Plant Archives Vol. 19, Supplement 2, 2019 pp. 181-184 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

BREEDING FOR DROUGHT TOLERANCE IN TROPICAL VEGETABLE CROPS : A REVIEW

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Abstract

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 per cent of its crops productivity is lost due to abiotic stress. Abiotic stresses reduce average yield of crops upto 50%. Abiotic stress tolerant breeding site CRIDA, Hyderabad, India concentrates on drought, water logging and heat. In Tamil Nadu 65 per cent of the area are drought prone. Drought stress has its effect on growth, photosynthesis, nitrogen and carbohydrate metabolism, nuclear acids and protein. Genetic variability within a species is a valuable tool for screening and breeding for drought tolerance, escape and avoidance. Back cross breeding serves as the best method. However, location and year variations makes it difficult.
Keywords : Stress, abiotic stress and drought

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 per cent (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 rain-fed 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 Tamil Nadu 65 per cent of the area is drought prone.

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 processes in order to reduce water use. As water loss progresses, leaves of some species may appear to change colour 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.

Drought symptoms resemble salt stress because high concentrations of salt in the root zone cause water loss from roots due to osmotic effect. Close examination of environmental and cultural conditions should help identify the specific problem. Aside from the moisture content of the soil, environmental conditions of high light intensity, high temperature, low relative humidity and high wind speed will significantly increase plant water loss. The prior environment of a plant also can influence the development of drought stress. Also, a plant that was well-watered prior to drought will usually survive drought better than a continuously drought-stressed plant.

Stress

Stress is any change in the environmental condition that may adversely affect the plant's growth, development and adaptability (Sharma, 2012). Plant stress can be divided into two primary categories. Abiotic stress is a physical (drought, flood, salt, light, temperature and others) or chemical insult that the environment may impose on a plant. Biotic stress is a biological insult, (insects, disease, bacteria, viruses, fungi, parasites and others) to which a plant may be exposed during its lifetime.

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 (Sinha, 1986). 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).

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. 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 introgression has also been found to associate with linkage drag phenomenon (Rauf, 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 other 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.

Plant Responses to Drought

Plants under water stress show a number of physiological responses at the cellular, molecular and whole-plant levels (Raghavendra *et al*., 2010). Water logging in soil is known, not only in natural ecosystem but also in agricultural and horticultural system, as a major abiotic factor affecting the growth, development and survival of plant species (Barman *et al*., 2011). As an early response to flooding, stomata close to decrease transpiration water loss resulting in reduced net photosynthesis and stomatal conductance. In contrast, early responses of plants to drought stress help the plant to indicate by the accretion of certain new metabolites related with the structural capabilities to enhance plant implementation under drought stress (Reddy *et al*., 2004).

Mechanism of Drought Tolerance

At genetic level, the adaptive mechanisms by which plants survive drought, collectively referred to drought tolerance (Jones *et al*., 1980), can be grouped into three categories, viz. drought escape, drought avoidance and drought tolerance (Leonardis *et al*., 2012). However, crop plants make use of more than one mechanism at a time to tolerate drought (Gaff, 1980).

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.

Drought avoidance: Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite the shortage of soil moisture.

Drought tolerance: The ability of a crop to endure moisture deficits at low tissue water potential or dehydration tolerance.

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 (Blum, 1988).

Table 1 : Screening procedure for drought tolerance (Kumar *et al*., 2012)

S.No	Instruments/ techniques used	Screening for the purpose of
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.	Infrared aerial photography	Dehydration postponemen
4.	Drought index measurement	Total yield and number of fruits
5.	Visual scoring or measurement	Maturity, leaf molding, leaf length, angle, orientation, root morphology and other morphological characters
6.	Diffusion porometry technique	Leaf water conductance
7.	Mini-rhizotron technique	Root penetration, distribution and density in the field

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 2).

Table 2 : Drought tolerant species (Kumar *et al.*, 2012)

S. No.	Vegetable Crops	Drought tolerant species
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.	Chilli	*C. chinense, C. baccatum var. pendulum, C. Eximium*
4.	Okra	*A. caillei, A. rugosus, A. Tuberosus*
5.	Onion	*Allium fistulosum, A. munzii,*
6.	French bean	*P. acutifolius*
7.	Water melon	*Citrullus colocynthis (L.) Schrad.*

Breeding Methods for Drought Stress Resilience

To develop a drought tolerance variety, the breeding methodology to be applied is the same as for other traits improvement programmes *viz.*, bulk and pedigree method could be used for self-pollinated crops, recurrent selection for cross-pollinated crops and mutation breeding, back cross breeding, transgenic plants and tissue culture could be used in both self and 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. Breeding achievements in drought tolerance variety present in Table 3.

Table 3 : Breeding achievements in drought tolerance variety

Parentage & Special features	Variety/ Hybrid	Crop	Breeding method
From IIHR 60 (collection from Australia)	Arka Komal (Sel. 9)	French bean	Pure line selection
From IIHR 324 (local collection)	Arka Lohit	Chilli	
From American variety (Tip Top)	Arka Vikas (Sel. 22)	Tomato	
-	Sree Subhra	White yam	
-	VLS6, IGSP 10, IGSP 14	Sweet potato	
Field tolerance	H-97	Tapioca	Heterosis
Field tolerance	H-226		
Highly resistant to drought	Sree Sahya		
Tolerant	Varsha	Sweet potato	
T.U.V.762 x V. unguiculata sub sp. sesquipedalis	Arka Garima	Cowpea	Backcross
Hebbal Avare -3 x IIHR 99	Arka Jay	Dolichos	Hybridization
Hebbal Avare-3 x Pusa early prolific	Arka Vijay		
Mutant of Puzhuthi kathiri	PKM 1 (rainfed cultivation)	Brinjal	Mutation

Conclusions

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 x 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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