Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(4): 352-357
Received: 07-05-2020
Accepted: 09-06-2020

Satvir Kaur
Department of Agronomy, School of Agriculture, Lovely Professional University, Punjab, India

Prasann Kumar
(1). Department of Agronomy, School of Agriculture, Lovely Professional University, Punjab, India
(2). Division of Research and Development, Lovely Professional University, Punjab, India

Corresponding Author:
Prasann Kumar
(1). Department of Agronomy, School of Agriculture, Lovely Professional University, Punjab, India
(2). Division of Research and Development, Lovely Professional University, Punjab, India

Morpho-physiological and biochemical response of plants under drought stress

Satvir Kaur and Prasann Kumar

Abstract
The growth and development of plants are affected by various forms of biotic and abiotic stress. Drought stress is one of the most important abiotic stress, which unfavourably affected crop development and advancement. These progressions are identified with changed metabolism, may reduce growth and plant death. Due to environmental stress, production gets limited. Consistent with different scholars 90% of the global arable land is affected by drought stress. Total 20% of the global agriculture land under drought stress. Drought also reduces chlorophyll content and pigments which are necessary for photosynthesis. Water stress causes an inclusive variability of plant reactions that is extending since cellular metabolism to variations in development improvement including final yield roots and shoots. Additionally, a conception of the morphological and biochemical response to water stress is fundamental to looking at plant tolerance mechanisms for dehydration conditions. The Drought stress affects the morphological, physiological as well as biochemical response of the plant. This review paper depicts a few viewpoints which are associated with drought Induced which alters the morpho-physiological and biochemical responses of plant.

Keywords: Abiotic, biochemical, drought, stress, morphological, physiological

Introduction
Nourishment efficiency is diminishing because of impeding impacts of different biotic and abiotic stresses; in this manner constraining these misfortunes are a significant zone of concern to secure nourishment safety under evolving atmosphere. Abiotic stresses in the environment are cold, drought, heavy salinity, or high metals, extreme temperature severely hinder crop plant development and profitability around the world. Drought is the crucial environmental stress, which strictly affects plant development and advancement of plant, reduces plant yield as well as the functions of the plant, greater than some another natural factor (Shao *et al*. 2009) [1]. Plants face water stress while water gives to the roots it gets complicated or as soon as transpiration level turns out to be exceptionally excessive. Existing water resources for effective crop yield have been diminishing in latest times. Also, considering distinct climatic variation models, researchers proposed that yield reduction because of expanding water in numerous districts of the globe. A deficiency will additionally disturb its effects. Drought effects such as water relations, membrane integrity, yield, development, osmotic adjustment, photosynthetic movement and pigment content (Benjamin and Nielsen 2006; Praba *et al*. 2009) [2]. Water stress is influenced by edaphic, agronomic and climatic factors. Plant weakness under water stress in plant species, varying with stress factors, the dependence of stress degree and its formative phases (Demirevska *et al*. 2009) [3]. Season of crop plants under water shortage is the consequence of various occasions, showing versatile changes in crop development, biochemical as well as a physiological process, for example, variations in plant structure, antioxidant defences, tissue osmotic potential and development rate (Duan *et al*. 2007) [4]. It becomes basic to clarify that adaptation and responses of crops under drought stress and taking activities for ameliorating the drought tolerance capacity of yield plant also make sure high yield production against adverse environmental conditions. Here, review aimed to give a summary of morpho-physiological as well as biochemical responses of plants under water stresses.

Morpho-Physiological Responses
Natural stress triggers extensive plant species that vary in development and efficiency from molecular metabolism and modified gene expressions.

Growth
To ensure that nutrition contributes to the development of the population, a complete understanding of the processes for crop development and improvement is needed to train

agricultural operations. Improving plant performance and maintainability under changing natural stress conditions, depending on how the plant's vegetative and regenerative patterns can be controlled. Crop development is an element of a complex interaction between the source and sinks, which creates the functional equilibrium between the two fundamental organs of the plant, the root and shoot system. The perpetual or impermanent water deficit severely impedes the development and improvement of the plant in addition to other environmental factors. The effects of disabled germination and poor stand foundation are particularly detrimental to water (Harris *et al*. 2002) [5]. The cell growth is regarded by the decreasing turgor pressure as major drought-delicate physiological measures. The development of daughter cells with the meristematic cell division leads to enormous immature cell expansions. Due to the interference of water movement through the xylem to extending cells under drought stress, cell expansion of developed plant can be prevented (Noami, 1998) [6]. Drought caused impending mitosis, cell growth and extension caused decreased development and characteristics of productivity (Hussain *et al*. 2008) [7]. Drought stress reduces soil quantity by reducing the lifetime of leaves per plant and the size of the leaf. The extension of the leaf area is dependent on temperature, leaf turgor and gracefully absorbed for advancement. Water stress caused a decrease in leaf area by concealing the extension of leaves in the course of photosynthesis (Rucker *et al*., 1995) [8]. Water stress also decreases leaf area as a consequence of turgor depletion and decreases the number of leaves (Farooq *et al*. 2010a) Leaf area indexes (LAI) are the share of the leaf area per unit area that gives the degree of absorbent intensity of the crop in environmental conditions. Water stress reduces LAI in yield plants in general. Such as Hussain *et al*. (2009) detailed reduces the Helianthus sp leaf area index. Revealed in the sprouting and blooming stage under water stress. Water stress undermines leaf development and plant tillers (Kramer and Boyer 1995), also reduces leaf area due to premature senescence (Nooden 1988) [10]. These elements decrease dry matter aggregation as well as water stress yield. Decreased leaf shape is fine with water deficiency; by adjusting to the cruel conditions, many xerophytes have small leaves. Using a previously mentioned leaf, confined water uses a little leaf and it is liable to benefit less (Sinclair and Muchow 2001) [11], but different genotypes are unexpectedly used. The decreased transpiration water depletion is different from significant drought avoidance habituations. The plant has developed several morphologic adaptations to achieve this, for instance, the proportion of roots and buds by low leaves and small leaves to overview water shortages, given the high budget and the minimum loss of water (Lei *et al*. 2006) [12]. Expanded stomata and rhizome tolerance, smaller stomatous and perpendicular leaf area also in the direction between significant droughts to limit transpiration for water underwater shortages (Sinclair and Muchow 2001, Wang & Yamauchi 2006) [11]. In any event, decreased leaf area and plant height are invaluable for confined water usage, but the yielding plant can also achieve minimal efficiency (Sinclair and Muchow, 2001) [11]. Optimum leaf area is essential for the production of dry matter and photosynthesis. Underwater scarcity, mostly reduced leaf growth and turn the leaf area in numerous spaces. Several different species also occur in plants such as Populus sp. (Wullschleger *et al*., 2005) [13], Glycine max (Zhang *et al*., 2004) (Farooq *et al*., 2009) [9]. In binary sympathies, critical interspecific changes, Populus sp. In total number, area and leaf biomass during water deficiency conditions were discovered (Wullschleger *et al*. 2005) [13]. Leaf development in Triticum aestivum more than Zea mays (Sacks *et al*. 1997), cowpea (Manivannan *et al*. 2007a) [14] and Helianthus annuus was a maximum delicate underwater deficiency, respectively (Manivannan *et al*. 2007b and 2008) [15].

Dry biomass and fresh output are reduced by a typical antagonistic impact of drought stress on yield plants (Zhao *et al*. 2006) [16]; (Khan *et al*. 2001), an investigation involving six treatments, particularly the control of 1-6 irrigations in Zea mays. The result was that the stem diameter, leaf areas and plant stature decreased markedly with increasing drought. The decrease in plant stature (Anjum *et al*. 2007) could be credited to a decrease in cell elongation as well as the maximum drought leaf senescence in plants (Manivannan *et al*. 2007a) [14]. Heschel and Rigions (2005) explained that plant stature was highly photosynthesized and extremely sensitive to ecological conditions. Plant stature decreased to 25 per cent underwater deficiency on citrus fruit (Wu *et al*. 2008); Ahmad *et al*. (2009) [19, 17] reported decreasing plant stature and dry matter as a result of the expandable controlled water deficiency. Ali Meo (2000) reported plant stature and quality of seed per head significantly declined by decreasing the level of nitrogen that would otherwise expand the conditions of water stress. Drought has led to a significant weakening of the maize 's developmental characteristics. Concerning plant stature, leaf area, cob length, fresh shoot and dry weight/plant and leave amount/plant. Besides, Kamara *et al*. (2003) [20], are delighted that water deficiency during various formal stages in Zea mays reduced absolute aggregation of biomass in the silking phase 37 per cent, the 34 per cent seed filling phase and the 21 per cent development phase.

Photosynthesis

Natural stress has an immediate impact on photosynthetic apparatus, basically through distressing every single significant part of photosynthesis which includes peroxidative destruction of lipids, the thylakoid electron transport, disturbance of water balance, carbon depletion cycle, stomatal controller on carbon dioxide distribution and with an expended collection of carbohydrates, (Allen and Ort, 2001) [21]. The capacity of harvest plant to adapt to various conditions instantly or incidentally related with its capacity to adapt at the degree of photosynthesis that influences biological and physiological procedures, therefore, development and production of the entire plant (Chandra, 2003) [22]. Water deficient condition seriously disrupted the gas conversation constraints of yield plant also it may be because of reduction in debilitated photosynthetic machinery, leaf growth, early leaf senescence, proteins and variations in the configuration of pigments as well as oxidation of chloroplast lipids (Menconi *et al*.1995). Anjum *et al*. (2011a) showed, water deficiency in *Zea mays.* Prompted significant decrease in intercellular carbon dioxide (5.86%) natural water use efficiency (11.58%), stomatal conductance (25.54%), net photosynthesis (33.22%), transpiration rate (37.84%) and water use efficiency (50.87%), when contrasted with irrigated water control. Numerous investigations have indicated that due to stomatal or non-stomatal mechanisms, photosynthetic movement decreased under water-deficient conditions (Ahmadi, 1998; Del Blanco *et al*. 2000; Samarah *et al*. 2009) [25] stomatal closure is major respond under water deficiency, resulting in a decreased proportion of photosynthesis and stomata are the entrance of water loss and CO_2 absorbability.

Photosynthetic carbon osmosis diminished for photorespiration and stomatal closure denies the leave of CO_2. Studying the previously reports along with the present data on water stress prompted the photosynthetic response; this demonstrates that stomata close continuously due to expanded water deficiency. It is notable, the water condition of the leaf constantly connected through conductivity of stomata and the better connection among the water capacity of leaf and the conductivity of stomata is constant, under water stress. This is presently evident, water stress prompted root for leaf signalling advanced through the drying of soil during transpiration stream, bringing about stomatal closure. The "non-stomatal" process involves variations in chlorophyll production, distribution of assimilates, transport, and disturbances in processes of accumulation, functional and structural changes in chloroplasts.

Chlorophyll

Chlorophyll plays a significant role in chloroplast components for relative chlorophyll content and photosynthesis that maintains a positive relationship with the photosynthetic rate. Due to a reduction in chlorophyll content under water-deficient conditions has been observed ordinary signs of oxidative stress and might be consequence pigment photo-oxidation and chlorophyll degradation pigment. The photosynthetic pigment is essential for plant mostly for harvesting light and creation of diminishing forces. Chlorophyll a and b are inclined under lack of moisture in the soil (Farooq *et al*., 2009) [9]. Diminished chlorophyll level has been accounted for in numerous classes, during drought stress that is depending upon the period and seriousness of water deficiency (Kpyoarissis *et al*. 1995; Zhang and Kirkham, 1996). Water stressed conditions induced a huge decrease in chlorophyll substance such as chlorophyll b as well as complete chlorophyll substance in various *Helianthus species* (Manivannan *et al*. 2007 b) [15]. Introduction of binary olive species to decreased irrigation prompted lesser chlorophyll a and b substances. *Chetoui sp.* and *Chemlali sp.*of olive were decreased by 29% and 42% chlorophyll a and b. (Guerfel *et al*. 2009) [27]. Lack of chlorophyll content during drought is detected because of inactivation of photosynthesis. Besides, water deficiency prompted decrease the content of chlorophyll has been attributed to alteration of the lamellae vesiculation, loss of chloroplast membranes and the presence of droplets such as excessive swelling and lipid (Kaiser *et al*. 1981) [28]. Fewer absorptions of photosynthetic pigment may instantly inhibit photosynthetic potential as well as consequently main yield. According to the approach of physiology, leaf chlorophyll substance is a factor of critical diversion in itself. Less number of chlorophyll into the plant due to lack of moisture in the soil which takes place in the mesophyll cells with a minor quantity being absent from the bundle sheath cells. Chlorophyll action is basic in drought tolerance that was decreased through extreme drought stress into the binary species of strawberry (Ghaderi and Siosemardeh, 2011) [29]. A different examination by Kirnak *et al*. (2001) [30], chlorophyll substance was diminished (55%) during water-deficient more than control. Antagonistic impact of drought on chlorophyll substance has recently been appeared in youthful *Prunus persica* tree (Steinberg *et al*. 1990). Water deficiency created variations in the proportion of carotenoid and chlorophyll a and b (Anjum *et al*. 2003b; Farooq *et al*. 2009) [36, 9]. Chlorophyll substance reduces during drought stress was investigated in *Gossypium sp.* (Massacci *et al*. 2008) [31] and Catharanthus roseus (Jaleel *et al*. 2008a-d) [32]. In *Helianthus sp.*, the chlorophyll substance diminished to a particular extent under drought stress conditions (Kiani *et al*., 2008) [33] and in Vaccinium myrtillus (Tahkokorpi *et al*., 2007).

Yield and related traits

Several yield-calculating procedures in plant react under water stress. Production correlates many of these processes in a problematic way. Hence, this is uncertain how plant assembles, showing the variable and uncertain process throughout the entire life span of the crop as well as consolidating. Crop productivity is the result of the demonstration and association certain plant growth elements. Drought stress causes diminishing in yield attributes of harvest plants most likely due to disturbance in leaf gas conversation property that not just constrained the shape of source and sink tissue but also phloem staking, acclimatize transfer and dry matter distributing are similarly debilitated (Farooq *et al*. 2009) [9]. Water deficiency restrains the dry matter yield largely by its inhibitory impacts on growth and improvement of leaves, therefore, decreased light interception (Nam *et al*., 1998). The stage of blooming usually fruitlessness under water stress. An important reason for it, still not individual, was the lack of assimilated transition for producing ear under certain threshold level important towards support optimum food development (Yadav *et al*., 2004) [35]. At the point, where *Zea mays.* the plant was revealed underwater deficiency at tasseling phase, this prompted a considerable decrease in productivity and productivity components, for example, kernels/cob, kernel row per cobs, kernel numbers per rows,100 kernels mass, harvest index natural production/plants and seed production per plants (Anjum *et al*., 2011a) [24]. water stress correlated decrease in productivity and productivity components of plants may be attributed to stomata close in to respond to water-deficient, that diminished the consumption of carbon dioxide and, accordingly, photosynthesis diminished (Chaves, 1991; Cornic, 2000; Flexas *et al*., 2004) [37]. Introduction of sunflower plant under water-deficient conditions, shoot initiation phase was more hindering under organic production and seed but in the seed-filling phase (Prabhudeva *et al*.1998) [38]. The quantity and shape of seeds were diminished to pre-anthesis water deficiency enormously decreased the seed production, that was subject on the degree of defoliation leading to drought stress through premature reproductive growth (Kamara *et al*., 2003; Monneveux *et al*., 2006) [20, 39]. Under drought conditions, diminishes seed production in *Glycine sp.* normally because of fewer pods as well as seed per area. (Specht *et al*. 2001) [40]. Due to drought stress in Glycine sp., seed production was lower while contrasted with irrigated control plants (Specht *et al*. 2001) [40]. Drought diminished head diameter, the mass of 100 achenes and production per plants in Helianthus sp. There was a negative relationship of head diameter through the mass of fresh shoot as well as root, whereas a positive between the mass of dry bud and achene production per plants during drought (Tahir and Mehid, 2001) [41]. Drought stress created at blooming and seed filling stages of different crops for twelve days (developed in sandy topsoil soil) resulted that, diminished achene production in *Helianthus sp.* (Mozaffari *et al*., 1996; Reddy *et al*., 2004) seed production in *Vigna radiata* (Webber *et al*., 2006), *Zea mays.* (Monneveux *et al*., 2006) [39] and *Petroselinum crispum* (Petropoulos *et al*., 2008). In short, prevailing water deficiency decreases plant development as well as improvement, prompting to hampered bloom yield

and seed filling so that it produces minimum and small seeds. Deficient in seed filling takes place because of a decrease in the acclimatize partitioning and starch synthesis enzymes and activates of sucrose.

Biochemical Responses

Superoxide dismutase enzymes (SOD)

It serves as an antioxidant and preserves cell parts from being oxidized through ROS (reactive oxygen species) in higher plants. (Alscher, 2002). ROS development because of herbicide, pesticide, injuries, photo inhabitation, drought, ozone, nutrient deficiencies, toxic metals, temperature above and below ground, Gamma or UV rays and plant metabolic activity (Smirnoff, 1993; Ray Chaudhuri *et al*, 2000) Especially, peroxide molecular is decreased to superoxide (a reactive oxygen species known as superoxide) whereas it retains excited electrons discharged through compounds of electron transport chain. Superoxide is called as section DNA, oxidize lipids and denature enzymes. Superoxide dismutase enzyme catalyzes producing oxide and hydroperoxide through superoxide (O_2^-) that brings about rarely unsafe reactants. At the point whereas acclimation to expanded degrees of oxidative pressure, Superoxide dismutase enzyme focuses commonly increment with the intensity of stressed conditions. The compartmentalization of various types of superoxide dismutase enzyme all through the plants causes them to balance stress very successfully. These are three notable and examined species of superoxide dismutase enzyme metallic coenzymes, which exists in the plant. To begin with, Fe superoxide dismutase enzyme consists of two classes such as homodimer (comprising 1 to 2 gram Fe) and tetramer (containing 2 to 4 gram Fe). These are believed to be mostly long-lived superoxide dismutase enzyme metalloenzymes and are discovered inside the eukaryotes and prokaryotes. Fe superoxide dismutase enzymes are mostly rich restricted within plant chloroplasts, whereas these are indigenous. Second, Mn superoxide dismutase enzyme comprises of a homotetramer and homodimer classes each inducing a singular Mn (III) atom/subunit. These are prevalently found in mitochondrion as well as in peroxisomes. Third, the electrical property of Cu-Zn superoxide dismutase is distinct from another two species. They are vigorous in the cytosol, chloroplast and extracellular conditions. Cu-Zn superoxide dismutase enzyme gives slighter security whereas Fe superoxide dismutase enzyme when limited in the chloroplast. It was accounted for such superoxide dismutase enzyme improves drought stress tolerance to plant. Cytosolic Cu/Zn-SOD was instigated emphatically by water deficient in tomato (Bowler *et al*. 1992). In cowpea also the same observation has been made by Manivannan (2007) [14, 15]. An increment in SOD activity was reported in tea plants at 10 days and 20 days of dehydration treatments and its activity was seen as diminished on rehydration (Upadhyaya *et al*., 2008).

Catalase

Catalase is the principle H_2O_2 scavenging enzyme in plants just as is found in peroxisomes/glyoxisomes (Asada, 1999). H_2O_2 is eliminated by catalases (CAT) (Asada, 1989; Scandalios *et al*., 1997). Dhinshaw *et al*., (1981) have been distinguished that in tobacco, a diminishing in catalase activity in water stress against control. In cowpea, a consistent decline in the particular activity of catalase occurs in all genotypes during improvement, maturation and senescence stage of leaves in plants developed in control as well as in the exploratory plots (Patel, 2007). Catalase activity expanded under water-deficient conditions in susceptible and tolerant genotypes of maize (Mousa, 2008). Accessibility of soil moisture also plays a significant part in plant improvement and to carry out different metabolic activities. In pot culture experiment the diminishing in soil moisture content has been seen in well-developed Ryegrass plants (Karsten 2001). A significant decrease in gravimetric soil moisture content was seen in tea crop developed plants and it was 12.88 and 3.55 per cent following 10 days and 20 days parchedness (Upadhyaya, 2008). The soil moisture at the time of planting in Indian mustard (Singh, 2009) was 12.4 to 14.45% (0 to15 centimetres), 12.8 to 15.85% (15 to 30 centimetre) and 13.5 to 16.8% (30 to 60) centimetre. In dryland, the soil moisture content decreased with the progression of the crop and rise to 3.0% (0-15 cm), 5.0% (30-60 cm) and 6.0% (30-60 cm) at that period of fully developed. Normal soil moisture during the water stress at 80 Diammonium phosphate (5.7% over two years) in cluster bean (Girdthai 2012) non-stressed treatment (11.5 per cent in 2006/2007 and 10.2 per cent in 2007/2008, separately) *et al*. 2009).

MDA

Malondialdehyde (MDA) creation is demonstrative in oxidative stress, spreads in crop plants as water stress increases and provides an index of lipid peroxidation. Destruction of the plasma membrane in peroxidation shows rapid desiccation, cell death and leakage of contents. The content of malondialdehyde is demonstrated on a protein basis due to most of the lipids present in the wheat leaf in the shape of membranes as, especially that related with chloroplast proteins and chloroplasts (Price and Hendry 1991). An expansion in malondialdehyde content with expanding drought stress was noted here. The outcomes were in acceptance with such of different investigations (Price and Hendry 1991, Zhang *et al*. 1990b) and suitable with the theory, drought stress can induce membrane-lipid peroxidation by mean of activated oxygen species.

Conclusion

Abiotic Stress indicating is an important area about increasing plant efficiency. Water stress is an overall world issue, which reduces global crop yield, also attributes genuinely as well as currently, worldwide environmental changes occur this circumstance progressively genuine. Drought stress affects the development, production and dry matter in plants. Severity and rate of improvement and duration without a doubt have a pivotal role in determining the plant responds under drought stress. Water deficiency influences the growth, development and production in plant crop however; the tolerance of crops under this stress varies unusually. Changes occur in morpho-physiological and biological aspects are commonly noted in response to drought stress. Plant responses to drought are significant for genotypes to water-limited conditions in screening tolerance.

Acknowledgement

P.K. and S.K. gratefully acknowledge the support provided by Lovely Professional University.

Author Contributions

The contribution of the authors in paper writing was equal.

Conflict of Interest Statement

The authors state that they have no interest in conflict.

References

1. Shao HB, Chu LY, Jaleel CA, Manivannan P, Panneerselvam R, Shao MA. Understanding water deficit stress-induced changes in the basic metabolism of higher plants-biotechnologically and sustainably improving agriculture and the eco-environment in arid regions of the globe. Crit. Rev. Biotechnol. 2009; 29:131-151.
2. Benjamin JG, Nielsen DC. Water deficit effects on root distribution of soybean, field pea and chickpea. Field Crops Res. 2006; 97:248-253.
3. Demirevska K, Zasheva D, Dimitrov R, Simova-Stoilova L, Stamenova M, Feller U. Drought stress effects on Rubisco in wheat: changes in the Rubisco large subunit. Acta Physiol. Plant. 2009; 31:11291138.
4. Duan B, Yang Y, Lu Y, Korpelainen H, Berninger F, Li C. Interactions between drought stress, ABA and genotypes in *Picea asperata*. J Exp. Bot. 2007; 58:3025-3036.
5. Harris D, Tripathi RS, Joshi A. On-farm seed priming to improve crop establishment and yield in dry direct-seeded rice, in: Pandey S., Mortimer M., Wade L., Tuong T.P., Lopes K., Hardy B. (Eds.), Direct seeding: Research Strategies and Opportunities, International Research Institute, Manila, Philippines, 2002, 231-240.
6. Nonami H. Plant water relations and control of cell elongation at low water potentials. J Plant Res. 1998; 111:373-382.
7. Hussain M, Malik MA, Farooq M, Ashraf MY, Cheema MA. Improving drought tolerance by exogenous application of glycinebetaine and salicylic acid in sunflower. J Agron. Crop Sci. 2008; 194:193-199.
8. Rucker KS, Kvien CK, Holbrook CC, Hook JE. Identification of peanut genotypes with improved drought avoidance traits. Peanut Sci., 1995; 24:14-18.
9. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. Plant drought stress: effects, mechanisms and management. Agron. Sustain. Dev. 2009; 29:185-212.
10. Nooden LD. The phenomena of senescence and ageing. In: Nooden LD, Leopald AC (eds) Senescence and aging in plants. Academic, USA, 1988, 1-50
11. Sin Sinclair TR, Muchow RC. System analysis of plant traits to increase grain yield on limited water supplies. Agron J. 2001; 93:263-270
12. Lei YB, Yin CY, Li CY. Differences in some morphological, physiological and biochemical responses to drought stress in two contrasting populations of Populus przewalskii. Physiol Plant. 2006; 127:182-19.
13. Wullschleger SD, Yin TM, DiFazio SP, Tschaplinski TJ, Gunter LE, Davis MF *et al*. Phenotypic variation in growth and biomass distribution for two advanced-generation pedigrees of hybrid poplar. Canadian J For. Res. 2005; 35:1779-1789
14. Manivannan P, Jaleel CA, Kishorekumar A, Sankar B, Somasundaram R, Sridharan R *et al*. Changes in antioxidant metabolism of *Vigna unguiculata* L. Walp. by propiconazole under water deficit stress. Colloids Surf B: Biointerf. 2007a; 57:69-74.
15. Manivannan P, Jaleel CA, Sankar B, Kishorekumar A, Somasundaram R, Alagu Lakshmanan GM *et al*. Growth, biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought stress. Colloids Surf. B: Biointerf. 2007b; 59:141-149
16. Zhao TJ, Sun S, Liu Y, Liu JM, Liu Q, Yan YB *et al*. Regulating the drought-responsive element (DRE)-mediated signalling pathway by synergic functions of trans-active and transactive DRE binding factors in *Brassica napus*. J Biol. Chem. 2006; 281:10752-10759.
17. Ahmad SH, Ahmad R, Ashraf MY, Ashraf M, Waraich EA. Sunflower (*Helianthus annuus* L.) response to drought stress at germination and seedling growth stages. Pak. J. Bot. 2009; 41(2):647-654
18. Ali Meo A. Impact of variable drought stress and nitrogen levels on plant height, root length and grain numbers per plant in sunflower (*Helianthus annuus* L.) Var. Shams. Pah. J. Agri. Sci. 2000; 37(1, 2):89-92.
19. Wu Y, Cosgrove DJ. Adaptation of roots to low water potentials by changes in cell wall extensibility and cell wall proteins. J Exp. Bot. 2000; 51:1543-1553.
20. Kamara AY, Menkir A, Badu-Apraku B, Ibikunle O. The influence of drought stress on growth, yield and yield components of selected maize genotypes. J Agric. Sci. 2003; 141:43-50
21. Allen DJ, Ort DR. Impact of chilling temperatures on photosynthesis in warm-climate plants. Trends Plant Sci. 2001; 6:36-42.
22. Chandra S. Effects of leaf age on transpiration and energy exchange of *Ficus glomerata*, a multipurpose tree species of central Himalayas. Physiol. Mol. Biol. Plants. 2003; 9:255-260.
23. Menconi M, Sgherri CLM, Pinzino C, Navari-Izzo F. Activated oxygen production and detoxification in wheat plants subjected to a water deficit programme. J Exp. Bot., 1995; 46:1123-1130.
24. Anjum SA, Wang LC, Farooq M, Hussain M, Xue LL, Zou CM. Brassinolide application improves the drought tolerance in maize through modulation of enzymatic antioxidants and leaf gas exchange. J Agron. Crop Sci., doi:10.1111/j.1439-037X.2010.00459.x, 2011a.
25. Ahmadi AA. Effect of post–anthesis water stress on yield regulating processes in wheat (*Triticum aestivum* L.). Ph.D. Thesis. University of London, Wye College, Wye, Ashford, U.K, 1998.
26. Kyparissis A, Petropoulun Y, Manetas Y. Summer survival of leaves in a soft-leaved shrub (*Phlomis fruticosa* L., Labiatae) under Mediterranean field conditions: avoidance of photoinhibitory damage through decreased chlorophyll contents. J. Exp. Bot. 1995; 46:1825-1831
27. Guerfel M, Baccouri O, Boujnah D, Chaibi W, Zarrouk M. Impacts of water stress on gas exchange, water relations, chlorophyll content and leaf structure in the two main Tunisian olive (*Olea europaea* L.) cultivars. Sci. Horticult. 2009; 119:257-263
28. Kaiser WM, Kaiser G, Schöner S, Neimanis S. Photosynthesis under osmotic stress. Differential recovery of photosynthetic activities of stroma enzymes, intact chloroplasts and leaf slices after exposure to high solute concentrations. Planta. 1981; 153:430-435
29. Ghaderi N, Siosemardeh A. Response to drought stress of two strawberry cultivars (cv. Kurdistan and Selva). Hort. Environ. Biotechnol. 2011; 52:6-12.
30. Kirnak C, Kaya IT, Higgs D. The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. Bulg. J Plant Physiol. 2001; 27:34-36.
31. Massacci A, Nabiev SM, Pietrosanti L, Nematov SK, Chernikova TN, Thor K *et al*. Response of the photosynthetic apparatus of cotton (*Gossypium hirsutum*) to the onset of drought stress under field conditions studied by gas-exchange analysis and chlorophyll

fluorescence imaging. Plant Physiol. Biochem. 2008; 46:189-195
32. Jaleel CA, Sankar B, Murali PV, Gomathinayagam M, Lakshmanan GMA, Panneerselvam R. Water deficit stress effects on reactive oxygen metabolism in *Catharanthus roseus*; impacts on ajmalicine accumulation. Colloids Surf. B: Biointerfaces. 2008e; 62:105-111
33. Kiani SP, Maury P, Sarrafi A, Grieu P. QTL analysis of chlorophyll fluorescence parameters in sunflower (*Helianthus annuus* L.) under well-watered and water-stressed conditions. Plant Sci., 2008; 175:565-573
34. Thykorpi Nam NH, Subbaroa GV, Chauhan YS, Johansen C. Importance of canopy attributes in determining dry matter accumulation of pigeon pea under contrasting moisture regimes. Crop Sci. 1998; 38:955-961.
35. Yadav RS, Hash CT, Bidinger FR, Devos KM, Howarth CJ. Genomic regions associated with grain yield and aspects of post flowering drought tolerance in pearl millet across environments and tester background. Euphytica, 2004; 136:265-277.
36. Anjum SA, Wang LC, Farooq M, Khan I, Xue LL. Methyl jasmonate-induced alteration in lipid peroxidation, antioxidative defense system and yield in soybean under drought. J. Agron. Crop Sci., doi:10.1111/j.1439-037X.2010.00468.x, 2011b.
37. Chaves MM. Effects of water deficits on carbon assimilation. J Exp. Bot. 1991; 42:1-16
38. Prabhudeva TV, Chalapathi MM, Thimmegowda S, Devakhumar N, Rao GG, Mallikarjuna K. Soil moisture stress and drought susceptibility index in sunflower. Indian Agric. 1998; 42:287-289 Prochazkova, D., R.K. Sairam, G.C. Srivastava and D.V. Singh, 2001.
39. Monneveux P, Sánchez C, Beck D, Edmeades GO. Drought tolerance improvement in tropical maize source populations: evidence of progress. Crop Sci., 2006; 46:180-191
40. Specht JE, Chase K, Macrander M, Graef GL, Chung J, Markwell JP *et al*. Soybean response to water. A QTL analysis of drought tolerance. Crop Sci. 2001; 41:493-509
41. Tahir MHN, Mehid SS. Evaluation of open pollinated sunflower (*Helianthus annuus* L.) populations under water stress and normal conditions. Int. J Agric. Biol., 2001; 3:236-238.