Anticipated effect of climate change on some insect pests of vegetables (Yukawa, 2008; Cannon, 2008).

Pest	Present distribution	Anticipated effect of climate change
Melon fly (*Bactrocera cucurbitae*)	South of Japanese archipelago	Invasion to Japanese archipelago
Sweet potato weevil (*Cylas fprmicarius*)	Tropical and subtropical regions of world	Invasion to temperate zones due to increase in temperature
Aphids (*Aphis gossypi; Aulacorthum solani*)	Worldwide distribution	Increase in number of generations per year resulted in more infestation due to lower developmental zero point, low thermal totals required for one generation
Fruit and Pod borer (*Helicoverpa armigera; Spodoptera litura*)	Worldwide distribution	Increase in number of generations per year resulted in more infestation
Colorado potato beetle (*Leptinotarsa decemlineata*)	North America, Southern Europe, Asia and much of Pacific ocean	Expansion in its potential northern limit by 400 km causing more potential risk to 99% potato growing areas
Diamond back moth (*Plutella xylostella*)	European origin, cosmopolitan in distribution	More frequent overwintering and increase in pest status drastically
Cabbage butter fly (Pieris *brassicae*)	Europe, NW Africa and Asia, Introduced to America and Australia	Increase in range, abundance and diversityDecrease in diversity is reported by Roy *et al.,* (2001)
Cabbage root fly (*Delia radicum*)	Europe, N. Africa, W. Asia and N. America	Populations become active a month earlier in UK with a mean temperature increase of 3^0C

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effectiveness of insect bio-control by fungi, reliability of economic threshold levels, insect diversity in ecosystems and parasitism as reviewed by Das *et al.,* (2011). A particular case study reported by Yukawa (2008) showed that *Nezara viridula*, a tropical and subtropical crop pest, is gradually moving northward in southwestern Japan, possibly due to global warming, replacing the more temperate species *Nezara antennata* (FAO, 2008). Migratory *Helicoverpa armigera* have also shown a "phenomenal increase" over the period 1969-2004, penetrating inland more frequently (Cannon, 2008). Several research workers (Awmack *et al.*, 1997; Yamamura and Kiritani, 1998) found that the activity and population of sucking pests such as aphids, whiteflies and thrips increases with increase in temperature. For instance, Fleming and Tatchell (1995) predicted that over the next 50 years, aphids will appear at least eight days earlier in the spring as measured by their presence in suction traps. These pests are the vectors of various viral diseases of vegetable crops mainly tomato, chilli, potato, egg plant, cucurbits, okra and legumes causing severe loss in yield of these crops.

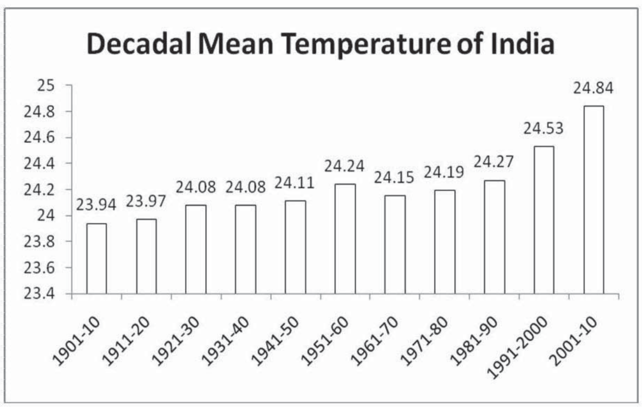

Fig 1: Decadal mean temperature (^{0}C) of India

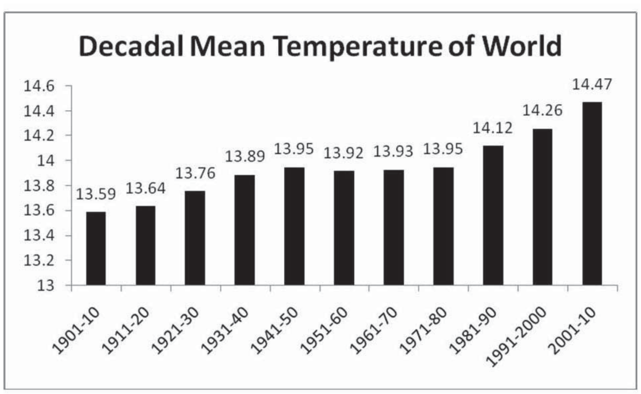

Fig 2: Decadal mean surface (land and ocean) temperature (^{0}C) of world

(Source of data: Data Portal India, 2013) (Source: WMO, 2013; Permission obtained)

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 (Termorshuizen, 2008). Higher temperatures cause faster disease cycles in air borne pathogens and increase their survival due to reduction in frost (Termorshuizen, 2008 and Boonekamp 2012). 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 (Thomas, 1989; Harrington *et al.*, 1995). Reduction in frost due to increased average minimum temperatures implies the removal of a limiting factor for pathogens such as *Fusarium* (Pautasso *et al.*, 2012).

Drought and salinity

Drought and salinity and are the most important side effects of global warming. The prevalence of drought conditions adversely affects the germination of seeds in vegetable crops like onion and okra and sprouting of tubers in potato (Arora *et al.*, 1987). Potato is highly sensitive to drought. A moderate level of water stress can also cause reductions in tuber yield (Jefferies and Mackerron, 1993). As succulent leaves are commercial products in leafy vegetables like amaranthus, palak and spinach, the drought conditions reduce their water content thereby reduces their quality (AVRDC, 1990). Drought increases the salt concentration in the soil and affects the reverse osmosis of loss of water from 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 (Pena and Hughes, 2007). Salt stress causes loss of turgor, reduction in growth, wilting, leaf abscission, decreased photosynthesis and respiration, loss of cellular integrity, tissue necrosis and finally death of the plant (Cheeseman, 1988).Onions are susceptible to saline soils, while cucumber, eggplant, pepper, and tomato are moderately sensitive to saline soils (Pena and Huges, 2007). Salinity causes a significant reduction in germination percentage, germination rate, and root and shoots length and fresh root and shoot weight in cabbage (Jamil and Rha, 2004). Salinity tends to reduce the tuber yield in potato. 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 (Bustan *et al.,* 2004). Salinity reduces dry matter production, leaf area, relative growth rate and net assimilation rate but increases leaf area ratio in chilli. The no. of fruits per plant is more affected by salinity than the individual fruit weight (Lopez *et al.*, 2011). 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 (Baysal *et al.*, 2004). 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-effected bean plants (Kaymakanov *et al.*, 2008). The high salinity levels of soil and irrigation water are known to affect many physiological and metabolic processes, leading to cell growth reduction (Gama *et al.*, 2007). Several diseases are less severe when available moisture is limited. Reduced root growth under moisture stress conditions diminishes the possible chance of infection by soil borne micro organisms as the chances of becoming contact of roots with pathogen propagules in soil will become less (Pertot *et al.*, 2012). 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 (Pautasso *et al.*, 2012).

Other stress factors

CO_2 and Relative Humidity

Due to increased anthropogenic activities, concentration of green house gases like CO_2 and CH_4 is increasing in the atmosphere day by day. They are not only responsible for global warming but also cause their own direct effect on growth and development of plants. Potato plants grown under elevated CO_2 may have larger photosynthetic rates up to some extent, later on with increase in CO_2 concentration the photosynthetic rates will come down (Burke *et al.*, 2001). The high atmospheric CO_2 content inhibits tomato fruit ripening. This inhibition is due to the suppression of the expression of ripening associated genes, which is probably related to the stress effect exerted by high CO_2 (Rothan *et al.*, 1997).

Relative humidity and CO_2 can potentially affect pest and disease occurrence (Hamilton *et al.,* 2005). Moreover, insects feed more on leaves with lower nitrogen content in order to get more nitrogen for their metabolism (Coviella and Trumble, 1999; Hunter, 2001). High atmospheric CO_2 increases food consumption by caterpillars, reproduction of aphids and decreases the nitrogen based plant defense, the beneficial effects are increased predation by predators, effect of foliar application of Bt., carbon based plant defense and decreased insect development rates as reviewed by Das *et al.* (2011). During the early season, soybeans grown in elevated CO_2 atmosphere had 57% more damage from insects than those grown in today's atmosphere and required an insecticide treatment in order to continue the experiment. It is thought that measured increases in the levels of simple sugars in the soybean leaves may have stimulated the additional insect feeding (Hamilton *et al.*, 2005). Elevated CO_2 may increase C_3 plant canopy size and density, resulting in a greater biomass with a much higher microclimate relative humidity. The slower decomposition rate due to increased bio mass as a result of elevated CO_2 will likely to increase the pathogen survival and helps in overwintering when these conditions are accomplished by warmer temperatures in winter. This is liable to promote plant diseases such as rusts, powdery mildews, leaf spots and blights (Manning and von Tiedemann 1995; Coakley *et al.*, 1999; Das *et al.*, 2011).

Precipitation washes some insects like whiteflies and thrips from fields, but high humidity due to high precipitation favors some insects like Tomato and legume pod borer *Helicoverpa armigera* and okra and egg plant leaf hopper *Amrasca biguttula biguttula.* However, high humidity also favors the fungal pathogens of insects. Increased precipitation and humid conditions obviously favor the development and survival of pathogens there by helps in increasing disease severity. Risk of pathogen infection will increase with host plants having holding high leaf wetness or having high canopy moisture content (Coakley *et al.*, 1999).

Air pollutants and UV radiation

Air pollutants such as SO_2, O_3, acid rain etc. affect the plant tissue and pathogens directly. There are considerable reports which indicate that plants show varied response to foliar pathogens under polluted air. In addition, root-attacking pathogens, such as plant nematodes may also be influenced due to host mediated effects of pollutants. Higher concentrations of SO_2 and O_3 (200-300 ppb) inhibited the germination, invasion and sporulation of plant pathogenic fungi, consequently plants developed diseases of lower severity growing in the stressed areas. However, air pollutants at lower concentrations such as 50-100 ppb may act as predisposing agent and aggravate plant diseases. SO_2 and O_3 at 50-100 ppb increased the severity of fungal and nematode diseases by stimulating spore germination and invasion of fungi and egg hatching, penetration and reproduction of plant parasitic nematodes (Khan, 2012).

The ever increasing concentration of the dioxides of nitrogen and sulfur in the atmosphere causes the degradation of ozone layer leading to the penetration of harmful UV rays on to the Earth surface. Vegetables like tomato, cabbage, potatoes and sugar beets are more susceptible to UV radiation than others (Pena and Huges, 2007). Exposure to higher level of UV-B significantly reduces dry weight, leaf area and plant height moreover, it inhibits tomato growth through reducing the photosynthetic area (Hao *et al.,* 1997). Exposing the leaves of french bean to ultra-violet light produces external effects such as glazing and bronzing and increases susceptibility to virus infection (Benda, 1955). Exposure to higher level of UV-B significantly reduces dry weight, leaf area and plant height moreover, it inhibits tomato growth through reducing the photosynthetic area (Hao *et al.,* 1997). Ultraviolet-B (UV-B) radiation negatively affects plant cell functions. Being a highly sensitive plant to UV rays, cucumber cotyledons are at real risk of exposure at early stages of germination to elevated UV radiation (Zajac and Kubis, 2010).

Case studies: *Effect of climate change on diseases of Potato and Tomato*

In potatoes, diseases like late blight, early blight, black scurf, soft rot, apical leaf curl and mosaics are more prevalent under Haryana (India) ecological conditions. During the last 10 years (2001-10) late blight was observed most destructive disease with a mean intensity of 16.5 in the state. The incidence of black scurf was observed in an increasing order. Common scab decreased from 2.8% to 0.1%. Early blight incidence ranged from 1.6 to 25.5% and was noticed to be serious in late sown conditions because relatively high temperature (20-28º C) and high RH (>80%) prevailed for longer duration. High severity of severe mosaic (11.0%) and leaf roll (10.8%) were coincided with high aphid population (98/10 compound leaves) in the month of February (Lakra, 2012), where the ETL for aphid population in potato is 20/100 leaves.

In West Bengal (India), the late blight disease intensity was found to be less than 20% in 1990-91 to 1999-2000, except in the 1994-95 seasons, but more frequent late blight epidemics have been reported throughout West Bengal in the last few years. The late blight epidemics were observed during the year 2006-07 and 2008-09. Onset of late blight is likely to be earlier in the growing season in the future decades as compared to the present decades (2011-20). The future trend is that the disease severity is likely to reduce by 5-7% from 1981-2010 periods to 2031-40 periods in the intensive potato growing areas of West Bengal (Luck *et al.,* 2010).

Potato and tomato late blight fungus *Phytophthora infestans* infects and reproduces most successfully during periods of high moisture within the temperature range between 7.2^0 C and 26.8^0 C (Wallin *et al.,* 1950). Increased nighttime and winter temperatures are contributing to the greater prevalence of tomato diseases. Wet vegetation promotes the germination of spores and the proliferation of fungi. Based on analysis of plant/disease/climate relations, late blight onset on tomatoes 1-2 weeks earlier than normal which means 2-3 additional sprays to achieve sufficient control of late blight. Accordingly, 1-3 more sprays will be applied at the incoming decades of the 2025-2100 (Fahim *et al.,* 2011).

Conclusion

Though the changes in climate is a continuous process, it has become recognizable in agricultural field from the past few years when it has started significant and lasting effect on crop production. The reasons for climate change are not completely known today, but as per the available information anthropogenic activities like industrialization and mechanization may contribute up to some extent. Effects of temperature generated by global warming on crop plants are the major among all the climate change effects. It is again responsible for other stresses like drought or moisture stress, salinity and floods and water logging in coastal areas due to melting of polar ice and increased sea levels. Among atmospheric gases CO_2 is playing major role effecting growth and development as well as pest and diseases of vegetable crops and it is the major component of green house gases, which are responsible for global warming. Therefore, it is clearly under stood that climate change will be having a larger impact on global food security in nearby future and limited availability of literature indicates that research on shifting of cropping seasons, growth and yield patterns, pest and disease scenario under changing climatic conditions in respect to vegetable crops and use of traditional knowledge (Rakshit and Bhowmik,

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2012) has been lacking, which has to be taken up as a missionary approach.

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