Influence of drought stress on photosynthetic enzymes, chlorophyll, protein and relative water content in crop plants

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Abstract

Water deficit/drought affects every aspect of plant growth and the yield modifying the anatomy, morphology, physiology, biochemistry and finally the productivity of crop. Water is an important factor in agricultural and food production yet it is a highly limited resource and is becoming increasingly more important over time for optimal crop production. While decreased Rubisco activity may not be the cause of photosynthetic reduction during water stress, its down-regulation may still be important because it could preclude a rapid recovery upon rewaterning. Chlorophyll is one the major chloroplast components for photosynthesis and relative chlorophyll content has a positive relationship with photosynthetic rate. Water stress causes deceleration of cell enlargement and thus reduces stem lengths by inhibiting inter nodal elongation and also checks the tillering capacity of plants. The importance of root system in acquiring water has long been recognized. Influence of drought stress on Photosynthetic enzymes, Chlorophyll, Protein and Relative water content in crop plants.

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Introduction
At present in consequence of global climate changes a progressive increase of the average annual temperature of the earth results in the development of some stress factors. This leads to the significant decrease of the productivity of agricultural plants in regions having water deficit. Modern biotechnological methods have been used now to investigate molecular-genetic bases of drought resistance to create cultures tolerant to drought and high temperature (Raines, 2006). Water stress is a major harmful factor in arid and semi-arid regions worldwide (Ranjana et al., 2006) that limits the area under cultivation and yield of crops. Drought is observed in irrigated areas due to insufficient supply of water and canal closure (Hafeez et al., 2003). Water deficit/drought affects every aspect of plant growth and the yield modifying the anatomy, morphology, physiology, biochemistry and finally the productivity of crop (Jones et al., 2003; Hafiz et al., 2004). Stress is the result of complex interactions between plants and the environment. In natural conditions the effect of only one stress factor without interaction with others does not occur. Many environmental factors in isolation may not cause stress, but in different combinations they can create stress conditions for plants (Slováková, 2007). Motivation and aims of the study is influence of drought stress on Photosynthetic enzymes, Chlorophyll, Protein and Relative water content in crop plants.

Materials and methods
This paper is a review article of the literature search on ISI, Scopus and the Information Center of Jahad and MAGIRAN SID is also abundant. Search library collection of books, reports, proceedings of the Congress was also performed. All efforts have been made to review articles and abstracts related to internal and external validity.

Result and discussion
Water resource management
Water is an important factor in agricultural and food production yet it is a highly limited resource and is becoming increasingly more important over time for optimal crop production (O'Shaughnessy et al., 2011; Wang et al., 2012). Therefore, research on irrigation and water management has focused on crop yield responses to water supply (Chen et al., 2010 a; Koksal, 2011). The use of remote sensing for irrigation practices, water resource management, and disease and insect management has been largely investigated (Ozdogan, 2011; Elmnetwalli et al., 2012).
progressively impaired from very early stages of water stress. Thus, these results present the possibility that some enzymes involved in the regeneration of RuBP could play a key regulatory role in photosynthesis under water stress. During water stress induced by polyethilenglycole, Rubisco activity significantly increased in young potato leaves, while decreased in mature leaves (Bussis et al., 1998). But NADP-GAPDH and PRK activities have been decreased and this change became faster in the course of drought. While decreased Rubisco activity may not be the cause of photosynthetic reduction during water stress, its down-regulation may still be important because it could preclude a rapid recovery upon rewatering (Ennahli and Earl, 2005). Similarly, some reports have shown strong drought-induced reductions of Rubisco activity per unit leaf area (Maroco et al., 2002) and per mg showed that the decrease of Rubisco activity in vivo was not connected with the protein content. It occurs because of CO2 concentration decrease in the carboxylation center in consequence of the partly closing of stomata (Flexas et al., 2006). But it is known, that enzyme regulation occurs not only in transcription, but also in posttranscriptional level. Activities of the tested enzymes are regulated by light as well as by the concentration of photosynthetic metabolites (Raines, 2006).

**Fig. 2.** Physiological mechanisms induced by water stress.

**Modern investigations of genotypes differing in their drought tolerance**

Modern investigations of genotypes differing in their drought tolerance within the same species and among the ancestors of crops may serve as a marker in obtaining more productive genotypes. Photosynthetic CO2 assimilation in C3-plants is affected by environmental variables including temperature, CO2 concentration and water availability. Of these variables, water is the main biotic factor limiting plant productivity in many regions of the world (Chaves et al., 2002).

**Chlorophyll**

Chlorophyll is one of the major chloroplast components for photosynthesis and relative chlorophyll content has a positive relationship with photosynthetic rate. Chen et al.( 2007) noted that assessment of pigment content has become an effective means of monitoring plant growth and estimating photosynthetic productivity while Fillella et al.(1995) reported that remote estimates of pigment concentration provides an improved evaluation of the spatial and temporal dynamics of plant stress. Chlorophyll concentration has been known as an index for evaluation of source therefore a decrease of this can be consideration of a non-stomata limiting factor in the drought stress conditions. Chlorophyll concentration has been known as an index for evaluation of source (Herzog, 1986), therefore decrease of this can be consideration as a nonstomata limiting factor in the drought stress conditions. There are reports about decrease of
chlorophyll in the drought stress conditions (Majumdar et al, 1981; Mayoral et al, 1981; Kuroda et al, 1990) Also, it is reported that chlorophyll content of resistant and sensitive cultivars to drought and thermal stress reduced. But resistant cultivar to drought and thermal stress conditions had high chlorophyll content (Sairam et al, 1997). Other reports have represented that drought stress did not have effect on chlorophyll concentration (Kulshreshtha et al, 1987). According to Maxwell and Johnson (2000) the measurement of chlorophyll fluorescence in situ is a useful tool to evaluate the tolerance of the photosynthetic apparatus to environmental stress which reduces the maximum efficiency of PSII photochemistry. It is used to determine how light use efficiency for photosynthesis occurs at the cellular level. It can also be used to estimate the activity of the thermal energy dissipation in photosystem II which protects photosystems from the adverse effects of light and heat stress.

Fig. 3. Schematic overview of a common System Biology approach to study abiotic stress responses in plants.

**Primary responses of plants to water deficit**

Water is a necessary factor in life and it influences the existence of plants and realization of their life cycle. One of the primary responses of plants to water deficit is stomata closure, which minimizes water loss (Carmo-Silvia, 2012). Plants wither and close stomata to limit transpiration and prevent more loss of water. Drought as abiotic stress is multidimensional in nature (Rahman, 2012).

Fig. 4. Water and salt stress tolerance mechanisms in plants.

**Reactive oxygen species**

Stress factors such as drought trigger common reactionsmin plants and lead to cellular damages mediated by reactive oxygen species (ROS). According to Price and Hendry (1991) who studied the role of oxygen radicals in different grasses exposed to drought, water deficit stress causes an overall inhibition of protein synthesis, inactivation of
several chloroplast enzymes, impairment of electron transport, increased membrane permeability, and increased activity of the H2O2 scavenger system. Antioxidative enzymes such as superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase (CAT) play an important role against drought stress (Apel and Hirt, 2004; Habibi and Hajiboland, 2011).

**Drought resistance**

Water stress can affect photosynthesis directly by causing changes in plant metabolism or indirectly by limiting the amount of CO2 available for fixation (Lawlor and Cornic, 2002). Drought resistance of a plant is related to its ability to maintain higher relative water content in the leaves under water stress. Many changes in gene expression occur in plants growing under limited water conditions (Bray, 2002). Provisional stresses existing in the intermediate stages of growth has a negative impact on the plant growth, but the plants that have a higher tolerance to dryness and after solving the stress can improve and rectify the losses, will indicate the lowest reduction in the function (Daneshian et al., 2009).

**Protein**

Water stress is reported to inhibit the incorporation of amino acids into proteins and to cause a decrease in the protein content of the tissues. Water deficit impedes protein synthesis at the ribosomal level: some proteins are apparently formed and inactivated quickly whereas others appear to be relatively stable. Studies on sunflower by Rao et al. (1987) showed that water deficit reduces seed protein content. Protein content, particularly soluble protein usually falls to about 40-60% of the initial content as the water deficit becomes intense in drought sensitive plants.

**Dry matter accumulation**

Dry matter accumulation is a result of assimilate flow from the resource organs to the storing organs. Dry matter accumulation is initially set by the storages themselves. The effect of the resource is not often direct, but it is through storing organs formation and it is indirect. Although the speed of assimilate transferring is depended on the transferring path, but the transferring path has the least effect in setting the distribution of dry matter of the plant (Marcelis, 1996). The available water for the plants is one of the most important factors limiting the potential function of agriculture in the semidry regions (Dogdalen et al. 2006, Stone et al. 2001). The increasing water shortage is the most important issue in many countries in the world (Zurat et al. 2004) and the limits of the availability of the water for irrigation needs fundamental changes in the irrigation management or application of methods in which the water resources are preserved better (Dogdalen et al. 2006).

**Models that adequately simulate the effects of water stress on yield**

Models that adequately simulate the effects of water stress on yield can be valuable tools in irrigation management. These models can be used to optimize the allocation of irrigation water between different crops and or the distribution of water during the crop season (Bryant et al., 1992; Cabelguenne et al., 1995; Cabelguenne et al., 1997; Howell et al., 1989; Stewart et al., 1975; Wenda and Hanks, 1981). Complete testing of a model is needed before it can be used for irrigation planning in a particular area. This will ensure that the model correctly simulates the main physiological processes that affect crop yield under water stress. Among the models that can be used for this task, a distinction can be made between crop growth simulation models, which simulate main processes of crop growth (leaf area growth, biomass production and partition), such as CERES-maize (Jones and Kiniry, 1986), Crop Syst (Stockle et al., 1994), EPIC (Williams et al., 1984), GOSSYM (Reddy et al., 1997), and SUCROS (Penning de Vries and Van Laar, 1982), and those models that do not explicitly simulate crop growth but that have been developed for irrigation planning. CROPWAT (Smith, 1992) is the best known among the latter.

**Ion uptake due water stress**

Since nutrient uptake is closely linked to water soil status, it is expected that, decline of available soil moisture might decrease the diffusion rate of
nutrients from soil matrix to roots. Evidence of decreased ion uptake due water stress effect was attributed to the reduction in root absorption power (Aldesuquy et al., 2012). Decreasing water availability under drought generally results in limited total nutrient uptake and their diminished tissue concentrations in crop plants. An important effect of water deficit is on the acquisition of nutrients by the root and their transport to shoots. Lowered absorption of the inorganic nutrients can result from interference in nutrient uptake and the unloading mechanism, and reduced transpirational flow (Garg, 2003; McWilliams, 2003). However, plant species and genotypes of a species may vary in their response to mineral uptake under water stress. In general, moisture stress induces an increase in N, a definitive decline in P and no definitive effects on K (Garg, 2003). Transpiration is inhibited by drought, as shown for beech (Peuke et al., 2002), but this may not necessarily affect nutrient uptake in a similar manner. Influence of drought on plant nutrition may also be related to limited availability of energy for assimilation of \( \text{NO}^{-3} / \text{NH}^{+4}, \text{PO}_4^{3-} \text{and SO}_4^{2-} \): they must be converted in energy-dependent processes before these ions can be used for growth and development of plants (Grossman and Takahashi, 2001). As nutrient and water requirements are closely related, fertilizer application is likely to increase the efficiency of crops in utilizing available water. This indicates a significant interaction between soil moisture deficits and nutrient acquisition. Studies show a positive response of crops to improved soil fertility under arid and semi-arid conditions. Currently, it is evident that crop yields can be substantially improved by enhancing the plant nutrient efficiency under limited moisture supply (Garg, 2003). It was shown that N and K uptake was hampered under drought stress in cotton (McWilliams, 2003). Likewise, P and \( \text{PO}_4^{3-} \) contents in the plant tissues diminished under drought, possibly because of lowered \( \text{PO}_4^{3-} \) mobility as a result of low moisture availability (Peuke and Rennenberg, 2004). In drought-treated sunflower, the degree of stomatal opening of K+-applied plants initially indicated quicker decline. However, at equally low soil water potential, diffusive resistance in the leaves of K+-applied plants remained lower than those receiving no K+ (Lindhauer et al., 2007). However root growth and potential root hydraulic conductance have been found to increase with inoculation (Pereyra, et al., 2006) who reported that inoculation is accompanied by biochemical changes in roots which, in turn, promote plant-growth and tolerance to water stress. Presumably, increased root growth would lead to a greater volume of soil explored and hence a greater potential reservoir of soil water. It is also possible that inoculation enables the plant to better withstand drought conditions due to its role in energy storage and protein formation. Thus, under such drought condition and continuous decrease in nutrient uptake of the soils the importance use of seed inoculation has been indicated by Damodor et al., (1999).

**Leaf water content**

Leaf water content is a useful indicator of plant water balance since it expresses the relative amount of water present on the plant tissues (Yamasaki and Dillenburg, 1999). The species adapted better to dry environments have higher relative water content at given water potential. Water deficit also causes leaf water potential and rates of elongation to decline more rapidly in rice than in maize or sorghum so that dry matter accumulation and nutrient uptake decline or cease. Leaf dehydration can be minimized by decreasing evapotranspiration or by increasing water absorption from the drying soil (Chaves et al., 2003).

**Shoot and root growth**

Water stress causes deceleration of cell enlargement and thus reduces stem lengths by inhibiting internodal elongation and also checks the tillering capacity of plants. The importance of root system 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). Differences in root length could confer tolerance to drought by some varieties. Greater plant fresh and dry weights under water deficit conditions
are desirable characters. A common adverse effect of water deficit on crop plants is the reduction in fresh and dry biomass production. However some genotypes shows better stress tolerance than the others. Studies by Mohammadian et al. (2005) showed that 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. Wullschleger et al. (2005) reported a decrease in the root dry weight under mild and severe water stress in populous species.

Stomata characteristics
Epidermis tissues have three types of main cells include epidermal cells, guard cells with their subsidiary cells and trichomes or leaf hairs (Munir et al., 2011). In most species, frequency of stomata in the lower epidermis are more than the upper epidermis (Muradoglu and Gundogdu, 2011). Traits of leaf epidermal tissue such as stomata size and shape as well as form of trichomes are valuable in taxonomy and identification of plant genera and species (Munir et al., 2011, Scatena et al., 2005; Dickison, 2000). Anatomical traits such as high stomatal density, a reduction of stomata size and deeply developed stomata can be used for identification of xerophytic plants (Martins and Zieri, 2003, Belhadj et al., 2007). Stomata characteristics such as frequency and dimensions are greatly affected by type of species and environmental factors (Munir et al., 2011, XueJun and XinShi, 2000). Environmental stresses such as water stress most effects on leaf traits (XueJun and XinShi, 2000).

Breeding program
In developing a breeding program to improve the drought resistance of a crop plant it is necessary to gain knowledge concerning the genetics and physiology of tolerance mechanisms (Clarke & Townley-Smith, 1984; Inoue et al., 2004). Yield is the principle selection index used under drought stress conditions. If we had known how to select for high yield potential using criteria other than grain yield, perhaps results could have been achieved by way of enhanced total plant productivity rather than just by changing the production ratio (Blum, 2005). The identification of physiological traits responsible for drought tolerance should be considered in the breeding program, because grain yield and drought resistance are controlled at independent genetic loci (Morgan, 1984). Therefore, the use of physiological traits as an indirect selection would be important in augmenting yield-based selection procedures. Selection efficiency could be improved if particular physiological and/or morphological attributes related to yield under a stress environment could be identified and employed as selection criteria for complementing traditional plant breeding (Acevedo, 1991). These morpho physiological traits should be highly heritable, greatly correlated with stress tolerance and can be easily assessed. A range of traits has been suggested that could be utilized to increase selection efficiency and used as indirect selection for improving yield under stress conditions.

Proline content
However it is reported that proline content in resistant wheat cultivars was more than in sensitive cultivar under the drought and salinity stress (kao, 1981). Also accumulation of proline has been reported under the drought stress in another various crops such as chick pea (cicer arietinum), (Ayerb & Tenori, 1998) corn (zea mays), (Serraj & Sinclair, 2002) and peanut (Arachis hypogaea ) (Smith et al, 2002). Ten & Hollaran ; (1982) expressed that the crops under the stress, accumulate the most amount of free proline in their leaves tissue by studying of changes and correlation of proline accumulation in spring wheat cultivars and comparison of performed experiments by another researchers . Increasing of proline amount due to drought stress has reported in another researches (Heuer , 1994; Safarnejad et al, 1996; Mattioni , 1997 ; Sharpe &Verslues , 1999; ; Staden et al , 1999; Serraj & Sinclair, 2002;Safarnejad ,2004).

Relative water content (RWC)
The difference of relative water content (RWC) has been reported as 18.6 and 21.8 percent for most resistant and most sensitive genotypes to drought
stress in 2 years of experiment. (Merah, 2001). In studies that performed on 4 cultivars of bread wheat, RWC reduced to 43 percent (from 88% to 45%) by moisture stress (Siddique et al., 2000). (Mattonn et al., 1989) represented a similar report as regards a drop in the amount of RWC in tolerant and sensitive cultivars of barley.

Evaporation from leaves

Fuchs and Tanner (1966) reported that it is well-known from energy balance considerations that leaf temperature varies with evaporation from leaves and hence is a function of stomata conductance (Jones, 1999). Leaf temperature is a physiological trait that can be used for monitoring plant water status (Jimenez-Bello et al., 2011). In general, water stress causes stomata closure in plants, and this leads to higher leaf temperature (Sdoodee, Kaewkong, 2006).

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