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REVIEW ARTICLE

Drought resilient breeding in vegetable crops: A Review

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Abstract

One of the most important constraint for agriculture is drought or moisture stress. Most recently global warming may be worsening this situation. Vegetables are more sensitive to drought as compare to many other crops. Improving yield under drought is a major goal of plant breeding. Responses of different genotypes to water deficit condition have been studied for a long time, and several morphological, physiological and biochemical characters have been suggested to be responsible for drought tolerance in vegetables. An attempt has been made in this review to compile the informations on concepts, genetics, various mechanisms and breeding approaches carried out by breeders in order to obtain varieties with improved drought tolerance.

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INTRODUCTION

Environmental stress is the primary cause of crop losses worldwide, reducing average yields for the major crops by more than 50 per cent (Bray *et al.*, 2000). Drought is an inevitable feature of climate that occurs in virtually all climate regimes. 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). 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 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). Being succulent in nature, most of the vegetable crops are sensitive to drought stress, particularly during flowering to seed development stage. 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).

Several physiological and biochemical processes essential for plant growth and development are significantly affected by drought stress, and plant develops various defense mechanisms against moisture stress at the molecular, cellular and whole plant levels. Detailed reviews on drought tolerance, mechanism of drought tolerance and approaches for drought tolerance was previously discussed by various researchers (Kumar *et al.,* 2008; Bahadur *et al.,* 2011 and Kumar *et al.,* 2012).

Mechanism of drought tolerance

Several mechanisms have been adopted by drought tolerant plants to adapt water stress including reduction in water loss by increasing stomatal resistance, increase of water uptake by developing large and deep root systems and accumulation of osmolytes. The osmolytes accumulated include amino acids such as proline, glutamate, glycine-betaine and sugars (mannitol, sorbitol and trehalose). These compounds play a key role in preventing membrane disintegration and enzyme inactivation in the low water activity environment. The identification of suitable plant characters for screening large numbers of genotypes in a short time at critical stages of crop growth, with the aim of selecting drought tolerant cultivars, remains a major challenge to the plant breeder.

Physiological parameters

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).

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*:** 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 associated 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 (Beard and Sifers 1997; Rivero *et al.* 2007).

***Drought tolerance*:** The ability of a crop to endure moisture deficits at low tissue water potential or dehydration tolerance (Levitt, 1972). 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 (Ugherughe, 1986).

Most of drought adaptations have disadvantages as the genotypes of short duration are less productive compared to that of normal duration. The drought tolerance mechanisms conferred by reducing water loss (such as stomatal closure and reduced leaf area) usually result in reduction of assimilation of carbon dioxide (Mitra, 2001). Drought tolerance can be increased through osmotic adjustment by maintaining plant turgor, but the increased solute concentration responsible for osmotic adjustment may have detrimental effect in addition to energy requirement for osmotic regulation (Turner, 1979). Therefore, crop adaptations to drought may be established through a balance between escape, avoidance and tolerance while maintaining adequate productivity.

Genetic mechanism for drought tolerance

An understanding of genetic basis of drought tolerance in vegetables is a pre-requisite for breeders to evolve superior genotype by adopting conventional breeding methodology. The identification, inheritance and action of genes responsible for morphological and physiological traits in some crops have been reported. Root characters are inherited polygenically (Ekanayake *et al.*, 1985) where the dominant alleles govern long and more numbers of roots while, thick root tip is governed by recessive alleles (Gaff, 1980). In cowpea, drought tolerance is reported to be governed by a single dominant gene (Mai Kodomi *et al.*, 1999). Besides morphological and physiological changes, biochemical changes involving biosynthesis of compatible solute is another way to impart drought. Among the horticultural traits, although number of pods per plant had shown good narrow sense heritability and genetic advance under drought, yet leaf water potential appeared to be better indicator for selection criteria owning to higher heritability under drought stress in okra (Ben-Ahmad *et al.*, 2006, Naveed *et al.*, 2009). Thus, chances to find stress tolerant material in segregating populations having high heritability and genetic advance may be higher.

Sources of drought stress tolerant vegetables

Sl. No	Crops	Genotypes	References
1	Tomato	*S. habrochaites, S. esculentum* var. *cerasiforme, S. hirsutum, S. cheesmanii, S. chilense,*	Rai *et al.* (2011)
2	Brinjal	*S. microcarpon, S. gilo S. macrosperma, S. integrifolium*	Rai *et al.* (2011)

3	Chilli	*C. chinense*, *C. baccatum* var. *pendulum, C. eximium*	Singh (2010)
4	Potato	*S. acaule, S. demissum, S. stenotomum*	Arvin and Donnelly (2008)
5	Okra	*A. caillei, A. rugosus, A. tuberosus*	Charrler (1984)
6	Onion	*Allium fistulosum, A. munzii,* Arka Kalyan	Singh (2010)
7	Cucumber	INGR-98018	Rai *et al.* (2008)
8	Water melon	*Citrullus colocynthis*	Dane *et al.* (2007)
9	French bean	*P. acutifolius*	Kavar *et al.* (2011)
10	Sweet potato	VLS6, IGSP 10, IGSP 14, Sree Bhadra	Singh (2010)

Source: Kumar *et al.*, (2012)

Approaches for drought stress resilience

To develop a drought tolerant 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 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 (Yunus and Paroda, 1982). There is no single trait that plant breeders can use to improve productivity of a given crop under drought stress. Hence, alternative potential systematic approach is to pyramid a number of traits in one genotype which can be helpful for the improvement for its drought tolerance.

Traits to be improved

Some of the key traits for breeding for drought tolerance includes phenology, rapid establishment, early vigor, root density and depths, low and high temperature tolerance, $_{13}$C discrimination (a measure of the extent to which photosynthesis is maintained while stomatal conductance decreases), root conductance, osmoregulation, low stomatal conductance, leaf posture, reflectance and duration, and sugar accumulation in stems to support later growth of yield components are important traits for breeding point of view. For the development of an improved drought tolerant high yielding variety, 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), and increased and stabilized yield during water stress period (drought tolerance) (Kumar *et al.*, 2012).

Molecular approaches

Many major crops lack the ability to synthesize the special osmoprotectants that are naturally accumulated by stress-tolerant organisms. The genetic engineering of metabolic pathways for the production of osmolytes such as mannitol, fructans, trehalose, proline, or glycinebetaine, might increase resistance to drought (Ramanjulu *et al.*, 2002). The active accumulation of osmolytes in the cytoplasm of plants decreases the cell's osmotic potential and maintains cell turgor.

Isolation of stress-responsive genes

Gene isolation and cloning through molecular biology research can be based on RNA or protein expression, differential screening, differential display technique, DNA insertions such as transposon or T-DNA insertions, map based cloning and methods of random cDNA sequencing and genome sequencing. The recent upsurge in activities concerned with identifying genes with unknown functions through research on expressed sequence tags (ESTs) and sequencing of total genomes is a boon for abiotic stress-related work.

Functional genomics approach

Functional genomics is a field of molecular biology that is attempting to make use of the vast wealth of data produced by genome sequencing projects to describe genome function. This technique uses highthroughput techniques like DNA microarrays, proteomics, metabolomics and mutation analysis to describe the function and interactions of genes. The recent discovery of promoter regulatory elements, like DRE or ABRE involved in both dehydration-and low temperature induced gene expression in *Arabidopsis,* as well as the identification of transcriptional factors interacting with those promoters, are exciting developments.

Conclusion

Moisture stress is one of the greatest factors in reducing yield in the arid and semi-arid tropics. Since the period of drought stress under variable environments is unpredictable, generalization on the effects of stress on fruit yield is difficult. Research must combine the latest genomics resources including quantitative genetics, genomics along with physiological, biochemical and molecular understandings of the interactions between crop plant genotypes and the growing environment to better inform crop improvement. Efforts have been focused on the genetic analysis of drought tolerance through identification of markers/quantitative trait loci (QTL) with effects on traits related to drought tolerance. However, QTLs with effects on drought tolerance have not yet been identified in many important vegetable crops and thus, it is of utmost importance to analyze genomic regions responsible for drought stress and manipulate accordingly to develop tolerant genotypes applying modern breeding approaches such as marker assisted selection (MAS). A deeper understanding of the transcription factors regulating drought response genes, the products of the major stress responsive genes and cross-talk between different signaling components should remain an area of intense research activity in future.

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