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Drought stress in vegetable crops: A review

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Abstract
India is the second largest producer of vegetables after China with an estimated area and production of 10.35 million hectare and 191.77 million tonnes of vegetables (Indian Horticultural Database, 2019-20). Per capita consumption of vegetables in our country is very low (180g/day/person) against the amount (300g/day/person) as recommended by FAO. In recent years, frequency of drought has increased due to erratic rainfall. Drought interferes with growth, nutrient and water uptake, photosynthesis of vegetable crops (Singh and Reddy, 2011) and ultimately cause a significant reduction in yield. It is important to increase the yield of vegetable crops in order to meet the required demand. Therefore, it is necessary to understand the mechanism of drought stress tolerance of vegetable crops at different stages of crop growth to mitigate the adverse effect of drought and to improve production. The major mechanisms include decreased transpiration rate through stomatal closure and reduced size of leaves, enhanced water uptake with deep root systems. Production of low molecular weight osmolytes like glycine betaine, proline, sugar alcohol and other amino acids sustain cellular functions under drought (Sprenger *et al*., 2016). Activation of antioxidant enzymes like SOD, CAT, POD, GR which reduces the adverse effects of water deficit (Sanchez-Rodriguez *et al.* 2010). At molecular levels, several stress proteins like late embryogenesis abundant protein (LEA), osmotin, dehydrin etc. are synthesized. Plant drought tolerance can be managed by adopting strategies such as germplasm selection, use of drought tolerant rootstocks, seed priming, exogenous application of antitranspirants, osmoprotectants, plant hormones, use of silicon etc.

Keywords: Drought, vegetable, enzymes, enzymes, enzymes

Introduction
India is the second largest producer of vegetables after China with an estimated area and production of 10.35-million-hectare and 191.77 million tonnes of vegetables (Indian Horticultural Database, 2019-20). Vegetables play an important role in human nutrition, called as protective food because of they can defend against several diseases and are rich source of minerals, vitamins and fiber with high calorific values. Vegetables are sensitive to drought stress, particularly during flowering to fruit development stage. Drought interferes with growth, nutrient and water uptake, photosynthesis of vegetable crops and ultimately cause a significant reduction in yield (Singh and Reddy, 2011) [33]. Drought stress triggers drought tolerance mechanisms involving certain morphological, physiological and biochemical responses in vegetables.

Drought stress response
Morphological response
Water stresses cause modification in morphology through a wide variety of change in plant growth, leaf morphology and movement and root development and finally productivity. Increase water absorption & transportation, reduction of transpiration, developed root system and higher root shoot ratio, thick leaf, smaller leaf area, thick cuticle, developed veins and bundle, increase in number of stomata. Cell growth is considered one of the most drought sensitive processes due to the reduction in turgor pressure. Under water deficiency cell elongation can be inhibited by interruption of water flow from the xylem to the surrounding elongating cells. Drought caused impaired mitosis; cell elongation and expansion resulted in reduced growth and yield. Water stress condition reduce the leaves size and number per plant, leaf life by reducing the soil's water potential.

Physiological & biochemical response
ABA accumulation causes closure of stomata. Increase in capacity of resistance to dehydration of cytoplasm due to rapid accumulation of osmolytes, stress protein, dehydrins etc.

Increased activity of antioxidant enzyme system Chlorophyll is one of the major chloroplast apparatuses for photosynthesis activity in plants. The decrease in chlorophyll content under drought stress has been reported and it may be the result of oxidative stress and chlorophyll degradation. The active accumulation of osmolytes in the cytoplasm of plants decreases osmotic potential and maintains turgor potential. Osmolytes such as mannitol, glycine betaine, proline and trehalose etc. are accumulated under drought stress.

Table 1: Impact of drought stress on vegetable crops

Vegetable crops	Critical period	Impact of water stress
Tomato	Flowering, fruit setting & enlargement	Flower shedding, lack of fertilization, reduced fruit size, development disorders i.e., blossom end rot (BER), fruit splitting, puffiness, poor seed viability
Brinjal		Reduces yield with poor color development in fruits, poor seed viability
Chilli and Capsicum		Shedding of flowers & young fruits, reduction in dry matter production, nutrient uptake, poor seed viability
Cauliflower, cabbage	Head/curd formation & enlargement	Development of disorders like splitting of head in cabbage; browning, buttoning in cauliflower
Leafy vegetables	Throughout growth period	Toughness of leaves, poor foliage growth, accumulation of nitrates
Sweet potato	Root enlargement	Reduced root with poor yield, cracking of root
Carrot, radish and turnip		Distorted, rough, poor growth of roots, strong, pungent odor in carrot & radish, hairiness, accumulation of harmful nitrates in roots
Cucumber	Flowering, fruit setting &development	Deformed, nonviable pollen grains, bitterness, deformity in fruits, poor seed viability
Onion	Bulb formation & enlargement	Splitting, doubling of bulb, poor storage life

Source: Bahadur *et al*. (2011) [5]; Kumar *et al*. (2012) [23].

Fig 1: Splitting & cracking of carrot

Fig 2: Tip burn of lettuce

Fig 3: Blossom end of tomato

Fig 4: Hairiness in carrot

Fig 5: Tomato fruit cracking

Fig 6: Puffiness in tomato

Genetic responses

The synthesis of plant hormones like ABA, ethylene, amino acids like proline and production of stress proteins like LEA, HSPs, osmolytes like mannitol, sorbitol, quercitol, pinitol, proline, glycine betaine etc. are regulated by drought stress induced genes.

Production of stress proteins

Stress proteins are highly hydrophilic, globular proteins, accumulates in seeds during maturation and desiccation. LEA proteins participate in protecting cellular components from dehydration, protect structure of cell membrane, prevent aggregation of proteins due to water stress, protect enzymatic activities (Reyes *et al*., 2005), and prevent misfolding and denaturation of important proteins, ion sequestration etc.

Osmolyte accumulation

Osmolytes are produced in vegetables against drought stress. Proline is a scavenger of OH- radical and plays an important role in osmotic adjustment during oxidative stress. It reduces the damaging effect of ROS to the membrane lipid and protein, enzymes and DNA (Anjum *et al.* 2000) [1]. Proline has an important role to sustain root growth under water stress condition. It accumulates in root growing zone and increases the activity of enzyme such as xyloglucan endotransglycosylase (XET) and the expansions which accelerate cell elongation by loosening of cell wall.

Aquaporins

Aquaporins are water channel proteins and act by facilitating the permeation of water across membranes driven by differences in water potential (Tyerman *et al*. 2002) [40]. In plants, aquaporins are present abundantly in the plasma membrane and in the vacuolar membrane. They can regulate the hydraulic conductivity of membranes and potentiate a ten-to twenty-fold increase in water permeability

Management of drought in vegetable crops

Germplasm selection: Short-duration varieties, having an efficient root system and capacity to recoup after the alleviation of stress need to be selected. Vegetable crops like French bean, cowpea, lima bean, chilli, cluster bean, drumstick, Brinjal, and okra are suitable for rainfed cultivation.

Use of drought stress tolerant rootstocks: Use of appropriate drought tolerant root stocks, their cultivation is possible under stressed conditions to a great extent.

Table 2: Crops and Genotypes

Crops	Genotypes
Tomato	*Solanum cerasiforme, S. hirsutum, S. cheesmanii, S. chilense*
Brinjal	*Solanum microcarpon, S. gilo S. macrosperma, S. integrifolium*
Chilli	*Capsicum chinense, C. baccatum var. pendulum, C. eximium*
Okra	*Abelmoschus caillei, A. rugosus, A. tuberosus*
Onion	*Allium fistulosum, A. munzii,*
Potato	*S Solanum demissum, S. stenotomum*

Arvin and Donnelly 2008 [4]; Choudhary and Padmanabhan, 2021 [8]; Kumar *et al*. 2017 [25], Bahadur *et al,* 2015 [6], Kumar *et al*. 2015 [24].

Seed priming: Seed priming is a technique by which seeds are partially hydrated to a point where germination-related metabolic processes begin but radicle emergence does not occur. Primed seeds show increase germination rate, greater germination uniformity. KCl, KH_2PO_4, $ZnSO_4$, $MnSO_4$, ascorbic acid, succinic acid, cycocel, $MgSO_4$, NaCl etc.

Uses of anti-transpirants

Anti-transpirants are chemicals sprayed on plants to form a film which increases the diffusion resistance of water from stomata and thus reduces transpiration losses of water. Several chemicals have been successfully used like acropyl in grapes, polycot in banana and kaolinite (3-8%) in different fruit plants.

Use of osmoprotectants

Osmoprotectants help in mediating osmotic adjustment and protect subcellular structures under stressed condition. Osmolytes like Proline, trehalose, fructan, mannitol, glycine betaine can be used against stress condition.

Use of plant growth regulators

ABA and Cycocel reduces shoot growth and increase root growth. Exogenous application of gibberellic acid increased the net photosynthetic rate, stomatal conductance and transpiration rate under drought stress. Exogenously applied uniconazole, brassinolide and abscisic acid increased yields both under well-watered and water deficit conditions. Plant growth regulator treatments significantly increased water potential, and improved chlorophyll content under water stress conditions.

Use of Silicon

Silicon improves drought tolerance in plants like rice, pepper, and cucumber. Silicon also increases heat tolerance by preserving membrane strength. As drought is seldom escorted by extraordinary temperature usage of silicon can lessen the destruction of together drought and heat (Halford *et al*. 2011) [19].

Conclusion

Frequent drought is the major consequence of global climate change. Tomato is sensitive to water deficit condition during each stage of life cycle. Physiological, biochemical, molecular changes occur in plant during stress condition. Low water availability reduces metabolic process such as water and mineral absorption, rate of photosynthesis, dry matter production and yield. Oxidative damage of cellular organization occurs during drought stress by the production reactive oxygen species. Plant has specific innate anti-oxidant mechanism to mitigate the effect of water stress. Water deficit reduces plant growth and development, leading to the production of smaller organs, and hampered flower production and grain filling. One of the major factors responsible for impaired plant growth and productivity under drought stress is the production of reactive oxygen species in organelles including chloroplasts, mitochondria and peroxisomes. The reactive oxygen species target the peroxidation of cellular membrane lipids and degradation of enzyme proteins and nucleic acids. Reduction in water loss is created by increasing stomatal resistance, increasing water uptake by developing large and deep root systems, accumulation of osmolytes and osmoprotectant synthesis. Salicylic acid, cytokinin and abscisic acid have been reported to play an important role in drought tolerance. Scavenging of reactive oxygen species by enzymatic and non-enzymatic systems, cell membrane stability, expression of aquaporins and stress proteins are also vital mechanisms of drought tolerance.

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