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Review article

VEGETABLE BREEDING-A CLIMATE RESILIENCE PERSPECTIVE

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ABSTRACT

The rising temperatures, droughts and other climatic aberrations are raising apprehension among the scientists. Global warming has become a serious threat for the food security. Vegetables are the main sources of dietary fiber, vitamins and minerals to the human. Vegetable crops are sensitive to the changes in the climate. Adapting vegetable systems to future climates requires the ability to accurately predict future climate scenarios in order to determine agricultural responses to climate change and set priorities for adaptation strategies. Screening the available germplasm for the heat tolerance, drought tolerance and salinity tolerance and using those tolerant genotypes in the breeding programmes is one of the feasible options to combat climate change. Further emphasis on the biotechnological interventions could pave the way for the successful development of durable climate resilient vegetable varieties and hybrids.

KEYWORDS: Vegetables, climate change, Elevated temperature, resilient.

INTRODUCTION:

Ward (2016) has defined vegetable as any kind of the plant life or plant product, namely “vegetable matter” in the broad sense. He further defined it in the narrow sense as the fresh edible portion of a herbaceous plant—roots, stems, leaves, flowers, or fruit. These plant parts are either eaten fresh or prepared in a number of ways. India is the second largest producer of vegetables (17.3 t/ha) after China (22.5 t/ha) (Kumar B *et al.* 2011). Vegetable crops can be classified as fruit vegetables such as tomato, cucumber, watermelon, peas; root and tuber/root vegetables such as carrot, potato, sweet potato, radish, elephant foot yam; green leafy vegetables such as Amaranthus, celery, cabbage, curry leaf and bulb vegetables such as onion and garlic (Damtew Abewoy, 2018).Vegetables are the major sources of the dietary fiber, vitamins, minerals and trace elements. The general recommendation for intake of fruits and vegetables is at least 400 grams per person per day (five serving of 80 g each day) or about 146 kg per person per year (FAO/WHO, 2003). Enhanced vegetable production globally can address the food security of developing and under developed nations to some extent. However the constraints in vegetable production have to be answered to achieve this. One such constraint which exacerbates the low vegetable yields is climate change. "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 (UNFCC, 1992).Horticulture and climate change are inextricably linked and the crop yield, biodiversity, water use and soil health are adversely affected. To address the malnutrition and food security issues, developing the climate resilient varieties and hybrids of vegetables is the need of the hour. This review focuses on the changes that occurred in climate, its future projections, impact of the climate change on vegetable crops and the mitigation strategies.

What are the changes that occurred in climate?

Increasing temperatures, declining and more unpredictable rainfall, more frequent extreme weather, droughts, increased level of CO$_2$ and higher severity of pest and disease incidence are the changes that took place in the climate gradually over decades (Parry *et al.*, 2007, Kotschi, 2007, Morton, 2007, Brown and Funk, 2008, Lobell *et al.*, 2008, Cotter and Tirado, 2008). The Industrialization era boosted up the climate change. The factors that arose due to climate change and affect crop cultivation is depicted in figure 1.With the changing climate, drought, and heat stress have become the most important limiting factors to crop productivity and ultimately the food security (Fahad *et al.*, 2007). The Intergovernmental Panel on Climate Change (IPCC) report concludes with unequivocal evidence that the air and ocean temperatures have warmed, and the concentrations of greenhouse gases have increased (IPCC, 2014). These two factors have direct influences on plant growth and crop yields (Bita and Gerats, 2013; Stocker *et al.*, 2013, Lamaoui, 2018). Average global combined temperature of land and ocean surface has increased by 0.85^0C between 1880 and 2012 (IPCC, 2014). An average increase of at least 0.2^0C per decade is projected from now onward. The reduced precipitation and changed rainfall patterns are causing the frequent onset of droughts around the world (Lobell *et al.*, 2011). Severe droughts have negative impacts on plant growth, physiology, and reproduction and thereby causing the reduction in crop yields (Yordanov *et al.*, 2000; Barnabas *et al.*, 2008). The atmospheric concentrations of the greenhouse gases carbon dioxide (CO$_2$), methane (CH4), and nitrous oxide (N$_2$O) have also risen, with net emissions approaching 300 ppm in the recent years which have become the major reason for global warming(Stocker *et al.*, 2013). Over the past 250 years a 30 and 150% rise in the concentration of the CO2 and methane has been observed (Lal, 2004; Friedlingstein *et al.*, 2010).

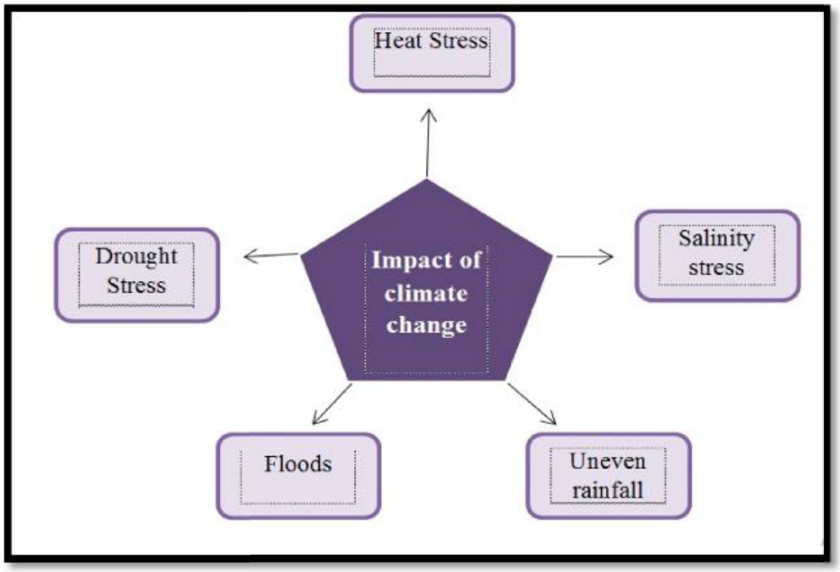

FIGURE 1: Impacts of climate change that affect crop cultivation.

Climate Change- Its Impact on Vegetable Production

The corollaries of climate change critically hit the vegetable production. 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 (Ayyogari *et al.,* 2014). The effect of light on tomatoes was higher than that of soil moisture in high-temperature environment (30°C or higher); while the speed of tomato plant growth and fruit development were improved by low light (Liming *et al.,* 2015). Indirectly, climate change affects water storage and availability of water for irrigation. Due to limited water availability, drought will become the major stress factor to vegetable production; further stressing farming systems (Verchot *et al.,* 2007). The further impacts on vegetable production are summarized below:

Temperature

J.L. Hatfield and J.H. Prueger (2015) have concluded some points in the context of effect of temperature on crop growth and productivity. 1).Temperature effects on plant growth and development is dependent upon plant species. 2).Under an increasing climate change scenario there is a greater likelihood of air temperatures exceeding the optimum range for many species. 3).Cool season species will have a constrained growing season because of the potential of average temperatures exceeding their range. 4).Exposure of plants to temperature extremes at the onset of the reproductive stage has a major impact on fruit or grain production across all species. 5).The effects of increased temperature exhibit a larger impact on grain yield than on vegetative growth because of the increased minimum temperatures. High temperature increases the rate of development in plants. A short life cycle, though less productive, can be beneficial for escaping drought and frost and late maturing cultivars could benefit from faster development rate. In colder regions, global warming could lead to longer of growth period and optimal assimilation at elevated temperatures (Naik P.S. *et al.,* 2013).

The mean daily temperatures for the tomato crop should be between 21°C and 24°C. If the crop experiences high temperature during seed germination then the number of days taken to germinate will be reduced (Sadashiva *et al.,* 2013). Elevated temperature usually lead to shorter crop duration but with small fruit size and lower yield (Rylski 1979, Sawheny and Polowick, 1985). Flowering is the most sensitive stage affected by high temperature. Elevated temperatures during vegetative stage leads to reduced flower production (Iwahori and Takahashi 1964; Iwahori 1965, 1966; Sugiyama *et al.,* 1966), reduction in pollen production, reduced ovule and pollen viability, failure of fertilization due to decreases in pollen germination, and pollen tube elongation (Iwahori, 1966; Weaver and Timm, 1989; Peet *et al.,* 1997 ; Sato *et al.,* 2000; Pressman *et al.,* 2002; Thomas and Prasad 2003), splitting of the antheridial cone, stigma, and stylar exsertion is also reported (Rudich *et al.,* 1977 ; Levy *et al.,* 1978; El Ahmadi and Stevens, 1979 a). Critical period of sensitivity to moderate high temperature (32/26°C) is 7–15 days before anthesis (Sato *et al.,* 2002). The reduction of fruit set in response to HT is mostly due to a reduction in pollen release and viability but not in pollen production (Sato *et al.,* 2006). In tomato, temperature had a considerable effect on the time of fruit maturation. The sensitivity of fruits to temperature increased in mature green fruits (Adams *et al.,* 2001). A decrease in sugar and lycopene content of cherry tomato has been reported when fruit reported when fruit temperatures were increased by approximately 1°C following fruit set through harvest under high fruit load (Gautier *et al.,* 2005). The optimum temperature for development of lycopene pigment in tomato is 25-30°C. Degradation of lycopene starts at above 27°C and it is completely destroyed at 40^0C (Ayyogari *et al.,* 2014).

The ideal night temperature for high yield of potato is between 12°C and 18°C (Pushkarnath 1976). Tuber number and size are affected by elevated temperature (Ewing 1997). It can also affect tuber quality by causing ‘heat sprouting’ which is premature growth of stolons from immature tubers (Wolfe *et al.,* 1983; Struik *et al.,* 1989) and internal necrosis (Sterrett *et al.,* 1991). In general large size tubers with high dry matter are preferred for potato processing. HT may reduce proportion of marketable and processing grade tubers for table and processing purposes (Singh B.P. *et al.* 2013).

In ripen chilli fruits HT stress causes flower drop, ovule abortion, poor fruit, fruit drop in chilli and affects red colour development (Arora *et al.,* 1987). 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). In melons the fluctuations in the temperature delays fruit ripening and reduces fruit sweetness. Low moisture content in the soil effects fruit quality and development in melons and gourds (Arora *et al.,* 1987) in cucurbitaceous vegetables like ash gourd, bottle gourd, pumpkin warm humid climate increase the vegetative growth and result in poor production of female flowers thereby leading to low yield (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°C (Dhankhar and Mishra, 2001), while in French bean flower abscission and ovule abortion occurs at temperature above 35°C (Prabhakara *et al.,* 2001). High temperature causes bolting in cole crops, which is not desirable when they are grown for vegetable purpose (Ayyogari *et al.* 2014).

Drought and Salinity

Tomato plant is sensitive to water deficits during and immediately after transplanting, at flowering stage, and during fruit development (Doorenbos and Kassam, 1979).Water deficit leads to reduction in tomato fruit size (Adams, 1990), thereby reducing the locular size and the capacity of the fruit to accumulate acids and sugars, which eventually leads to poor flavor (Stevens *et al.,* 1977). The germination of seeds in vegetable crops like onion and okra and sprouting of tubers in potato are seriously affected by drought conditions (Arora *et al.,* 1987). Reductions in tuber yield are reported when the crop experiences moderate level of water stress during growth period (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).

Salt stress may lead to loss of turgor, reduction in growth, wilting, leaf abscission, decreased photosynthesis and respiration, loss of cellular integrity, tissue necrosis and eventually 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). Reduction in germination percentage, germination rate, and root and shoots length and fresh root and shoot weight in cabbage is also reported due to salt stress (Jamil and Rha, 2004). Salinity lowers dry matter production, leaf area, relative growth rate and net assimilation rate but increases leaf area ratio in chilli. The number of fruits per plant is more affected by salinity than the individual fruit weight (Lopez *et al.,* 2011).

Impact of climate change on diseases and pests:

Boonekamp (2012) explained few impacts of climate changes on disease incidence. They are:

1. Some features of climate change will definitively affect disease phenology. Higher temperatures will speed up the life cycle of many pathogenic fungi, multiplying inoculum in a shorter time and consequently increasing the infection pressure.
2. A second effect is that prolonged generations of diseases will be able to infect crops at a later growth stage then at present.
3. Third, climate change will affect the expression of the plant resistance traits in a positive or negative way.
4. Fourth, 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.

The appearance of potato peach aphid (*Myzus persicae*) is reported to advance by 2 weeks for every 1°C rise in mean temperature, and population build-up is positively correlated with maximum temperature and minimum relative humidity (Dias *et al.,* 1980; Biswas *et al.,* 2004). Studies conducted at CIP, Peru, to work out the risk of late blight (expressed as number of sprays) at global level climate change scenario revealed that with rise in global temperature of 2°C, there will be lower risk of late blight in warmer areas (<22°C) and higher risk in cooler areas (>13°C) (Singh B.P. *et al.,* 2013). During the last 12 years (1994-2008), some new viral strains (PVY ntn, PVY nw) have been detected indicating that climate change may introduce new viral strains. As regards insects, *Bemisia tabaci* was a minor pest till recently in India. Data on population build up during the last 20 years revealed that average population of *B. tabaci* was 11 white fly/100 leaves during 1984 which rose to 24.24 in 2004. During this period, average ambient temperature increased by 1.07°C. This indicates that warming may lead to white fly infestation in Indo-Gangetic plains (Singh *et al.,* 2013).

Breeding for Climate resilience

Breeding the vegetable crops for the climate resilience is one of the cost-effective and reliable methods. First step is the screening of germplasm for biotic and abiotic stress resistance. Heat tolerant germplasm of tomato has been summarised in table 1. Screening of germplasm for heat and drought tolerance can be done in the open- field conditions or in controlled conditions. The resistant/tolerant germplasm can then be used in the breeding programmes to incorporate resistance. In tomato, drought tests show that *S. chilense* is five times more tolerant of wilting than cultivated tomato. S. pennellii has the ability to increase its water use efficiency under drought conditions unlike the cultivated *S. lycopersicum* (O'Connell *et al.,* 2007). An advanced drought-tolerant line (RF4A) has been developed at Indian Institute of Horticultural Research by interspecific hybridization with *S. pennellii.* Sources of resistance to drought have been reported in several accessions of wild taxa which includes LA0429 (*S. cheesmaniae* Ecuador), LA1401 (*S. cheesmaniae* Ecuador), LA3661 (*S. chmielewskii* Peru), LA2680 (S. *chmielewskii* Peru), LA1334 (S. *lycopersicum* var. *cerasiforme* Peru), LA1421 (S. *lycopersicum* var. *cerasiforme*), LA2133 (S. *neorickii* Ecuador), LA3657 (*S. neorickii* Peru), LA1335 (*S. pimpinellifolium* Peru), LA1416 (*S. pimpinellifolium* Ecuador), and RF4A (*S. pennellii* derived, IIHR, India) (Source: Sadashiva *et al.* 2014).

TABLE 1: List of heat tolerant tomato germplasm (Source: Sadashiva A.T. *et al.,* 2013).

Tomato	Fla. 7156, Fla. 7771, Fla. 7776, CL- 5915, CLN-1621 F, Red Cherry, Nagcarlan, Beaverlodge-6804 & 6806, *L. esculentum* var. *cerasiforme* (PI 190256), Fresh Market 9, Saladette, Processor 40, Solar Set, CLN5915-206, CLN2498D, CLN2413D, CLN2366A & CLN2123C

Conventional breeding combined with molecular marker assistance is the paramount choice for resistance breeding. Wild species the reservoirs of several resistant genes. For example, in tomato, the genes for TYLCV are derived from *L. pimpinillifolium* while insect resistance from *L. pennellii.* Drought resistance genes are found located in *L. chilense* and *L. pennellii.* Similarly, bacterial wilt which is caused by *Ralstonia solanacearum* is a major disease in many parts of Asia. The resistance source is found in Hawaii 7,996 accession. Similarly in peppers, many wild relatives have important genes for resistance against fungi and viruses in species like *Capsicum chinense* , *C. baccatum* and *C. frutescens.* Pyramiding genes and alleles is a continuous process, and this will lead to a durable resistance to the released hybrids (Aravind Kapoor, 2013). The cucurbit germplasm resistant to diseases/insect pets are summarized in table 2. Tolerance to saline conditions is a developmentally regulated, stage-specific phenomenon; tolerance at one stage of plant development does not always correlate with tolerance at other stages (Foolad, 2004).

Biotechnological Approaches

Identifying the QTL's and marker assisted breeding are some of the novel tools that aid in the development of climate resilient vegetable varieties and hybrids. In potato tubers Starch biosynthesis and dry matter accumulation were enhanced by plant transformation with glgC gene from *E. coli* encoding ADPGPP enzyme. The glgC gene has been introduced in rice also, and the yield potential of these lines is being evaluated. In tomato, florigen gene is identified for yield enhancement. A hybrid tomato plant that gives a bumper crop of sweeter tomatoes has been created by scientists, by crossbreeding from two parent plants (Aravind Kapoor, 2013). Four QTLs associated with seed germination, drought tolerance, were identified, two of which were contributed by *S. pimpinellifolium* (Foolad *et al.*, 2010). Lin *et al.*, identified random amplified polymorphic DNA (RAPD) markers linked to heat tolerance in AVRDC-The World Vegetable Center's tomato line CL5915. A follow-up study is currently underway at the Center to fully understand the genetic mechanism of heat tolerance of CL5915. Studies indicate that stress tolerance is quantitatively inherited and in some cases, tolerance is dependent on the developmental stage of the plant (Abewoy, 2018).

TABLE 2: Cucurbit germplasm resistant to diseases/ insect pests (Source: Naik P.S. *et al.* 2013)

Crop	Disease/insect pests	Resistance source	References
Cucumber	Powdery mildew	PI 197087, Poinestee, Yomaki, Sparton Salad, PI 197088, *Cucumis ficifolia*, *C. anguria*, *C. dinteri* and *C. sagittatus*, *C. ficifolia* accessions IVf 1801 and PI 280231, *C. anguria* PI 147065, *C. anguria* var. *anguria*, *C. dinteri* PI 374209, and *C. sagittatus* PI 282441	Barnes 1966, Imam and Morkes 1975,Omara 1979, Munger 1979, Lebeda 1984,Choudhary and Fageria 2002, Seshadri US 1990
Cucumber	Downy mildew	Chinese Long and Poinsette	Imam and Morkes 1975, Seshadri 1986,Lower and Edwards 1986
Cucumber	Anthracnose	PI 197087 and PI 175111	Barnes and Epps 1952, Abul-Hayja *et al.* 1978, Abul-Hayja and Peterson 1978
Cucumber	CMV	TMG-1, Tokyo Long Green, Chinese Long, Wisconsin and Table Green	Provvidenti 1985, Provvidenti and Hampton 1992
Cucumber	CGMMV	*Cucumis anguria*	Den-Nij 1982
Cucumber	WMV	Table Green and Sarinam	Takeda and Gilbert 1975 & Provvidenti 1985
Musk melon	Powdery mildew	Edisto, PMR-45 and PMR-450; Georgia-47 and C-68; Campo and PMR-6; Arka Rajhans, RM-43 and Pusa Sharbati Campo, Jacumba, Levlita, PM-5 and PMR-6, PI 164323, and PI 180283	Copeland 1957, Bohn and Whitaker 1964, Takada *et al.* 1975, Norton and Cosper 1985, Choudhury and Sivakami 1972, Khan 1973
Musk melon	Fusarium wilt	Delicious-51 and *C. melo* var. *reticulatus*, *indorus*, *chito*, and *flexuosus*	Munger 1954 and Zink *et al.* 1983
Musk melon	Gummy stem blight	Line PI 140471	Norton and Cosper 1989
Musk melon	CMV	Freeman	Karachi 1975
Musk melon	WMV	PI 414723, B 66–5 and *C. metuliferus*	Webb and Bohn 1962, Webb 1979, Provvidenti and Robinson 1977
Musk melon	Zucchini yellow mosaic virus	PI 161375	Lecoq and Pitrat 1985
Watermelon	Powdery mildew, downy mildew, and anthracnose	Arka Manik	Nath 1973
Watermelon	Anthracnose	Black Stone, Charleston Gray, and Cargo	Robinson and Shail 1981 & Suvanjrakorn and Norton 1980

CONCLUSION

Climate change and global warming are the serious threats to the nutritional food security. Vegetables are highly sensitive to the climate changes. To maintain sustainable yield even in the future generations, the climate resilient varieties and hybrids have to be developed. Conventional breeding is the age old method used to develop the resistant hybrids and varieties while MAS breeding and transgenic breeding are the emerging breeding tools. Further research in these areas could help in the rapid progress of the hybrid development. By using the crop simulation models, an idea of the impact of climate change on the vegetable production at different regions of the world can be assessed. There is an urgent need to identify the most vulnerable regions of climate change and ensure both breeding programs and seed delivery systems are able to deliver improved varieties to recover from the imminent losses under climate change within these regions.

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