MITIGATION OF DROUGHT STRESS IN PRODUCTION OF PULSES

P. SUBBARAMAMMA
Assistant Professor, Plant Physiology, College of Horticulture, Venkataramannagudem

M. SANGAMITRA
D. MANJUSHA
Ph D Scholars, College of Horticulture, Venkataramannagudem

ABSTRACT

Pulses are the major source of protein in Asia and constitute an important supplement to the cereal-based diet. With rise in atmospheric temperature, the biotic and abiotic stresses are predicted to become more severe and adversely affect the stability and productivity in pulse crops. The abrupt climatic change, particularly the erratic rainfall is one of the major causes for reduction of pulse production in India. Occurrence of drought during very early vegetative stage impaired the seed germination and plant stand establishment. Drought during late vegetative period (trifoliate leaf formation) is tolerable in legume plants. Moisture stress during reproductive stage is often the most critical phase reduced the yield by 43.4% by reducing cell division, cell elongation, leaf area, leaf area index, photosynthetic rate, increased the membrane damage and disturbed the activity of various enzymes. Drymater accumulation, nutrient availability, uptake, transport from root to shoot and their metabolism, nodule formation, nitrogen fixation, number of branches/plant, number of pods/plant, number of seeds/pod and seed weight were reduced drastically. Drought during flowering stage often resulted in bareness due to reduction in the flux of assimilate to the developing seeds and also due to reduction in the activity of starch synthesizing enzymes during grain filling period. The drought tolerant Mungbean variety (SML-668) had maintained the highest root to shoot ratio, thickening of the cellwall, amount of cutinization and lignification, xylem water potential (XWP), transpiration resistance (TR) and lowest leaf diffusive resistance (LDR) and canopy temperature minus air temperature (Tc–Ta), presence of waxy coating and pubescence on leaf surface, high free proline content and higher grain yield than in drought susceptible varieties. Grain legumes resist the drought by means of i) drought escape i.e. development of early maturing varieties ii) drought avoidance via efficient stomatal regulation had maintain high leaf water content during mild drought conditions and (iii) drought tolerance via osmotic adjustment which usually allows root growth to proceed under drought condition, requires less energy demand and less severely affect the productivity than drought avoidance. The phenological plasticity could be an important trait for selecting drought-resistant species (i.e., able to maintain high yield following a period of water stress). Water uptake rate of faba bean was found to be proportional to root length density at high soil water potentials, but not at water potential lower than ~25 kPa. Potassium application can moderate the adverse effects of water shortage on plant growth and help the plants to adjust to low soil water potential. Develop new germplasm lines in grain legumes to improve the WUE efficiency by regulating leaf water losses under high vapor pressure deficit and increased atmospheric CO₂ concentration. Use of Plant growth substances viz., salicylic acid, auxins, gibberrellins, cytokinin and abscisic acid, antioxidants and application of osmoprotectants to seed or growing plant can modulate the plant responses towards drought. Drought tolerance in grain legumes can be managed by adopting mass screening and breeding, marker-assisted
selection as well as genetic engineering strategies for achieving significant genetic improvement in most economically valuable legume crops.

**Key words:** Climate change, Occurrence of drought, Mitigation of drought, stomatal conductance, Osmotic regulation, Nutrients, hormones, Enzymes, Antioxidants

**Genetic engineering**

**Introduction:**

World's population is increasing at an alarming rate and is expected to reach about nine to ten billion by the end of the year 2050. The growing population will result in an additional demand for food and it will also contribute towards changing climate, which is an alarming issue to the world's food safety. The productivity of crops is predicted to depress by 10–40% by 2080–2100. It will not only put a severe strain on national economy but will also pose a formidable challenge for achieving food security at the national level. Global legume production has increased from 150 million tons in 1980’s to 300 million tons in 2000’s with an expected 40% increase in world population. So, the agricultural sector faces an immediate challenge to increase food production by 70% or even 100% by 2050. To meet the projected requirement of 29.43 million tons of pulses by 2025, the growth rate has to be accelerated to the level of 3.5 per cent.

Legumes have positive impacts on yield when grown in rotation or as cover crops with cereals; they have also been found to increase soil carbon (C) and N content, reduce the soil erosion, and also reduce the incidence of certain soil pathogens (Bagayoko et al., 2000; Sainju et al., 2005). When used as manure in conservation agriculture, legumes can enhance soil porosity and reduce bulk density (Sultani et al., 2007). Promoting legume cultivation in developing countries could therefore emerge as an effective approach in achieving the Millenium Development Goals in reducing poverty and hunger, improvement of health and maintenance of environmental sustainability (Abate et al., 2012).

Abiotic and biotic stresses negatively influence the survival, biomass production and crop yield. Due to the effect of various abiotic stresses the food productivity is decreasing, and a major concern for all nations is to minimize these losses to cope with an increasing food requirements. Of various abiotic stresses, drought stress holds an important position on the globe. So there is an urgent need to know the impact of severity of water stress on growth and development of grain legumes, implementation of approaches for mitigation and adaptation to combat adverse impacts of climate change and climate variability on Indian agriculture especially in dryland areas which account for 40% the total food production of the country. This review encompasses an overview of the current work reported on some effects and mechanisms of drought tolerance in higher plants and important management strategies to overcome the effect of drought, mainly in grain legumes.
Impact of drought on plant growth and development:
The effects of drought range from morphological to molecular levels and are evident at all phenological stages of plant growth at whatever the stage, water deficit takes place. An account of various drought stress effects and their extent is elaborated below.

Impact of drought during early vegetative phase:
The first and foremost effect of drought is impaired the germination and early seedling growth of five pea cultivars tested (Okcu et al., 2005), finally the growth and productivity of legume crops (Belayet et al., 2010). Growth is accomplished through cell division, cell enlargement and cell differentiation and involves genetic, physiological, ecological and morphological events and their complex interactions. The quality and quantity of plant growth depends on cell division, cell elongation and cell turgor pressure. Cell growth is one of the most drought-sensitive physiological processes due to reduction in turgor pressure (Taiz and Zeiger, 2006). Under severe water deficiency, cell elongation of higher plants can be inhibited by interruption of water flow from the xylem to the surrounding elongating cells (Nonami, 1998). Impaired mitosis, cell elongation and expansion can reduced the plant height, leaf area and crop growth under drought (Srivalli et al., 2003) stress. Drought-induced yield reduction has been reported in many crop species, which depends upon the severity and duration of the stress period.

Impact of drought during late vegetative phase:
Therefore, drought that happens during the later vegetative periods (e.g., trifoliate formation) was relatively more tolerable to the plants even though they might have experience retarded cell division, elongation and differentiation (Farooq et al., 2009). The plants still able to maintain their growth functions under stress because early drought may lead to immediate survival or acclimation where the plants modify their metabolic and structural capabilities mediated by altered gene expression (Chaves et al., 2002).

Impact of drought during Reproductive phase:
The reproductive stage is often the most critical phase influencing the yield of crops harvested for grains or seeds. Drought that occurred during reproductive stage (i.e., from flowering to maturity) resulted in yield reduction (43.4%) similar to the reduction observed when drought occurred throughout the growing season (42.1%) (Bhaswatee Baroowa et al., 2012). Drought usually reduces the yield in grain legumes by one or the combination of following mechanisms: (i) shortening of the duration of reproductive development, (ii) reducing branching and consequently the number of pods (Frederick et al., 1991; Frederick et al., 2001); (iii) reducing seed weight and the number of seeds per pod (Dogan et al., 2007). Drought that occurred during the early reproductive stage (i.e., flowering) were more devastating (yield reduced by 37.3%) as compared to those that occurred during the late generative stage i.e., pod filling to maturity (yield reduced by 26.89%). Drought during flowering stage has often resulted in bareness due to a reduction in the flux of assimilate to the
developing seeds below the threshold level necessary to sustain optimal growth. Similarly, reduction in the assimilate partitioning and activity of starch synthesizing enzymes (i.e., sucrose synthase, adenosine diphosphate glucose pyrophosphorylase, starch synthase and starch branching enzyme) occurred during the grain-filling period (Farooq et al., 2009). In pigeonpea, coincidence of drought stress with flowering stage reduced the seed yield by 40–55% (Nam et al., 2001).

**Impact of drought on plant water relations:**

The drought tolerant mung bean varieties (SML-668 and Pant Mung - 3) showed the highest xylem water potentials (XWP), transpiration rates (TR) and the lowest leaf diffusive resistances (LDR), canopy temperature (Tc), and canopy temperature minus air temperature difference (Tc-Ta°C) than in susceptible varieties (Naresh et al., 2013). Under drought stress, sensitive pea genotypes were more affected by a decline in relative water content (RWC) than tolerant ones (Upreti et al., 2000). Moreover, change in leaf temperature may be an important factor in controlling leaf water status under drought stress. Drought-tolerant species *viz.*, pea can maintain high water-use efficiency (WUE) by reducing the water loss (Angadi et al., 2008). However, in the events where plant growth was hindered to a greater extent, water efficiency was also reduced significantly. Water stress increases the root-shoot ratio, thickness of cell walls and the amount of cutinization and lignifications (Srivalli et al., 2003). Further, water stress decreases the leaf area index in Mungbean (Jordan and Ritichie, 2002).

**Impact of drought on plant Nutrient relations:**

The decrease in water availability under drought generally results in limited total nutrient uptake by the root, their transport to the shoot and also reduced the unloading mechanism due to reduced transpirational flow (Garg, 2003; McWilliams, 2003). In general, moisture stress induces an increase in N, a definitive decline in P and no definitive effects on K (Garg, 2003). Influence of drought on plant nutrition may also be related to limited availability of energy for assimilation of NO₃⁻/NH₄⁺, PO₄³⁻ and SO₄²⁻. At flowering and pod filling stages there is a competition between nodules and developing fruits for photosynthates and as a consequence, nitrogen fixation is drastically reduced. The legume species that exhibit relatively high N₂ fixation during drought (e.g., groundnut and faba bean) period also tend to produce higher yields during drought as compared to the species that have limited N₂ fixation during drought (e.g., green gram, black gram and cowpea) (Serraj et al., 1999). Thus the competition was compounded with cessation of root growth and impaired water uptake due to water stress would make the symbiotic plant especially sensitive to water stress.

**Impact of drought on Photosynthesis:**

Photosynthetic rate was decreased under moisture stress condition due to reduction in leaf area (Srivalli et al., 2003; Bhaswatee Baroowa et al., 2012), leaf area index (Jordan and Ritichie, 2002) by inhibiting cell division and cell elongation. Ethylene also produced under stress conditions, reduces the leaf area by enhancing
the leaf abscission (Kacperska and Kubacka-Zebalska, 1989). Carbon dioxide diffusion into mesophyll chloroplast was decreased due to closure of stomata by ABA signalling and also due to reduction in stomatal conductance (Daryanto et al., 2015) under moisture stress conditions thereby produced the reactive oxygen species, which cause damage to the thylakoid membrane and inhibit the photosynthetic activity and productivity (Athar and Ashraf, 2005). Moisture stress also down regulate the non-cyclic photophosphorylation in the plants and inhibit the photosynthetic activity through obstruction of ATP synthesis. Low tissue water potential induces the formation of inhibitors that bind to the carboxylation site of the RUBISCO, which lower the Rubisco activity, low tissue water potential also decreased the activity of NADP-ME, PPDK, PEPCase enzymes.

**Impact of drought on Assimilate flux into the developing pods:**

Drought stress frequently enhances allocation of drymatter to the roots, which can enhance water uptake and growth of the root system before flowering and pod formation stage in grain legumes. Drought stress decreases the current photosynthetic rate, and disrupts the carbohydrate metabolism and level of sucrose in leaves that spills over to a decreased export rate. This is presumably due to drought stress-induced increased activity of acid invertase (Kim et al., 2000). Limited photosynthesis and sucrose accumulation in the leaves may hamper the rate of sucrose export to the sink organs and ultimately affect the reproductive development. Drought-induced carbohydrate deprivation, enhanced the endogenous abscisic acid concentration, and impaired the ability to utilize the incoming sucrose by the reproductive sinks are potential factors contributing to flower and seed abortion in grain legumes. A reduced acid invertase activity can arrest the development of reproductive tissues due to improper phloem unloading (Goetz et al., 2001), and low supply of hexose sugars to young developing ovules inhibits the cell division in embryo and endosperm tissue resulting in weak sink activity and may ultimately leads to pod abortion.

**Impact of drought on production of Reactive oxygen species:**

Reactive oxygen species like superoxide anion radicals (O$_2^-$), hydroxyl radicals (OH$^-$), hydrogen peroxide (H$_2$O$_2$), alkoxy radicals (RO) and singlet oxygen (O$_2^1$) production is stimulated under water stress (Blokhina et al., 2003) conditions. Reactive oxygen species react with lipids, proteins, enzymes and DNA cause lipid peroxidation, degradation of structural and functional proteins, nucleic acids, enzyme inactivation consequently membrane injuries and impaired the normal cell functions (Sairam et al., 2005). Oxidatively-damaged proteins can accumulate in pea leaves subjected to moderate water stress (Moran et al., 1994).

**Drought Resistant Mechanisms:**

Drought tolerance is defined as the ability to grow, flower and display economic yield under suboptimal water supply. Drought tolerant plants can respond and adapt to and survive under drought stress by the induction of various morphological, biochemical and physiological responses.
Morphological mechanisms:

Drought tolerance in plants involves the changes at tissue, whole-plant, physiological and molecular levels. Manifestation of a single or a combination of inherent changes determines the ability of the plant to sustain itself under limited moisture supply.

Drought Escape:

Drought escape occurs when phenological development is successfully matched with the periods of available soil moisture, where the growing season is shorter and terminal drought stress predominates (Araus et al., 2002). Development of short-duration varieties in grain legumes has been found to be an effective strategy for minimizing yield loss from terminal drought, as early maturity helps the crop to avoid the period of stress.

Drought avoidance:

Drought avoidance consists of mechanisms that reduce water loss from plants, due to stomatal control of transpiration, and also to maintain water uptake through an extensive and prolific root system (Turner et al., 2001; Kavar et al., 2007). The drought tolerant mung been varieties (SML-668 and Pant Mung - 3) showed the highest xylem water potentials (XWP), transpiration rates (TR) and the lowest leaf diffusive resistances (LDR), canopy temperature (Tc), and canopy temperature minus air temperature difference (Tc-Ta0°C) than in susceptible varieties (Naresh et al., 2013). Legume plants such as common bean, cowpea, and lupin are able to maintain high leaf water content and avoid the tissue dehydration during mild drought by controlling their stomatal conductance and closure (Pinheiro et al., 2001; Cruz de Carvalho et al., 1998 Campos et al., 1999). Stomatal closure, consequently, can lead to a decrease in internal CO2 concentrations, which eventually limit the photosynthesis and shoot growth. Maintenance of turgor and plant water content by lowering epidermal conductance have been considered as an important trait in several legumes (e.g., chickpea, cowpea, common bean, pigeon pea) (Amede and Schubert, 2003); Sinclair and Ludlow (1986), while lowering of osmotic potential has been observed in other beans (e.g., common bean, faba bean and cowpea) in response to water deficit. Some legumes may use both mechanisms (e.g., common bean and cowpea) while other species (e.g., chickpea) can only use one mechanism (Amede and Schubert, 2003).

Glaucousness or waxy bloom on leaves of grain legumes helps in maintenance of high tissue water potential, and is therefore considered as a desirable trait for drought tolerance (Richards et al., 1986; Ludlow and Muchow, 1990). Glaucousness of the leaf reduced the leaf temperature by 0.5°C for 6h per day was sufficient to extend the grain filling period by more than 3 days (Farooq et al., 2009).

Leaf pubescence is a xeromorphic trait that helps to protect the leaves from excessive heat load. Hairy leaves have reduced the leaf temperatures and transpiration (Sandquist and Ehleringer, 2003).
Leaf movement in large leaves, leaf movement can provide additional protection against heating during water stress. Leaves that orient themselves away from the sun are called paraheliotropic. Leaves that gain energy by orienting themselves normal (perpendicular) to the sunlight are referred to as diaheliotropic.

Leaf wilting alter the interception of radiation by changing the leaf angle. The root characters such as biomass, length, density and depth are the main drought avoidance traits that contribute to final yield under terminal drought environments. The greater root growth normally supports larger extraction of soil moisture, this trait is of limited importance under soil conditions that restrict root growth (e.g., in dry clayed soil) (Sponchiado et al., 1989). Water uptake rate of faba bean, for example, was found to be proportional to root length density at high soil water potentials, but not at water potentials lower than −25 kPa (Shein and Pachepsky, 1995). Selection for a deep and extensive root system has been advocated to increase the productivity of food legumes under moisture-deficit conditions as it can optimize the capacity to acquire water (Subbarao et al., 1995).

**Physiological mechanisms:**

**Osmotic adjustment:**

Generally the accumulation of compatible solutes in osmotic adjustment to protect the plants from stress through different means such as contribution towards osmotic adjustment, detoxification of reactive oxygen species, stabilization of membranes, and native structures of enzymes and proteins. Osmotic adjustment allows the cell to decrease osmotic potential and, as a consequence, increases the gradient for water influx and maintenance of turgor. Improved tissue water status may be achieved through osmotic adjustment and/or changes in cell wall elasticity. This is essential for maintaining physiological activity for extended periods of drought (Kramer and Boyer, 1995). With the accumulation of solutes, which mostly consists of organic substrates (i.e., sugars (sucrose, sugar alcohols (mannitol, sorbitol) and aminoacid, proline, quartenary amine-glycine betaine, organic acids, calcium, potassium, chloride ions, etc.), the osmotic potential of the cell is lowered, which attracts water into the cell and helps in maintenance of turgor. The allocation of these organic substrates to the roots lowered their osmotic potential (e.g., common bean, faba bean and cowpea), which allows the plant roots to extract the water continuously from low soil water potentials (Subbarao et al., 2000). The osmotic adjustment also facilitates a better translocation of pre-anthesis carbohydrate partitioning during grain filling (Subbarao et al., 2000), while high turgor maintenance can leads to higher photosynthetic rate and growth (Ludlow and Muchow, 1990; Subbarao et al., 2000). Drought tolerance through osmotic adjustment has less severely impact the productivity in legumes (Tuner, 1986). Free Proline contents were more in pea cultivars (Alexieva et al., 2001) and in SML-668 Moong bean variety (Naresh et al., 2013) under drought stress. Variation in osmotic adjustment among chickpea cultivars in response to soil drought has been observed, and seed yield of chickpea was correlated with the degree of osmotic adjustment when grown under a line-source
irrigation system in the field (Moinuddin and Khannu-Chopra, 2004). Nevertheless, other studies opined that determination of leaf water status in the morning and water content in leaves in the afternoon were potentially useful for screening drought tolerance in chickpea (Pannu et al., 1993).

**Antioxidant defense mechanism:**

The enzymatic and non-enzymatic antioxidant systems are being the most efficient mechanisms against oxidative stress (Farooq et al., 2008). The enzymatic antioxidants viz., catalase, various peroxidases and peroxiredoxins, ascorbate peroxidase, dehydroascorbate reductase, monodehydroascorbate reductase and glutathione reductase are actively involved in scavenging of superoxide radicals and \( \text{H}_2\text{O}_2 \). Superoxide dismutase can scavenge the oxygen free radical superoxide into less toxic products of \( \text{O}_2 \) and \( \text{H}_2\text{O}_2 \). Carotenoids and abietane diterpene compound have the capacity to scavenge singlet oxygen and lipid peroxy-radicals, as well as to inhibit lipid peroxidation and superoxide generation under dehydrative forces (Deltoro et al., 1998). The non-enzymatic antioxidant system viz., \( \beta \)-carotenes, ascorbic acid, \( \alpha \)-tocopherol, reduced glutathione are also effectively scavenge the oxygen free radicals produced under stress conditions.

**Cell membrane stability:**

Cell membrane stability, reciprocal to cell membrane injury, is a physiological index widely used for the evaluation of drought tolerance (Premachandra et al., 1991). Tolerance to drought was evaluated as an increase in cell membrane stability under water deficit conditions is used to differentiate between cultivars and correlated well with a reduction in relative growth rate under stress (Premachandra et al., 1991). A decrease in cellular volume causes crowding and increases the viscosity of cytoplasmic components. This increases the chances of molecular interactions that can cause protein denaturation and membrane fusion. The compounds such as proline, glutamate, glycinebetaine, carnitine, mannitol, sorbitol, fructans, polyols, trehalose, sucrose and oligosaccharides (Folkert et al., 2001) can prevent the adverse molecular interactions in the cell membrane. Another possibility of ion leakage from the cell may be due to thermal induced inhibition of membrane-bound enzymes responsible for maintaining chemical gradients in the cell (Reynolds et al., 2001).

**Endogenous plant growth regulators:**

Under drought, endogenous contents of auxins, gibberellins and cytokinin usually decrease, while those of abscisic acid and ethylene contents were increased (Nilsen and Orcutte, 1996). Nevertheless, phytohormones play vital roles in drought tolerance of plants. Auxins induce new root formation by breaking root apical dominance induced by cytokinins. Experiments with indole-3-yl-acetic acid and ethylene glycol tetra-acetic acid (EGTA) suggested that calcium and auxin participate in signaling mechanisms of drought-induced proline accumulation (Sadiqov et al., 2002). The drought induced rhizogenesis was highly increased in the gibberrellic acid biosynthetic mutant \( ga5 \), suggesting that some gibberrellic acids might also participate
in this process (Vartanian et al., 1994). Increase in abscisic acid and decline in cytokinins levels favor stomatal closure and limit water loss through transpiration under water stress (Morgan, 1990). Abscisic acid alters the relative growth rates of various plant parts such as increase in the root-to-shoot dry weight ratio, inhibition of leaf area development and production of prolific and deeper roots (Sharp et al., 1994). It triggers the occurrence of a complex series of events leading to stomatal closure, which is an important water-conservation response (Turner et al., 2001). Ethylene may serve to regulate leaf performance throughout its lifespan as well as to determine the onset of natural senescence and to mediate drought-induced senescence (Young et al., 2004). Salicylic acid potentiates the generation of reactive oxygen species in photosynthetic tissues of *Arabidopsis thaliana* during osmotic stress (Borsani et al., 2001). Being cationic, polyamines can associate with anionic components of the membrane, such as phospholipids, thereby protecting the lipid bilayer from deteriorating effects of stress (Bouchereau et al., 1999).

**Molecular mechanisms:**

Various genes are induced in response to drought at the transcriptional level, and these gene products are thought to function in response to drought tolerance (Kavar et al., 2007).

**Aquaporins:**

Aquaporins have the ability to facilitate and regulate passive exchange of water across membranes. They are intrinsic membrane proteins, abundantly present in plasmamembrane and in vacuolar membranes. The structural analysis of aquaporins has revealed the general mechanism of protein-mediated membrane water transport. Aquaporins can regulate the hydraulic conductivity of membranes and potentiate a ten- to twenty-fold increase in water permeability. Aquaporins play a major role in overall root water uptake (Javot and Maurel, 2002), and play a role in cellular osmoregulation of highly compartmented root cells. Phosphorylation, Calcium and pH are important factors, modulating the aquaporin activity. The aquaporins play a specific role in controlling transcellular water transport.

**Stress proteins:**

Synthesis of a variety of transcription factors and stress proteins is exclusively implicated in drought tolerance (Taiz and Zeiger, 2006). Dehydration-responsive element-binding gene1 and dehydration-responsive element-binding gene2 are induced in response to cold and dehydration respectively. The dehydration-responsive element-binding genes are involved in the abiotic stress signaling pathway. It was possible to engineer stress tolerance in transgenic plants by manipulating the expression of dehydration-responsive element binding genes (Agarwal et al., 2006). Introduction of a novel dehydration-responsive element-binding gene transcriptional factor can effectively improved the drought tolerance ability in groundnut (Mathur et al., 2004). Drought stress causes many changes in the expression levels of late embryogenesis abundant/dehydrin-type genes and molecular
chaperones that protect the cellular proteins from denaturation (Mahajan and Tuteja, 2005).

Membrane-stabilizing proteins and late embryogenic abundant proteins are another important protein group responsible for conferring drought tolerance. These proteins increase the water binding capacity by creating a protective environment for other proteins or structures, referred to as dehydrins. They also play a major role in the sequestration of ions that are concentrated during cellular dehydration. These proteins help to protect the partner protein from degradation and proteinases that function to remove denatured and damaged proteins. In addition to their synthesis at the desiccating stage of seed, they also accumulate during periods of water deficit in vegetative tissues.

**Drought management strategies:**

Various strategies of paramount importance to accomplish this objective may entail production of appropriate plant varieties and improvement of the existing high-yielding varieties. The two most important strategies may include: (a) selection of the desired plant materials either through traditional breeding methods or through molecular and biotechnological means, including production of genetically modified or transgenic plants and (b) induction of drought tolerance in susceptible plants either through priming or through hormonal application.

**Use of Selection and breeding strategies:**

Conventional breeding has been based on empirical selection for yield (Atlin and Lafitte, 2002). It is strongly believed that understanding of a physiological and molecular basis of yield that may help to target the key traits that limit yield. Screening of the germplasm lines under natural environment for drought tolerance is difficult, but under controlled stress environments and rain-out shelters is more manageable. Considerable efforts have been targeted at the genetic analysis of secondary traits such as root system architecture, leaf water potential, osmotic adjustment and relative water content (Jongdee et al., 2002). A suitable secondary trait is: (1) genetically associated with grain yield under drought; (2) highly heritable; (3) stable and feasible to measure and (4) not associated with yield loss under ideal growing conditions (Edmeades et al., 2001). Drought tolerant species reduce the water loss either by reducing the leaf area or by restricting stomatal opening or both (Lazaridou et al., 2003; Abbate et al., 2004; Lazaridou and Koutroubas, 2004) simultaneously with with less effect on the biomass production (Lazaridou et al., 2003; Abbate et al., 2004; Lazaridou and Koutroubas, 2004).

**Molecular and functional genomics approaches:**

Many laboratory and field studies have shown that transgenic expression of some of the stress-regulated genes results in an increased tolerance to drought and other stresses. The transgenic approaches are currently the mainstream to bioengineer drought tolerance in crop plants (Bahieldina et al., 2005). However, enhanced expression of these genes is frequently associated with retarded growth and thus may
limit its practical applications. Since drought tolerance is a genetically controlled phenomenon, many quantitative trait loci for membrane stability and other functionally related phenomena genes have been characterized by using bioinformatics tools (Tripathy et al., 2000; Fu et al., 2007).

1. $\Delta^1$-pyrroline-5-carboxylate synthase a key enzyme in proline biosynthetic pathway is activated

2. The introduction of genes synthesizing Betaine aldehyde dehydrogenase, an enzyme involved in glycine betaine accumulation into non-accumulators of glycine betaine proved to be effective in increasing tolerance to various abiotic stresses (Sakamoto and Murata, 2002).

3. Myo-Inositol 6-o methyl transferase, a rate limiting enzyme in the accumulation of cyclic sugar alcohol called pinitol.

4. Glyceraldehyde-3-phosphate dehydrogenase perhaps to allow an increased carbon flow into organic solutes for osmotic adjustment

5. Trehalose is a non-reducing disaccharide of glucose that functions as a compatible solute in the stabilization of biological structures under abiotic stress (Goddijn et al., 1997). Physiological roles of trehalose include efficient stabilization of dehydrated enzymes, proteins and lipid membranes, as well as protection of biological structures under desiccation stress (Wingler, 2002) rather than regulating water potential (Lee et al., 2004). At molecular level, exogenously applied trehalose may trigger the abscisic acid-insensitive 4 gene expression but decrease sucrose induction, by providing a possible molecular mechanism for the trehalose effect on plant gene expression and growth (Ramon et al., 2007). Trehalose-accumulating organisms produce this sugar in a two-step process by the action of the enzymes trehalose-6-phosphate synthase and trehalose-6-phosphate phosphatase when exposed to stress. Improved drought tolerance has been reported in the transgenic plants by overproducing the trehalose-6-phosphate synthase in spite of minute accumulation of trehalose (Karim et al., 2007).

6. Genes encoding for Enzymes involved (S-adenosylmethionine synthase and peroxidase) in lignin biosynthesis are also controlled by osmotic stress.

7. The accumulation of sugar alcohol mannitol in response to osmotic stress appears not to be brought about by the up-regulation of genes producing enzymes involved in mannitol biosynthesis, but rather by the down regulation of genes of associated with sucrose production and mannitol degradation.

8. Genes regulated by osmotic stress that encode proteins associated with membrane transport including ATPases and water channel aquaporin proteins.

On the other hand, the identification of quantitative trait loci associated with drought tolerance is also an important tool in marker-assisted selection of desirable
plants. In a recent study, mapping of quantitative trait loci for grain yield and its components using a simple sequence repeat/expressed sequence tag marker map explain the considerable variation in chromosome 4A of wheat (Kirigwi et al., 2007). It makes clear that the combination of traditional and molecular breeding, marker-assisted selection and genetic engineering may allow a more rapid way to improve abiotic stress tolerance in crops (Chaves and Oliveira, 2004).

**Induction of Drought Resistance:**

Exogenous use of various growth regulating and other chemicals has proven worthwhile in producing drought resistance at various growth stages in a number of plants.

**Seed priming:**

Seed priming is a technique by which seeds are partially hydrated to a point where germination-related metabolic processes has begin but radicle emergence does not occur (Farooq et al., 2006). Primed seeds usually exhibit increased germination rate, greater germination uniformity, and sometimes greater total germination percentage (Kaya et al., 2006; Farooq et al., 2007). Du and Tuong (2002) noted that osmopriming with 4% KCl solution and saturated CaHPO4 solution was found to be successful in improving the seedling emergence, crop stand establishment and yield in rice under moisture stress condition. The beneficial effects of priming includes faster emergence of crop seedlings, early flowering and higher grain yield even under drought stress (Kaur et al., 2005). In sunflower, osmopriming with KNO3 and hydropriming improved the germination and stand establishment under stress conditions (Kaya et al., 2006).

**Use of plant growth regulators:**

Drought stress alone inhibited increases in length and fresh weight of the hypocotyl, while gibberrellic acid reversed this effect. In this case, gibberrellic acid partially increased the water status of the seedlings and partially sustained the protein synthesis (Taiz and Zeiger, 2006). Exogenous application of 1-aminocyclopropane-1-carboxylic acid also improves the drought tolerance by delaying senescence (Todd et al., 2004). In another study, exogenously applied uniconazole, brassinolide and abscisic acid increased soybean yields both under well-watered and water deficit conditions. Under water stress conditions, plant growth regulator treatments significantly increased the water potential, and improved the chlorophyll content (Zhang et al., 2004). Exogenously applied jasmonic acid induced the drought tolerance by increasing the betaine level in pear (Gao et al., 2004). Exogenous application of brassinolide, uniconazole and methyl jasmonate improved the drought tolerance owing to an increase in the activities of superoxide dismutase, catalase and ascorbate peroxidase, abscisic acid and total carotenoid contents (Li et al., 1998). Exogenous application of salicylic acid improved the drought tolerance by an increase in catalase activity (Horváth et al., 2007). Pretreatment of maize seeds with 0.5 mM salicylic acid for 1 day promoted the drought tolerance by increasing their polyamine content in 2-week-old maize plants (Németh et al., 2002).
Use of osmoprotectants:

Osmoprotectants (proline, trehalose, fructan, mannitol, glycinebetaine) are involved in signaling and regulating the plant responses against multiple stresses (Zhu, 2002). Ashraf and Foolad (2007) outlined three approaches to increase the concentrations of these compounds in plants grown under stress conditions to enhance their stress tolerance are: (1) use of traditional protocols of plant genetics and breeding to develop cultivars with natural abilities to produce high levels of these compounds under stress conditions, (2) engineering of genetically modified plants capable of producing sufficient amounts of these compounds in response to environmental stresses and (3) as a short-cut method, exogenous use of these osmolytes on plants to enhance their stress tolerance ability. Exogenous application of glycinebetaine has been reported to improve drought tolerance. Foliar-applied glycinebetaine improved the growth of plants subjected to water deficit by maintenance of leaf water status due to improved osmotic adjustment and enhanced photosynthesis, primarily due to a greater stomatal conductance and carboxylation efficiency of Rubisco (Sakamoto and Murata, 2002). Glycinebetaine application at vegetative stage was found to be more effective in ameliorating the adverse effects of drought (Azam et al., 2005). Glycine betaine also increased the anti-oxidative enzyme activities under water deficit (Ma et al., 2007). Exogenously applied proline enhanced the endogenous accumulation of free proline and improved the drought tolerance in petunia (Yamada et al., 2005). Exogenous application of polyamines to the stressed cells or tissues could alleviate the stress injury and promote the growth.

Use of nutrients:

Potassium plays an important role in survival of crop plants under water stress condition. Potassium application under water stress moderates the adverse effects of water shortage on plant growth (Sangakkara et al., 2000 and 2001; Singh and Kumar, 2009). Yield limiting effects of water deficit could be overcome by increasing potassium supply (Damon and Rengel, 2007). During stress conditions, reactive oxygen species (ROS) formation was induced and oxidative damage to cells was nullified by potassium application (Foyer et al., 2002). Potassium influences the water economy and crop growth through its effects on water uptake, root growth, maintenance of turgor, transpiration and stomatal regulation (Nelson, 1980). Potassium helps the plant to adjust to low water potential under drought stress (Bukhsh et al., 2012).

Exogenously applied silicon lowered the shoot to root ratio, indicating the facilitation of root growth, maintenance of a higher photosynthetic rate and stomatal conductance compared with plants grown without silicon application under drought stress (Hattori et al., 2005). Gong et al. (2005) opined that the silicon-triggered improvement in drought tolerance of wheat plants was associated with an increase in antioxidant defense, thereby alleviating oxidative stress on functional molecules of cells. Sorghum (Sorghum bicolor) plants grown in pots in presence of silicon had higher relative water content and dry matter by improving shoot water uptake (Hattori

**Conclusions:**

Pulses are the major source of protein in Asia and constitute an important supplement to the cereal-based diet. The abrupt climatic change, particularly the erratic rainfall is one of the major causes for reduction of pulse production in India. Occurrence of drought during very early vegetative stage impaired the seed germination and plant stand establishment. Drought during late vegetative period (trifoliate leaf formation) is tolerable in legume plants. Moisture stress during reproductive stage is often the most critical phase and reduced the yield by reducing the number of branches/plant, number of seeds/pod and seed weight. Drought during flowering stage has often resulted in bareness due to reduction in the flux of assimilate to the developing seeds below the threshold level necessary to sustain optimal growth. Similarly, reduction in the assimilate partitioning and activity of starch-synthesizing enzymes. Under drought stress, sensitive genotypes were more affected by a decline in relative water content (RWC), WUE, nodule formation, nitrogen fixation, nutrient assimilation, availability, uptake, transport from root to shoot and unloading mechanism than tolerant ones. Photosynthetic rate was decreased under moisture stress condition due to reduction in leaf area, leaf area index by inhibition of cell division, cell elongation and cell turgor pressure, down regulation of non-cyclic photophosphorylation reduced the ATP synthesis, production of reactive oxygen species that cause damage to the thylakoid membrane and also due to reduction in rubisco activity. Drought tolerance can be induced by various mechanisms viz, drought escape, drought avoidance through stomatal regulation and osmotic adjustment, development of antioxidant defense system, cell membrane stability, use of endogenous plant growth regulators, formation of aquaporin and stress proteins. In pulses drought stress can be effectively managed by adopting by suitable breeding methods for selection of desirable plant materials, gene mapping, cloning and development of new strains through genetic engineering, development of plant materials carrying QTL through marker assisted selection, development of plant materials carrying multiple genes through gene pyramiding, induction of drought tolerance in susceptible genotypes through seed priming with salts, osmoprotectants, use of plant growth regulators and nutrients.

**References:**


