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Breeding for Drought Tolerance in Vegetable Crops: A Review

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ABSTRACT

Drought or moisture stress is one of the most significant environmental stresses causing huge loss to the agriculture worldwide. Vegetables are more sensitive to drought as compare to many other crops. Improving yield under drought is a major goal of plant breeding. An understanding of genetic basis of drought tolerance is a pre-requisite for plant breeders to evolve superior genotype through conventional breeding methodology. Drought is often accompanied by relatively high temperatures, which promote evapotranspiration and affects photosynthetic kinetics, thus intensifying the effects of drought and further reducing crop yields. Traditionally, plant breeders have addressed the problem of environmental stress by selecting for suitability of performance over a series of environmental conditions using extensive testing and biometrical approaches. Progress requires the introduction of traits that reduce the gap between yield potential and actual yield in drought-prone environments. An attempt has been made in this review to compile the scattered information on concepts, genetics, and traditional breeding approaches of drought tolerance with suitable illustrations. A comprehensive list of genes responsible for drought and examples of species and genotypes of vegetables with drought tolerance has also been provided.

Keywords Breeding, Drought tolerance, Vegetables, Genetic basis, Yield Potential.

INTRODUCTION

Vegetables are regarded as protective foods as they are rich in minerals, vitamins and antioxidants. India is the second largest producer, producing about 169.9 MT however 42% (Indian Horticulture Database 2014) of its crops productivity is lost due to abiotic stress. Vegetable are succulent and sensitive plants. During domestication, crop plants were subjected to intense selection pressure resulting in their narrow genetic base. Abiotic stresses reduce average yield of crops upto 50%. In India also 67% of the area is rained and crops in these areas invariably experience droughts at different magnitudes. Annually about 42% of the crop productivity is lost owing to various abiotic stress factors. By 2025, 30% of crop production will be at risk due to the declining water availability. World Bank projects that the climate change will depress crop yield by 20% or more by the year 2050.

In nature, water is usually the most limiting factor for plant growth. If plants do not receive adequate rainfall or irrigation, the resulting drought stresses combined. A plant responds to lack of water by halting growth and reducing photosynthesis and other plant

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processes in order to reduce water use. As water loss progresses, leaves of some species may appear to change color usually to blue-green. Foliage begins to wilt and, if the plant is not irrigated, leaves will fall off and the plant will eventually die. Moisture stress is one of the greatest environmental factors in reducing yield in the arid and semi-arid tropics. From agricultural point of view, its working definition would be the inadequacy of water availability, including precipitation and soil moisture storage capacity, in quantity and distribution during the life cycle of a crop plant that restricts the expression of full genetic potential of the plant. The ability of a plant to produce its economic product with minimum loss under water deficit environment in relation to the water constraint-free management is referred as drought tolerance (Mitra 2001).

Drought

Crop plants are exposed to several environmental stresses, all affecting plant growth and development, which consequently hampers the productivity of crop plants (Seki *et al.* 2003, Farooq *et al.* 2009). Moisture stress is one of the greatest environmental factors in reducing yield in the arid and semi-arid tropics. From agricultural point of view, its working definition would be the inadequacy of water availability, including precipitation and soil moisture storage capacity, in quantity and distribution during the life cycle of a crop plant that restricts the expression of full genetic potential of the plant. Vegetables are the second most irrigated crops (10%), following only cereals (60%), primarily rice. However, in Serbia only 0.7% of the utilized agricultural area (1.1% of all arable fields and gardens) is actually irrigated. Drought can be described as a climatic hazard which implies the absence or very low level of rainfall for a period of time, long enough to cause moisture depletion in soil with a decline of water potential in plant tissues. Plant species adapt to this adverse condition through different ways. Some plants can (i) complete their life cycle under optimum conditions, (ii) reduce water loss by reducing leaf size or reducing stomatal pores, (iii) maintain growth even during water deficit by retaining water content, (iv) increase water use efficiency of limited available water (Bressan *et al.* 2002). In other words, drought can be described as a climatic hazard which implies the absence or very low level of rainfall for a period of time, long enough to cause moisture depletion in soil with a decline of water potential in plant tissues. Drought is often accompanied by relatively high temperatures, which promote evapotranspiration and affects photosynthetic kinetics, thus intensifying the effects of drought and further reducing crop yields (Mir *et al.* 2012). Drought stress is the major abiotic stress for many Indian states viz., Rajasthan, parts of Gujarat, Haryana and Andhra Pradesh (Mitra 2001). About two thirds of the geographic area of India receives low rainfall (less than 1000 mm), which is also characterized by uneven and erratic distributions. Out of net sown area of 140 million hectares about 68 % is reported to be vulnerable to drought conditions and about 50 % of such vulnerable area is classified as 'severe', where frequency of drought is almost regular (http://www.dsc.nrsc.gov.in/). Being succulent in nature, most of the vegetable crops are sensitive to drought stress, particularly during flowering to seed development stage. Moreover, the legume vegetables, for instance cowpea, vegetable pea, Indian beans, grown in arid and semi-arid regions are generally affected by drought at the reproductive stage. A perceptive of how the interaction of physico-chemical environment reduces plant development and yield will pave the ways for a combination of breeding methods for plant modification to improve tolerance against environmental stresses. Drought stress modifies photosynthetic rate, relative water content, leaf water potential, and stomatal conductance. Ultimately, it destabilizes the membrane structure and permeability, protein structure and function, leading to cell death (Bhardwaj and Yadav 2012).

About two thirds of the geographic area of India receives low rainfall (less than 1000 mm), which is also characterized by uneven and erratic distributions. Out of net sown area of 140 million hectares about 68 % is reported to be vulnerable to drought conditions and about 50 % of such vulnerable area is classified as 'severe', where frequency of drought is almost regular. Being succulent in nature, most of the vegetable crops are sensitive to drought stress, particularly during flowering to seed development stage. A continuous shortfall in precipitation (meteorological drought) coupled with higher evapotranspiration demand leads to agricultural drought (Mishra and Cherkauer 2010). Agricultural drought is the lack of ample moisture required for normal plant growth and development to complete the life cycle (Manivannan *et al.* 2008). Drought severely affects plant growth and development with substantial reductions in crop growth rate and biomass accumulation. The main consequences of drought in crop plants are reduced rate of cell division and expansion, leaf size, stem elongation and root proliferation, and disturbed stomatal oscillations, plant water and nutrient relations with diminished crop productivity, and water use efficiency (Li *et al.* 2009, Farooq *et al.* 2009).

Success of plant breeding program for drought tolerance depends on the usable genetic variability that may exist in the cultivated germplasm. The first step in the drought tolerance in cultivated germplasm. The wild germplasm is the second option and is used only when existing genetic variability is low since intorsions has also been found to associate with linkage drag phenomenon (Rauf and Sadaqat 2008). Higher plant economical yield is the ultimate objective of any breeding program. However, yield under irrigated and drought conditions have been differentially maximized by yield contributing traits. Therefore, improvement of yield in another environment. Furthermore, direct selection for yield is handicapped by low heritability and genetic advance. As a logic consequence, plant breeders shifted their efforts in the selection of traits related to drought tolerance.

The concept and mechanism of drought tolerance

Drought is a sustained period of time without significant rainfall. Whereas, that such rainfall deficit does not constitute drought in a crop production system until the water scarcity begins to limit the growth and development of crop plants. At genetic level, the adaptive mechanisms by which plants survive drought, collectively referred to drought tolerance-can be grouped into three categories, viz., drought escape, drought avoidance and drought tolerance (Fig. 1) (Leonardis *et al.* 2012). However, crop plants make use of more than one mechanism at a time to tolerate drought.

Drought escape: The ability of a crop plant to complete its life cycle before development of serious soil and plant water deficits is called as drought escape. This mechanism involves rapid phenological development i.e., early flowering and maturity, variation in duration of growth period depending on the extent of water scarcity. For instance, in cow pea early erect cultivars, such as ‘Ein El Gazal’ and ‘Melakh’, have performed well when the rainfall season was short but distinct due to their ability to escape late-season drought (Hall 2004).

Drought avoidance: It refers to the ability of a crop to endure periods without significant rainfall even as maintaining a high plant status at high plant water potential, i.e., dehydration postponement or drought avoidance. In other way, drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture. Improving the mechanisms of water uptake, storing in plant cell and reducing water loss confer drought avoidance. Drought avoidance mechanisms are asso-

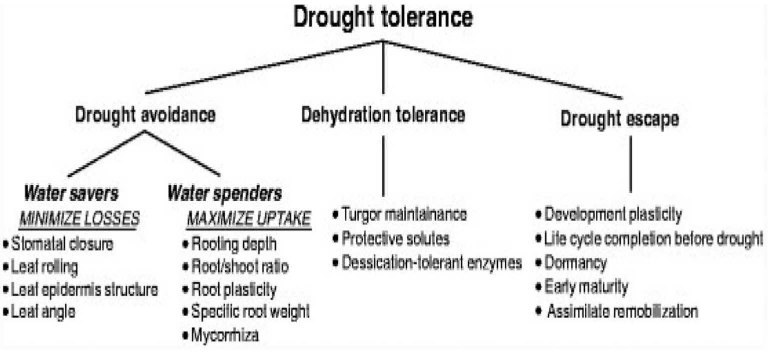

Fig. 1. Drought escape, drought avoidance and drought tolerance.

ciated with physiological whole-plant mechanisms such as canopy tolerance and leaf area reduction (which decrease radiation, adsorption and transpiration), stomatal closure and cuticular wax formation, and adjustments of sink-source relationships through altering root depth and density, root hair development and root hydraulic conductance.

Drought tolerance: The ability of a crop to endure moisture deficits at low tissue water potential or dehydration tolerance. Under drought condition, plants survive through a balancing act between maintenance of turgor with reduction of water loss. Drought tolerance mechanisms are balancing of turgor through osmotic adjustment (solute accumulation in cell), increase in elasticity in cell but decrease in cell size and desiccation tolerance by protoplasmic tolerance. In an *in-vitro* study of tomato, cv PS-10 showed low osmotic potential at all polyethylene glycol (PEG), treatments and thus it turned to be a better drought tolerant cultivar than Roma while cv Peto and Nora showed average drought tolerance (Aazami *et al.* 2010).

Table 1. Effective screening procedure for drought tolerance have been realized utilizing different procedures.

Sl. No.	Instrument technical used	Screening purpose for
1	Infrared thermometry	Efficient water uptake
2	Banding herbicide metribuzin at a certain depth of soil, and use of iodine-131 and hydroponic culture under stress of 15 bar	Root growth
3	Adaptation of psychometric procedure	Evaluation of osmotic
4	Diffusion pyrometry technique	Leaf water conductance
5	Mini-rhizotron technique	Root penetration, distribution and density in the field
6	Infrared aerial photography carbon isotope discrimination	Dehydration postponement increased water-use efficiency
7	Drought index measurement	Total yield and number of fruits
8	Visual scoring or measurement	Maturity, leaf moulding, leaf length, angle, orientation, root morphology and other morphological characters

Screening for drought tolerance

The diversity among the genotypes may serve as primary source for screening against drought stress. Drought tolerance is the interactive result of diverse morphological, physiological and biochemical traits and thus, these components could be used as strong selection criteria to screen out appropriate plant ideotype. Implications of developing an effective screening procedure for drought tolerance have been realized utilizing different procedures (Table 1). Traditionally, plant breeders have addressed the problem of environmental stress by selecting for suitability of performance over a series of environmental conditions using extensive testing and biometrical approaches. water stress, mostly at critical period of growth may Water stress, mostly at critical period of growth breeding achievements in drought tolerance variety (Table 2). Combination of different traits of direct relevance, rather than a single trait, should be used as selection criteria for drought stress. A corresponding experiment including 46 sugar beet genotypes representing different genetic backgrounds grown in drought and irrigated conditions led to similar results (Ober *et al.* 2004). Sugar beet genotypes with high yielding capacity when irrigated also tended to perform well under drought and vice versa. At seedling stage *in vitro* application of PEG is commonly used to stimulate osmotic stress effects in petridishes to control water potential in seed germination. A culture medium supplemented with PEG resulted in highest proline accumulation in tomato cv Roma (Aazami *et al.* 2010). A drought tolerant tomato line (IIHR-2274) was identified (Chavan 2007) on the basis of number of fruits under different moisture stress regime i.e., imposing drought after two weeks of transplanting to 11 genotypes with two treatments (depth of irrigation (IW)/ cumulative pan evaporation (CPE) ratio of 0.40 and 1.20) at different phenological stages viz., 45, 75 days after transplanting and at harvesting stage.

A potential source of drought stress-tolerant traits in *Phaseolus vulgaris* has been reported through interspecific hybridization with *P. acutifolius. P. acutifolius* possesses both morphological and physiological characteristics that enable it to complete well its life cycle and yield under hot arid conditions. However, progress in the development of tolerant

Table 2. Breeding achievements in drought tolerance variety.

Parentage special and features	Variety and hybrid	Crop	Breeding method
From IIHR 60 (collection from Australia)	Arka Komal (Sel 9)	French bean	
From IIHR 324 (local collection)	Arka Lohit	Chilli	
From American variety (Tip top)	Arka Vikas (Sel 22)	Tomato	Pure line selection
Hebbal Avare -3 x IIHR 99	Arka Jay	Dolichos	
Hebbal Avare-3 x Pusa early prolific	Arka Vijay		Hybridization
mutant of Puzhuthikathiri PKM 1 (rainfed cultivation) mutation	PKM 1(rainfed cultivation)	Brinjal	Mutation

lines is slow due to the lack of simple traits associated with drought tolerance. Therefore, it is important to identify the characteristic traits associated with pod setting, the number of pods reaching maturity, and the seed yield with the purpose to use as a marker to screen germplasm with drought tolerance (Omae *et al.* 2005). Trehalose played a role in drought tolerance of rhizobia/legume symbioses, particularly in common beans. Modulated plants that accumulate only small amounts of trehalose were poor drought-tolerant, whereas those accumulating higher concentrations were more tolerant to drought stress.

Approaches for drought stress resilience

To develop a drought tolerance variety, the breeding methodology to be applied is the same as for other traits improvement programs viz., bulk and pedigree method could be used for self-pollinated crops and recurrent selection for cross-pollinated crops. Conversely, if transfer of few drought tolerance traits to a high-yielding genotype is the aim, then back cross method is adopted. In contrast, biparental mating (half sib and full sib) maintains the broad genetic base in addition to provides the possibility to evolve the desired genotype of drought tolerance. Development and adaptation to drought tolerance in a plant is the result of overall expression of many traits in a specific environment. In view of the fact that many adaptative traits are effective only for certain aspects of drought tolerance and over a limited range of moisture stress, there is no single trait that plant breeders can use to improve productivity of a given crop under drought stress.

Table 3. Sources of drought stress tolerant vegetables.

Sl. No.	Vegetable crops	Drought tolerance
1	Tomato	*S. habrochaites, S. pennelli, S. Pimpinellifoloium, S. esculentum var. cerasiforme, S. hirsutum, S. cheesmanii, S. chilense, S. habrochaites, S. sitiens*
2	Brinjal	*S. microcarpon, S. gilo, S. macrosperma, S. integrifolium, S. sodomaeum (syn S. linneanum)*
3	Okra	*A. caillei, A. rugosus, A. auberosus*
4	Chilli	*C. chinense, C. baccatum var. pendulum, C. eximium*
5	Onion	*Allium fistulosum, A. munzii*
6	French bean	*P. acutifolius*
7	Water melon	*Citrullus colocynthis* (L.) *Schrad*

Traits to be improved for drought tolerant

It is necessary that the variety should have short life span (drought escape), well-developed root system, high stomatal tolerance, high water use efficiency (drought avoidance), Increased and stabilized yield during water stress period (drought tolerance).

Sources of drought stress tolerant vegetables

Potential sources of drought tolerance species and genotypes of major vegetable crops have been identified in many of the vegetable crops (Table 3).

CONCLUSION

Drought is the predominant cause of yield reduction in crop production systems, but until recently, little systematic effort has been made to breed drought tolerant cultivars. The complex nature of drought tolerance, genotypes × environment interaction, and the difficulty of effective drought screening complicate the development of drought tolerant varieties. However progress on drought tolerant variety have been made by a collaborative network of Indian breeding programs.

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