



Full Length Article

Drought Stress in Plants: A Review on Morphological Characteristics and Pigments Composition

CHERUTH ABDUL JALEEL¹, PARAMASIVAM MANIVANNAN[†], ABDUL WAHID[‡], MUHAMMAD FAROOQ[¶], HAMEED JASIM AL-JUBURI, RAMAMURTHY SOMASUNDARAM[†] AND RAJARAM PANNEERSELVAM[†]

DMJM International (Cansult Maunsell/Aecom Ltd.), Consultant of Gardens Sector Projects, Alain Municipality and Eastern Emirates, P.O. Box 1419, Al-Ain, Abu Dhabi, United Arab Emirates

[†]*Stress Physiology Lab, Department of Botany, Annamalai University, Annamalai Nagar 608 002, Tamil Nadu, India*

[‡]*Department of Botany, University of Agriculture, Faisalabad-38040, Pakistan*

[¶]*Department of Agronomy, University of Agriculture, Faisalabad-38040, Pakistan*

¹Corresponding author's e-mail: abdul79jaleel@yahoo.co.in

ABSTRACT

Plant growth and productivity is adversely affected by nature's wrath in the form of various biotic and abiotic stress factors. Water deficit is one of the major abiotic stresses, which adversely affects crop growth and yield. These changes are mainly related to altered metabolic functions, one of those is either loss of or reduced synthesis of photosynthetic pigments. This results in declined light harvesting and generation of reducing powers, which are a source of energy for dark reactions of photosynthesis. These changes in the amounts of photosynthetic pigments are closely associated to plant biomass yield. This review describes some aspects of drought induced changes in morphological, physiological and pigments composition in higher plants.

Key Words: Morphological characters; Secondary metabolism; Pigments composition; Yield

INTRODUCTION

Stress is an altered physiological condition caused by factors that tend to disrupt the equilibrium. Strain is any physical and chemical change produced by a stress (Gaspar *et al.*, 2002). The term stress is used with various meanings, the physiological definition and appropriate term as responses in different situations. The flexibility of normal metabolism allows the response initiation to the environmental changes, which fluctuate regularly and are predictable over daily and seasonal cycles. Thus every deviation of a factor from its optimum does not necessarily result in stress. Stress being a constraint or highly unpredictable fluctuations imposed on regular metabolic patterns cause injury, disease or aberrant physiology. Plants are frequently exposed to many stresses such as drought, low temperature, salt, flooding, heat, oxidative stress and heavy metal toxicity, while growing in nature.

Drought is a meteorological term and is commonly defined as a period without significant rainfall. Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Drought stress tolerance is seen in almost all plants but its extent varies from species to species and even within species. Water deficit and salt stresses are global issues to ensure survival

of agricultural crops and sustainable food production (Jaleel *et al.*, 2007b-e; Nakayama *et al.*, 2007). Conventional plant breeding attempts have changed over to use physiological selection criteria since they are time consuming and rely on present genetic variability (Zhu, 2002). Tolerance to abiotic stresses is very complex, due to the intricate of interactions between stress factors and various molecular, biochemical and physiological phenomena affecting plant growth and development (Razmjoo *et al.*, 2008). High yield potential under drought stress is the target of crop breeding. In many cases, high yield potential can contribute to yield in moderate stress environment (Blum, 1996).

Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Desiccation is much more extensive loss of water, which can potentially lead to gross disruption of metabolism and cell structure and eventually to the cessation of enzyme catalyzed reactions (Smirnov, 1993; Jaleel *et al.*, 2007d). Drought stress is characterized by reduction of water content, diminished leaf water potential and turgor loss, closure of stomata and decrease in cell enlargement and growth (Fig. 1). Severe water stress may result in the arrest of photosynthesis, disturbance of metabolism and finally the death of plant (Jaleel *et al.*, 2008c).

Water stress inhibits cell enlargement more than cell

division. It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism and growth promoters (Jaleel *et al.*, 2008a-e; Farooq *et al.*, 2008). In plants, a better understanding of the morpho-anatomical and physiological basis of changes in water stress resistance could be used to select or create new varieties of crops to obtain a better productivity under water stress conditions (Nam *et al.*, 2001; Martinez *et al.*, 2007). The reactions of plants to water stress differ significantly at various organizational levels depending upon intensity and duration of stress as well as plant species and its stage of growth (Chaves *et al.*, 2002; Jaleel *et al.*, 2008b). Understanding plant responses to drought is of great importance and also a fundamental part for making the crops stress tolerant (Reddy *et al.*, 2004; Zhao *et al.*, 2008).

Effects of drought stress on morphological characteristics. It has been established that drought stress is a very important limiting factor at the initial phase of plant growth and establishment. It affects both elongation and expansion growth (Anjum *et al.*, 2003a; Bhatt & Srinivasa Rao, 2005; Kusaka *et al.*, 2005; Shao *et al.*, 2008). Among the crops, rice as a submerged crop, is probably more susceptible to drought stress than most other plant species (Fig. 2). In soybean, the stem length was decreased under water deficit conditions (Specht *et al.*, 2001). The plant height was reduced up to 25% in water stressed citrus seedlings (Wu *et al.*, 2008). Stem length was significantly affected under water stress in potato (Heuer & Nadler, 1995), *Abelmoschus esculentus* (Sankar *et al.*, 2007 & 08); *Vigna unguiculata* (Manivannan *et al.*, 2007a); soybean (Zhang *et al.*, 2004) and parsley (*Petroselinum crispum*) (Petropoulos *et al.*, 2008).

Water stress greatly suppresses cell expansion and cell growth due to the low turgor pressure. Osmotic regulation can enable the maintenance of cell turgor for survival or to assist plant growth under severe drought conditions in pearl millet (Shao *et al.*, 2008). The reduction in plant height was associated with a decline in the cell enlargement and more leaf senescence in *A. esculentus* under water stress (Bhatt & Srinivasa Rao, 2005). Development of optimal leaf area is important to photosynthesis and dry matter yield. Water deficit stress mostly reduced leaf growth and in turn the leaf areas in many species of plant like *Populus* (Wullschleger *et al.*, 2005), soybean (Zhang *et al.*, 2004) and many other species (Farooq *et al.*, 2009). Significant inter-specific differences between two sympatric *Populus* species were found in total number of leaves, total leaf area and total leaf biomass under drought stress (Wullschleger *et al.*, 2005). The leaf growth was more sensitive to water stress in wheat than in maize (Sacks *et al.*, 1997); *Vigna unguiculata* (Manivannan *et al.*, 2007a) and sunflower (Manivannan *et al.*, 2007b & 2008).

Production of ramified root system under drought is important to above ground dry mass and the plant species or

varieties of a species show great differences in the production of roots (e.g., rice; Fig. 3). The importance of root systems in acquiring water has long been recognized. A prolific root system can confer the advantage to support accelerated plant growth during the early crop growth stage and extract water from shallow soil layers that is otherwise easily lost by evaporation in legumes (Johansen *et al.*, 1992). The development of root system increases the water uptake and maintains requisite osmotic pressure through higher proline levels in *Phoenix dactylifera* (Djibril *et al.*, 2005). An increased root growth due to water stress was reported in sunflower (Tahir *et al.*, 2002) and *Catharanthus roseus* (Jaleel *et al.*, 2008a & c). The root dry weight was decreased under mild and severe water stress in *Populus* species (Wullschleger *et al.*, 2005). An increase in root to shoot ratio under drought conditions was related to ABA content of roots and shoots (Sharp & LeNoble, 2002; Manivannan *et al.*, 2007b). The root growth was not significantly reduced under water deficits in maize and wheat (Sacks *et al.*, 1997).

Greater plant fresh and dry weights under water limited conditions are desirable characters. A common adverse effect of water stress on crop plants is the reduction in fresh and dry biomass production (Farooq *et al.*, 2009). Plant productivity under drought stress is strongly related to the processes of dry matter partitioning and temporal biomass distribution (Kage *et al.*, 2004). Diminished biomass due to water stress was observed in almost all genotypes of sunflower (Tahir & Mehid, 2001). However, some genotypes showed better stress tolerance than the others. Mild water stress affected the shoot dry weight, while shoot dry weight was greater than root dry weight loss under severe stress in sugar beet genotypes (Mohammadian *et al.*, 2005). Reduced biomass was seen in water stressed soybean (Specht *et al.*, 2001), *Poncirus trifoliatae* seedlings (Wu *et al.*, 2008), common bean and green gram (Webber *et al.*, 2006) and *Petroselinum crispum* (Petropoulos *et al.*, 2008). A moderate stress tolerance in terms of shoot dry mass plants was noticed in rice (Lafitte *et al.*, 2007).

Yield and related traits. Fetching greater harvestable yield is the ultimate purpose of growing crops. The crop species show great differences for final harvestable yield under drought stress (Fig. 4). In early plantings of sunflower, the yield increase was associated with both an increase in grain number and in individual grain weight (Soriano *et al.*, 2002). The partitioning of dry matter to the head is critical in the process of yield determination in water stressed parsley (Petropoulos *et al.*, 2008). The effect of water deficits on the harvest index of sunflower is complex due to the interactions between the timing and intensity of the stress relative to the developmental processes that determine the components of yield (Soriano *et al.*, 2002). Exposure of sunflower plants to drought stress at bud initiation stage was more detrimental to seed and biological yield than at seed filling stage (Prabhudeva *et al.*, 1998). The yield components like grain number and grain size were

decreased under pre-anthesis drought stress treatment in wheat (Edward & Wright, 2008). In some other studies on maize, drought stress greatly reduced the grain yield, which was dependent on the level of defoliation due to water stress during early reproductive growth (Kamara *et al.*, 2003; Monneveux *et al.*, 2006). Water stress reduces seed yield in soybean usually as a result of fewer pods and seeds per unit area (Specht *et al.*, 2001).

In water stressed soybean the seed yield was far below when compared to well-watered control plants (Specht *et al.*, 2001). Water stress reduced the head diameter, 100-achene weight and yield per plant in sunflower. There was a negative correlation of head diameter with fresh root and shoot weight, while a positive one between dry shoot weight and achene yield per plant under water stress (Tahir & Mehid, 2001). Water stress for longer than 12 days at grain filling and flowering stage of sunflower (grown in sandy loam soil) was the most damaging in reducing the achene yield in sunflower (Mozaffari *et al.*, 1996; Reddy *et al.*, 2004), seed yield in common bean and green gram (Webber *et al.*, 2006), maize (Monneveux *et al.*, 2006) and *Petroselinum crispum* (Petropoulos *et al.*, 2008).

Effects of drought stress on pigment composition.

Photosynthetic pigments are important to plants mainly for harvesting light and production of reducing powers. Both the chlorophyll a and b are prone to soil drying (Farooq *et al.*, 2009). However, carotenoids have additional roles and partially help the plants to withstand adversaries of drought. A brief account of changes in chlorophylls and carotenoids in drought stressed plants is given below:

Chlorophylls. Drought stress produced changes in the ratio of chlorophyll 'a' and 'b' and carotenoids (Anjum *et al.*, 2003b; Farooq *et al.*, 2009). A reduction in chlorophyll content was reported in drought stressed cotton (Massacci *et al.*, 2008) and *Catharanthus roseus* (Jaleel *et al.*, 2008a-d). The chlorophyll content decreased to a significant level at higher water deficits in sunflower plants (Kiani *et al.*, 2008) and in *Vaccinium myrtillus* (Tahkokorpi *et al.*, 2007). The foliar photosynthetic rate of higher plants is known to decrease as the relative water content and leaf water potential decreases (Lawlor & Cornic, 2002). However, the debate continues as, whether drought mainly limits photosynthesis through stomatal closure or through metabolic impairment (Lawson *et al.*, 2003; Anjum *et al.*, 2003b). Both stomatal and non-stomatal limitation was generally accepted to be the main determinant of reduced photosynthesis under drought stress (Farooq *et al.*, 2009). The limitation of photosynthesis under drought through metabolic impairment is more complex phenomenon than stomatal limitation and mainly it is through reduced photosynthetic pigment contents in sunflower (Reddy *et al.*, 2004). Chlorophyll b content increased in two lines of okra, whereas chlorophyll a remained unaffected resulting in a significant reduction in Chl a: b ratio in both cultivars under water limiting regimes (Estill *et al.*, 1991; Ashraf *et al.*, 1994).

Fig. 1. Some important causes of growth reduction in plants under drought stress

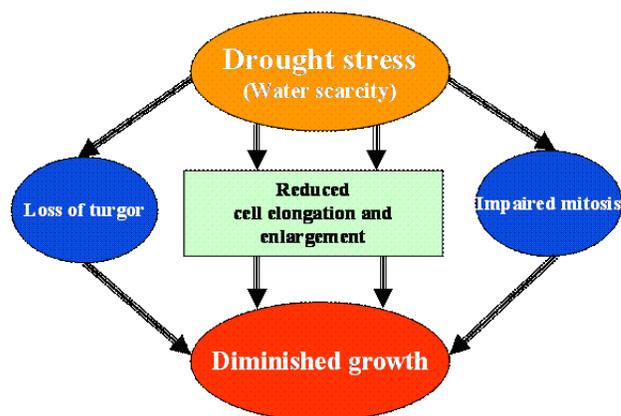


Fig. 2. Effect of drought stress on the vegetative growth of rice (cv. IR64). Both the plants were grown under well-watered conditions up to 20 days following emergence. One pot (on the right) was submitted to progressive soil drying (drought stress) for 20 days. The decrease in soil moisture was controlled by partial re-watering of the stressed pots to avoid a quicker imposition of stress and to homogenize the development of drought stress. Well-watered control pot was maintained at initial target weight by adding the daily water loss back to the pot



Carotenoids. Carotenoids are a large class of isoprenoid molecules, which are *de novo* synthesized by all photosynthetic and many non-photosynthetic organisms (Andrew *et al.*, 2008). They are divided into the hydrocarbon carotenes, such as lycopene and β -carotene or

Fig. 3. Root growth and proliferation under well-watered and drought stress conditions in various rice genotypes grown in root box. Rice genotypes, Nip, sl 13, sl 34, sl 45 and sl 50 were grown under well-watered and drought (15% soil moisture contents) stress and harvested 38 days after seeding (courtesy Ms. Mana Kano)

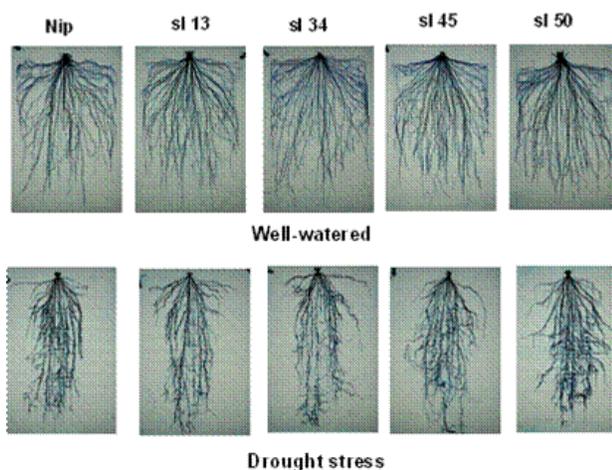
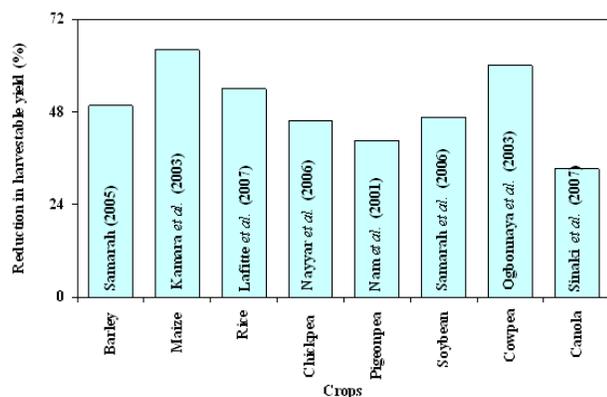


Fig. 4. Loss of harvestable yield in different crop species when the drought stress was applied at reproductive stage (as indicated in the sources mentioned in the bars)



xanthophylls, typified by lutein (Jaleel *et al.*, 2007c). Oxidative damage generated by drought stress in the plant tissue is alleviated by a concerted action of both enzymatic and non-enzymatic antioxidant systems. These include β -carotenes, ascorbate (AA), α -tocopherol (α -toc), reduced glutathione (GSH) and enzymes including superoxide dismutase (SOD), peroxidase (POD), ascorbate peroxidase (APX), catalase (CAT), polyphenol oxidase (PPO) and glutathione reductase (GR; Prochazkova *et al.*, 2001). Carotenes form a key part of the plant antioxidant defense system, but they are very susceptible to oxidative destruction. β -carotene, present in the chloroplasts of all green plants is exclusively bound to the core complexes of PSI and PSII (Havaux, 1998). Protection against damaging

effects of ROS at this site is essential for chloroplast functioning. Here β -carotene, in addition to function as an accessory pigment, acts as an effective antioxidant and plays a unique role in protecting photochemical processes and sustaining them (Havaux, 1998). A major protective role of β -carotene in photosynthetic tissue may be through direct quenching of triplet chlorophyll, which prevents the generation of singlet oxygen and protects from oxidative damage (Farooq *et al.*, 2009).

Improving pigments synthesis. Water stress, among other changes, has the ability to reduce the tissue concentrations of chlorophylls and carotenoids (Havaux, 1998; Kiani *et al.*, 2008), primarily with the production of ROS in the thylakoids (Niyogi, 1999; Reddy *et al.*, 2004). However, reports dealing with the strategies to improve the pigments contents under water stress are entirely scarce. The available reports show that exogenous application of brassinolide, uniconazole and methyl jasmonate improved the drought tolerance with increased activities of SOD, CAT and APX, ABA and total improved carotenoid contents in maize (Li *et al.*, 1998), while methyl jasmonate brought about a threefold increase in the β -carotene synthesis as well as degradation of the chlorophyll contents in the epidermal peels (Pérez *et al.*, 1993). Likewise, an important role of tocopherols, lipid-soluble antioxidant in chloroplasts, has been envisioned in improved pigments contents under stress conditions in the photosynthetic organisms including tobacco (Tanaka *et al.*, 1999) and *Arabidopsis thaliana* and *Synechocystis* sp. PCC6803 (DellaPenna & Pogson, 2006). These data warrant concerted efforts on the either the induction of pigment synthesis or modification of pigment biosynthesis pathways for enhanced drought tolerance in plants.

CONCLUSION

Drought stress affects the growth, dry matter and harvestable yield in a number of plant species, but the tolerance of any species to this menace varies remarkably. A ramified root system has been implicated in the drought tolerance and high biomass production primarily due to its ability to extract more water from soil and its transport to aboveground parts for photosynthesis. In addition to other factors, changes in photosynthetic pigments are of paramount importance to drought tolerance. Of the two photosynthetic pigments classes, carotenoids show multifarious roles in drought tolerance including light harvesting and protection from oxidative damage caused by drought. Thus, increased contents specifically of carotenoids are important for stress tolerance.

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