Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 04, Issue: 03 (MAY-JUNE, 2024)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

Abiotic Stress in Vegetable Crops: Challenges and Strategies

(Shivali Dhiman[1], *Balbir Singh Dogra[1], Shiv Pratap Singh[1] and Anuj Sohi[2])
[1]Department of Vegetable Science, Dr Yashwant Singh Parmar University of Horticulture and Forestry, College of Horticulture and Forestry, Neri, Hamirpur, HP-177 001, India
[2]Department of Vegetable Science, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP-173 230, India
*Corresponding Author's email: dogra1970bs@gmail.com

Abiotic stress is the negative impact of environmental factors on plants. Abiotic stress such as, drought, high soil salinity, high temperature, cold, oxidative stress and heavy metal toxicity are the common adverse environmental conditions that affect and limit crop productivity worldwide (Raza *et al.*, 2022). In addition, declining water resources, deforestation and inadvertent climate change may further increase the risk of exposure of plants to abiotic stresses. Ever since the industrial revolution started i.e., approximately 200 years ago, global atmospheric CO_2 has increased from 270 to 401 ppm, whereas the average global temperature has risen by 0.85 °C. It is expected that by the end of this century, CO_2 will increase up to 700ppm, and global temperatures are projected to rise by 4 °C or more based on current greenhouse gas emission. Vegetables confer immense health benefits to humans when consumed regularly. Vegetables are an important component of human nutrition that are a rich source of fiber, protein, vitamins, antioxidants, carbohydrates and minerals. Such diverse bioactive compounds confer immunomodulation and prevention against infections and non-communicable diseases. Most of the vegetables are sensitive to environmental extremes due to succulent in nature, shallow root system and vulnerability to attack of pests and diseases. Worldwide, increasing temperatures, reduced irrigation water availability, flooding and salinity are major limiting factors for sustaining and increasing vegetable productivity. Abiotic stressors cause morphological, biochemical, physiological and molecular changes in vegetable crops, leading to a significant crop loss.

Drought stress

Water is important for all physiological processes of plants as it is a medium for transporting metabolites and nutrients. Drought is a situation that lowers plant water potential and turgor to the extent that plants face difficulties in executing normal physiological functions. Unpredictable drought is the most important factor affecting world food security and the catalyst of the great famines of the past. Drought occurs in many parts of the world every year, frequently experienced in the field grown plants under arid and semi-arid climates. Regions with adequate but nonuniform precipitation also experience water limiting environments. Vegetables consist of more than 90% water, and drought stress at any stage greatly influence vegetable productivity and quality. Drought stress causes an increase of solute concentration in the soil environment, leading to an osmotic flow of water out of 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. Soil moisture deficit at critical growth stages such as active growth, flowering and fruit enlargement greatly reduces vegetable production and product quality. Low fruit set in tomato and chili, splitting in tomato, cabbage, nitrate toxicity in root vegetables and watermelon, bitterness, and crooked fruits in cucumber, etc. are some important consequence of drought stresses.

Waterlogging or flooding stress

More erratic and uneven distribution of rainfall would cause drought and flooding as well. Vegetable production in the tropics is often limited during the rainy season due to excessive moisture brought about by heavy rain. Waterlogging is one of the most hazardous natural occurrences, which can also be called as flood, submergence, soil saturation, anoxia and hypoxia, which are generally used to describe waterlogging conditions depending upon the moisture or water level on the field. Waterlogging and flooding are common in rain-fed ecosystems, especially in soils with poor drainage (Fukao *et al*., 2019). Most vegetables are highly sensitive to flooding and genetic variation with respect to this character is limited. In general, damage to vegetables by excessive soil moisture 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. Low oxygen levels stimulate an increased production of the ethylene precursor, 1-aminocyclopropane-1-carboxylic acid (ACC) in the roots. The rapid development of epinasty growth of leaves is a characteristic response of tomato to waterlogged conditions and the role of ethylene accumulation has been implicated. 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.

Salinity stress

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+ ratio, and leads to a buildup in Na^+ and Cl^- concentrations that are detrimental to plants. Salinity fluctuates with the season, being generally high in the dry season and low during rainy season when freshwater flushing is prevalent. In hot and dry environments, high evapotranspiration results in substantial water loss, thus leaving salt around the plant roots which interferes with the plant's ability to uptake water (Machado and Serralheiro, 2017). Plant sensitivity to salt stress is reflected in the 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.

High temperature stress

High temperature affects vegetable crops in several ways. Increase in temperatures can reduce crop duration, increase plant respiration, alter photosynthesis process, affect the survival and distribution of pest population, hasten nutrient mineralization in soil, increase evapo-transpiration, etc. High temperature (HT) causes reduction in pollen formation or viability in tomatoes at temperature above 37 °C. Fruit set in tomato occurs only when night temperatures ranging between 12.8-24 °C. The typical red colour of most tomato cultivars does not develop when temperatures go above 30 °C, but yellow pigment continues to develop. Fruit cracking in tomato occurs, if high temperature (above 32 °C) is accompanied with high humidity (Aleem *et al*., 2020). Also, extreme high or low temperatures which interfere with pollination, low light, excessive nitrogen and heavy rainfall contribute to puffiness in tomatoes. Sun burning in tomato occurs, if fruits are exposed above 45 °C for 4 hours. In sweet pepper, the optimum temperature for growth ranges between 20 and 25 °C. When the temperature falls below 15 °C or exceeds 32 °C, growth is usually retarded and yield decreases. High temperature (29/23 °C D/N) reduces per cent fruit set and size significantly in sweet pepper as compared to optimum (24/18 °C D/N) temperature condition. In pepper, there is blossom drop if day temperature is 33 °C or above or night temperature remain above 26.5 °C. Hot chili does not set fruit well when night temperatures are greater than 24 °C. Moderate HT stress (32/26 °C D/N) in bell pepper, one week before anthesis remarkably reduced the pollen germination and seeds in fruits. HT increases capsaicin biosynthesis in capsicum, but floral abortion occurs when temperatures exceed 30 ºC. During ripening red colour development in capsicum is inhibited above 27 ºC. In common bean, HT stresses (35/20 °C D/N) during anthesis reduce pollen germination, pollen tube growth, fertilization, pod and seed set. In broccoli and cauliflower, temperature above 29 °C can triggered flowers too soon and causes heat injury, yellowing/ browning and loosening of head.

Low temperature stress

Low temperature (chilling / freezing) injury can occur in all plants, but the mechanisms and types of damage vary considerably. Many vegetables of tropical origin experience physiological damage when subjected to temperatures below 12 °C (well above freezing temperatures). Chilling injury is damage to plant parts caused by temperatures above the freezing point (0 °C). Frost and freeze injury are closely related. Frost damage occurs during a radiation freeze, while freeze damage occurs during an advection freeze. In both cases, ice crystals form in plant tissues, dehydrating cells and disrupting membranes. Tropical vegetables can endure temperatures below 10 °C, but above freezing for few hours without any harmful effect, if warm temperatures soon follow the low temperature exposure. In vegetables, susceptibility to cold and chilling temperature varies with species and stage of plant development; flowering and fruit development are highly susceptible. Frost sensitive crops are adversely affected by periods of low temperatures. These conditions can be associated with low night temperatures and warm days. Low temperatures can also adversely affect flowering and fruit set in crops such as beans, tomatoes and most cucurbits. Short term fluctuations in lower temperatures and the associated impact of chilling, frost, fogginess and impaired sun-shine may sometimes cause heavy loss to agriculture. Temperature range below optimum affects both photosynthesis and respiration, but rate of decrease is more for photosynthesis. Further, the rate of protein synthesis in the development of new cells is also decreased. In the upper range of optimum night temperature, vigorous vegetative growth takes place, if there is high rate of photosynthesis and normal rate of respiration during daytime. On the contrary, at lower range of night temperature, moderately vigorous vegetative growth is induced with consequent storing of more carbohydrate. This situation is ideally conceived in potato, sweet potato and yam. Thus, ideal crop growth and yield may be achieved if upper range of optimum night temperature in the early vegetative phase and lower range of the optimum night temperature in the late vegetative phase and reproductive phase of the crop are prevailed. Low temperatures reduce growth rate. In lettuce, temperatures below 13 °C sharply reduce plant growth and N uptake. In addition, many crops experience photomorphogenic changes at low temperatures. In biennials, such as onions and cole crops, exposure to too low temperatures can lead to premature flowering.

Light stress

Light intensity is the number of quanta or photon light falling on any surface. In general, 10000 lux is regarded as low light intensity, whereas; 50000 lux or more is known as high intensity. The rate of photosynthesis of plants is proportional to the intensity of light up to about 1200ft-c. Photosynthesis is negligible at about 5 lux, and the light compensation points for many crop species is about 1000 lux or 1200-foot candles. At this light intensity, the rate of net photosynthesis is zero. Optimum light intensity is the range in which rate of gross photosynthesis is high and rate of respiration is normal, resulting in higher net photosynthesis in particular crop (Table 3). Most of the vegetables, including root crops require high light intensity of 3000-8000-foot candles. Leafy vegetables can be grown in partial shading, but vegetables producing fruits requires full sunlight.

Strategies to Alleviate the Effect of Abiotic Stresses

Plants exposed to abiotic stresses produce Reactive Oxygen Species (ROS) or free radicals as a byproduct in various cellular parts, especially mitochondria and chloroplasts in association with different kinds of oxidases. These ROS are important for signaling in several growth and developmental processes and in severe abiotic stresses programmed cell death occurs. But when ROS are present in excess quantities, they cause severe damage to cellular structure and macromolecules. There are many scavenging systems comprising of antioxidants and enzymes counter these ROS and convert them into less toxic products in the cell. The acclimation of the plant to drought is indicated by the accumulation of certain new metabolites associated with the structural capabilities to improve plant functioning under drought stress (Sharma *et al*., 2019). Drought avoidance is usually achieved through morphological changes in the plant, such as reduced stomatal conductance, decreased leaf area, development of extensive root systems and increased root/shoot ratios. On the other hand, drought tolerance is achieved by cell and tissue specific physiological, biochemical and molecular mechanisms, which include specific gene expression and accumulation of specific proteins. Drought stress can be mitigated by making provision of water harvesting in micro and/ or macro catchments, supplemental irrigations at critical crop stages (flowering and fruit enlargement), minimum or zero tillage, furrow irrigated raised bed practice, drip irrigation, mulching and growing of drought tolerant/ escaped vegetable cultivars. Use of organic mulches (7.5-10 tones/ha) or plastic mulch, particularly of black polythene (25-40 microns) can reduce the water requirements of the crop by 20- 35%, and thereby drought tolerance. Growing vegetable crops on raised bed, light soils and under rain shelter structures are some measures to mitigate the effect of food or water stagnation. Grafting can provide tolerance to flooding if appropriate tolerant rootstocks are used. Grafting experiments related to waterlogging tolerance were conducted at ICAR-IIVR, Varanasi revealed that using brinjal as rootstocks (IC 111056 and IC 354557), the high yielding tomato scions (Arka Rakshak, Arka Samrat and Kashi Aman) can survive waterlogging condition 48HR during early growth stage and 96- 120HR during reproductive stage without significant reduction in yield. The detrimental effect of high temperature and light can manage through making provision of various protective structures such as shading net, green house, appropriate irrigation scheduling, development of tolerant vegetable cultivars, etc. Low temperature (frost, freeze and cold) effect may be counter by proper selection of vegetable varieties, use of hot caps and clothes, row cover, poly tunnels, plastic mulch, wind breaks or shelter belt, smokes, air mixing, frequent or sprinkler irrigation, etc.

Conclusion

In view of increasing challenges posed by abiotic factors owing to changing environmental conditions, the total production of vegetables are likely to get significant setback, which has potential to give a ruinous blow to the efforts being taken for food security. In this context, understanding various stresses by vegetable crops and devising and adopting the innovative means for their timely and effective mitigation would be a pragmatic approach in order to better equip farming communities against such impending challenges.

References

1. Raza, A., Mubarik, M.S., Sharif, R., Habib, M. and Jabeen, W. (2022). Developing drought-smart, ready-to-grow future crops. *Plant Genome*, **16**(1): 70-79.

2. Aleem, S., Sharif, I., Amin, E., Tahir, M. and Parveen, N. (2020). Heat tolerance in vegetables in the current genomic era: An overview. *Journal of Plant Growth Regulation*, **92**: 497-516.
3. Sharma, A., Shahzad, B., Kumar, V., Kohli, S.K. and Sidhu, G.P.S. (2019). Phytohormones regulate accumulation of osmolytes under abiotic stress. *Biomolecules*, **9**(7): 285.
4. Fukao, T., Barrera, F.B.E., Juntawong, P. and Pena, C.J.M. (2019). Submergence and waterlogging stress in plants: A review highlighting research opportunities and understudied aspects. *Frontiers in Plant Science*, **10**: 340.
5. Machado, R.M. and Serralheiro, R.P. (2017). Soil salinity: Effect on vegetable crop growth, management practices to prevent and mitigate soil salinization. *Journal of Horticultural Sciences*, **3**(2): 30-33.