

The effect of triazole induced photosynthetic pigments and biochemical constituents of *Zea mays* L. (Maize) under drought stress

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Received: 15 May 2015 / Accepted: 15 July 2015 / Published online: 29 July 2015
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Abstract In this investigation, pot culture experiment was carried out to estimate the ameliorating effect of triazole compounds, namely Triadimefon (TDM), Tebuconazole (TBZ), and Propiconazole (PCZ) on drought stress, photosynthetic pigments, and biochemical constituents of *Zea mays* L. (Maize). From 30 days after sowing (DAS), the plants were subjected to 4 days interval drought (DID) stress and drought with TDM at 15 mg l⁻¹, TBZ at 10 mg l⁻¹, and PCZ at 15 mg l⁻¹. Irrigation at 1-day interval was kept as control. Irrigation performed on alternative day. The plant samples were collected on 40, 50, and 60 DAS and separated into root, stem, and leaf for estimating the photosynthetic pigments and biochemical constituents. Drought and drought with triazole compounds treatment increased the biochemical glycine betaine content, whereas the protein and the pigments contents chlorophyll-a, chlorophyll-b, total chlorophyll, carotenoid, and anthocyanin decreased when compared to control. The triazole treatment mitigated the adverse effects of drought stress by increasing the biochemical potentials and paved the way to overcome drought stress in corn plant.

Keywords Drought · Triazole · Triadimefon · Tebuconazole · Propiconazole · Biochemical · Pigment

Introduction

Water stress is the major problem in agriculture and the ability to withstand such stress is of immense economic importance. Water stress tolerance involves subtle changes in cellular biochemistry. It appears to be the result of accumulation of compatible solutes and of specific proteins that can be rapidly induced by osmotic stress (Rhodes 1987). The numerous physiological responses of plant-to-water deficits generally vary with the severity, as well as the duration, of water stress (Mathews et al. 1984; Weber and Gates 1990; Rose et al. 1993; Li 2000; Correia et al. 2001; Pane and Goldstein 2001; Pita and Pardes 2001; Weigh 2001; Shao and Chu 2005; Shao et al. 2005, 2006b, 2007a, b, 2008a, b, c). One of the most important abiotic stresses for crop yields concerns about plant dehydration (Shao et al. 2006b; Boudsocq and Lauriere 2005; Mittler 2006). Plants suffer from dehydration under the condition of drought, high salinity, and low temperatures, all of which cause hyper-osmotic stress characterized by a decreased turgor pressure and water loss (Shao et al. 2003, 2006a, 2007b; Sun et al. 2005; Munns 2005; Humphreys et al. 2006).

Drought stress is well known as a major environmental stress that restricts the growth and yield of crop plants worldwide and can trigger a series of physiological and biochemical responses in plants (Yue et al. 2012). The changes of environment and global climate, drought stress not only seriously affects plant development and evolution, but also reveals the ecological equilibrium of the ecosystem (Zhao et al. 2011; Shi et al. 2014). Drought is a complex physical–chemical process, in which many biological macromolecules and small molecules are involved, such as nucleic acids (DNA, RNA, microRNA), proteins, carbohydrates, lipids, hormones, ions, free radicals, and

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mineral elements (Munns 2002; Casson and Lindsey 2003; Casati and Walbot 2004). In addition, drought is also related to salt stress, cold stress, high temperature stress, acid stress, alkaline stress, pathological reactions, senescence, growth, development, cell cycle, UV-B damage, wounding, embryogenesis, flowering, signal transduction, and so on (Zhu 2002; Jiang and Zhang 2004). Therefore, drought is connected with almost all aspects of biology. Currently, drought study has been one of the main directions in global plant biology and biological breeding. Plants sense the loss of water and adapt the drought stress which mainly dependent on the regulated expression of drought-related genes.

The expression of various stress response genes is mediated by a number of transcription factors. In the transcription factors interact with specific cis-acting elements existing in target gene promoters and regulate elaborate networks of drought-responsive genes and associated biochemical and physiological adaptations (yang et al. 2014). Most of these adaptation responses are determined by several secondary messengers including some plant hormones (Qin et al. 2011; Du et al. 2013). Diverse sets of genes expressed in response to abiotic stress have been identified, and elucidation of their physiological or cellular roles in terms of either stress tolerance or sensitivity is a critical issue in current plant biology (Huang et al. 2012; Jirschitzka et al. 2013). It is essential to study the functions of stress-responsive genes to ameliorate stress tolerance in crop plants (Cabello et al. 2014; Ismail et al. 2014).

Maize (*Zea mays* L.) is one of the most important crops in the world (Kresovic et al. 2014). It was first domesticated in South-West Mexico about 6000 years ago. With more than 880 million tons produced in 2011, it is now the crop with the largest production and constitutes the third most important staple crop for human after rice and wheat. Within the European Union, it ranks second in terms of volume of production after wheat—but third in harvested area only to wheat and barley (FAOSTAT 2013). The Maize production in these regions plays a significant role in ensuring food security, but their climates vary dramatically, with the annual accumulated temperature above 10 °C, total sunshine hours, and total precipitation of 2000–4700 °C day, 2100–2900 h, and 3400–800 mm, respectively (Li and Wang 2010). These climatic differences have a significant influence on maize growth and development (Liu et al. 2013).

Triazole compounds have both fungitoxic and plant growth-regulating properties. In addition, they can also protect plants against various environmental stresses. Triazoles affect the isoprenoid pathway and alter the levels of certain plant hormones by inhibiting gibberellin synthesis, reducing ethylene evolution, and increasing cytokinin

levels (Jaleel et al. 2008). Plant growth regulators play vital roles in coordination of many growth and behavioral processes in rice, which regulates the amount, type, and direction of plant growth (Anjum et al. 2011). Drought stress amelioration by triazole compounds is of major research interest, because, these compounds have innate potentiality for increasing antioxidant enzymes and molecules in oxidative stressed plants (Fletcher et al. 2000).

Materials and methods

The hybrid seeds of maize variety NK-6240 were obtained from Syngenta India limited and employed for this investigation; Plastic pots of 40 cm diameter and 45 cm height size were used for culture study. The pots were filled with 10 kg of soil mixture containing red soil; sand and farm yard manure in 1:1:1 ratio. Two hundred and fifty pots were arranged in Completely Randomized Block Design (CRBD). Single lot of 50 pots was kept as control, three sets of 150 pots were used for drought with triazole treatment at 4 days interval, and the remaining one set was kept in drought treatment in order to impose drought stress at 4 days interval. Triadimefon (15 mg l^{-1}), Tebuconazole (10 mg l^{-1}), and Propiconazole (15 mg l^{-1}) were used to determine their effect on *Zea mays*. The treatments were given as soil drenching, 30 days after sowing (DAS). The plants were left for 30 DAS with alternative day irrigation. From day 30 to 60, control plants were irrigated on every alternative day, drought treated, and drought with triazole-treated plants were irrigated at every 4 days interval. After drought treatment, all the pots were irrigated on alternative day and it last up to harvest. Plants were uprooted randomly on DAS 40, 50, and 60, washed with water, and separated into root, stem, and leaf for estimating photosynthetic pigments and biochemical constituents.

Estimation of photosynthetic pigments

Estimation of chlorophyll and carotenoid contents

Chlorophyll and carotenoid contents were extracted from the leaves and estimated according to the method suggested by (Arnon 1949).

Extraction Five hundred milligram of fresh leaf material was ground with 10 ml of 80 % acetone at 4 °C in a pestle and mortar and centrifuged at 2500 g for 10 min at 4 °C. The residue was re-extracted with 80 % acetone until the green color disappeared in the residue and the extracts were pooled and transferred to graduated tube and made up to 20 ml with 80 % acetone and assayed immediately.

Estimation Three milliliters aliquots of the extract were transferred to cuvette and the absorbance was measured at 645, 663, and 480 nm with a spectrophotometer (U-200 1-Hitachi) against 80 % acetone as blank. Chlorophyll content was calculated using the formula of Arnon 1949 and carotenoid content was calculated using the formula of Kirk and Allen 1965 and were expressed in milligram per gram fresh weight.

Estimation of anthocyanin content

Anthocyanin content was extracted and estimated by the method of Zhang and Quantick 1997.

In a pestle and mortar, 500 mg of tissue was ground with 10 ml of 1 % methanol and repeated three times. The homogenate was centrifuged at 19,000 g for 15 min. The resultant supernatant was diluted with 1 % HCl–methanol to 50 ml. The absorbance of diluents was measured at 530 nm. The anthocyanin contents were expressed in mg/gram fresh weight.

Estimation of biochemical constituents

Estimation of soluble protein content

According to the (Bradford 1976) soluble protein was estimated.

Extraction One gram of plant material was ground in mortar and pestle with 20 ml of 20 % trichloro acetic acid (TCA). The homogenate was centrifuged for 15 min at 800 rpm. The supernatant was discarded, and to the pellet 5 ml of 0.1 N NaOH was added to solubilize the protein and the solution was centrifuged again at 800 rpm for 15 min. The supernatant was saved and made up to 10 ml with 0.1 N NaOH and used for the estimation of protein content.

Estimation Protein solution containing 10–50 µg protein in a volume of 0.1 ml was pipetted in 12 × 100 mm test tubes, and to this 5 ml of protein reagent was added and the contents were mixed by vortexing. The absorbance at 595 nm was measured after 2 min against a reagent blank. The reagent blank was prepared with distilled water, 0.1 ml of 0.1 N NaOH and 5 ml of Bradford reagent. The weight of protein was plotted against the corresponding absorbance resulting in a standard curve and it was used to determine the protein in unknown samples and the results were expressed in milligram per gram dry weight.

Estimation of glycine betaine content

The samples were extracted and estimated by the method of Grieve and Grattan 1983.

Extraction Five hundred milligram of finely ground dry plant sample was mechanically shaken with 20 ml of distilled water for 24 h at 25 °C. The time required for this step was determined by extracting the plant samples for 4, 8, 16, 24, and 48 h. The samples were then filtered through Whatman No.1 filter paper and the filtrate was made up to 20 ml with deionised water and used for estimation immediately.

Estimation One milliliter of the extract was diluted with one milliliter of 2 N H₂SO₄ and 0.5 ml of this acidified extract was cooled in ice water for an hour. Later 0.2 ml of cold potassium triiodide solution was added and mixed gently with a vortex mixture, and the tubes were stored at 4 °C for 15 min and then centrifuged at 10,000 g for 15 min. The supernatant was aspirated with a fine tipped glass tube. The per iodide crystals were dissolved in 9.0 ml of 1, 2-dichloroethane with vigorous vortexing. After 2.5 h, the absorbance was measured at 365 nm in a spectrophotometer. Reference standard of glycine betaine was prepared in 1 N H₂SO₄ and used for estimating the glycine betaine content and the results were expressed in microgram per gram dry weight.

Preparation of reagent: potassium triiodide reagent 15.7 g of iodine and 20 g of potassium iodide were dissolved in 100 ml of distilled water and gently stirred in a vortex mixture.

Statistical analysis

The pot culture was carried out in completely randomized design (CRBD). The data are expressed as mean ± SE for seven samples in each group.

Results

Effect of drought and drought with triazole combination on photosynthetic pigments

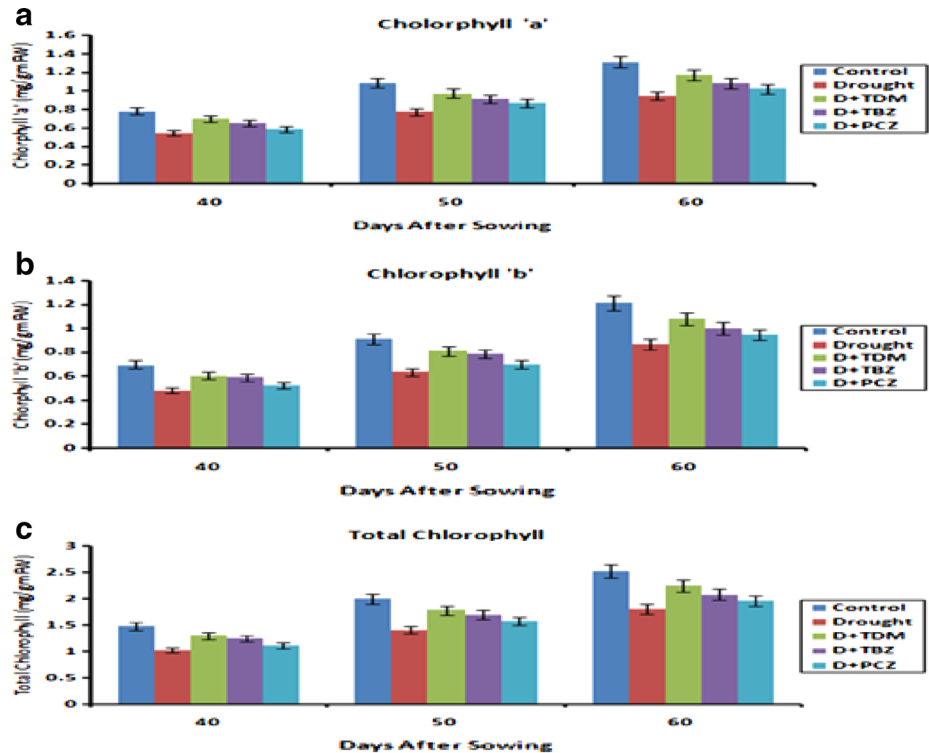
Chlorophyll and carotenoid contents

The photosynthetic pigments like chlorophyll-a, chlorophyll-b, and total chlorophyll contents decreased in drought stress and drought with triazole treatments when compared to control (Fig. 1). The carotenoid content decreased significantly in all the treatments when compared to control (Fig. 2).

Anthocyanin content

Drought stress and drought with TDM, TBZ, and PCZ treatments decreased the anthocyanin content when compared to control (Fig. 3).

Fig. 1 Effect of drought stress and drought with triazole combination on the chlorophyll content of *Zea mays* (Expressed in mg/g fresh weight)



Effect of drought and drought with triazole combination on biochemical constituents

Protein content

The protein content of root, stem, and leaf of maize plants was decreased by drought stress and drought with triazole treatments when compared to control (Fig. 4).

Glycine betaine content

One of the most important mechanisms exerted by higher plants under stress condition is the accumulation of compatible solutes such as glycine betaine. In the present study, the amount of glycine betaine content increased in root,

stem, and leaf to a larger extent under drought stress and drought with triazole treatments (Figure 5).

Discussion

Drought stress decreased the chlorophyll content when compared to control. A reduction in chlorophyll content was reported in drought-stressed *Helianthus annuus* (Manivanan et al. 2007). The chlorophyll content in the wheat leaf decreased due to chemical desiccation treatments (Shao et al. 2009). A reduction in chlorophyll content was reported in drought-stressed soybean plants by Zhang et al. (2006). The chlorophyll content decreased to a significant level at higher water deficits in maize and wheat plants (Nayyar and

Fig. 2 Effect of drought stress and drought with triazole combination on the carotenoid content of *Zea mays* (Expressed in mg/g fresh weight)

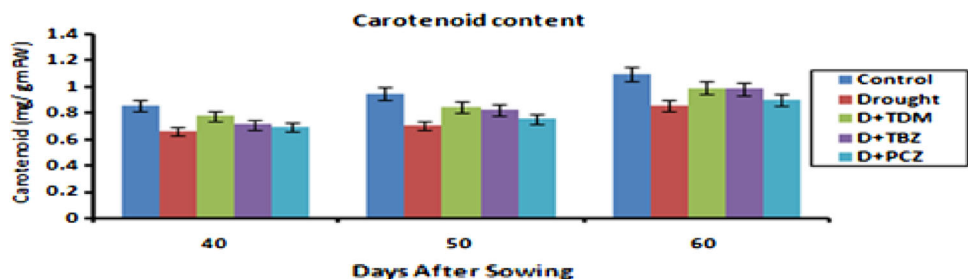


Fig. 3 Effect of drought stress and drought with triazole combination on the anthocyanin content of *Zea mays* (Expressed in mg/g fresh weight)

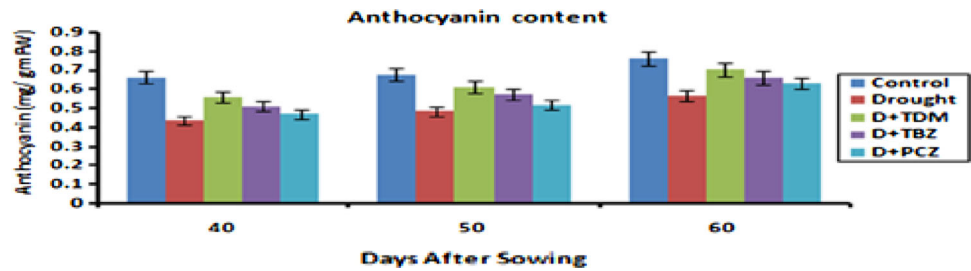
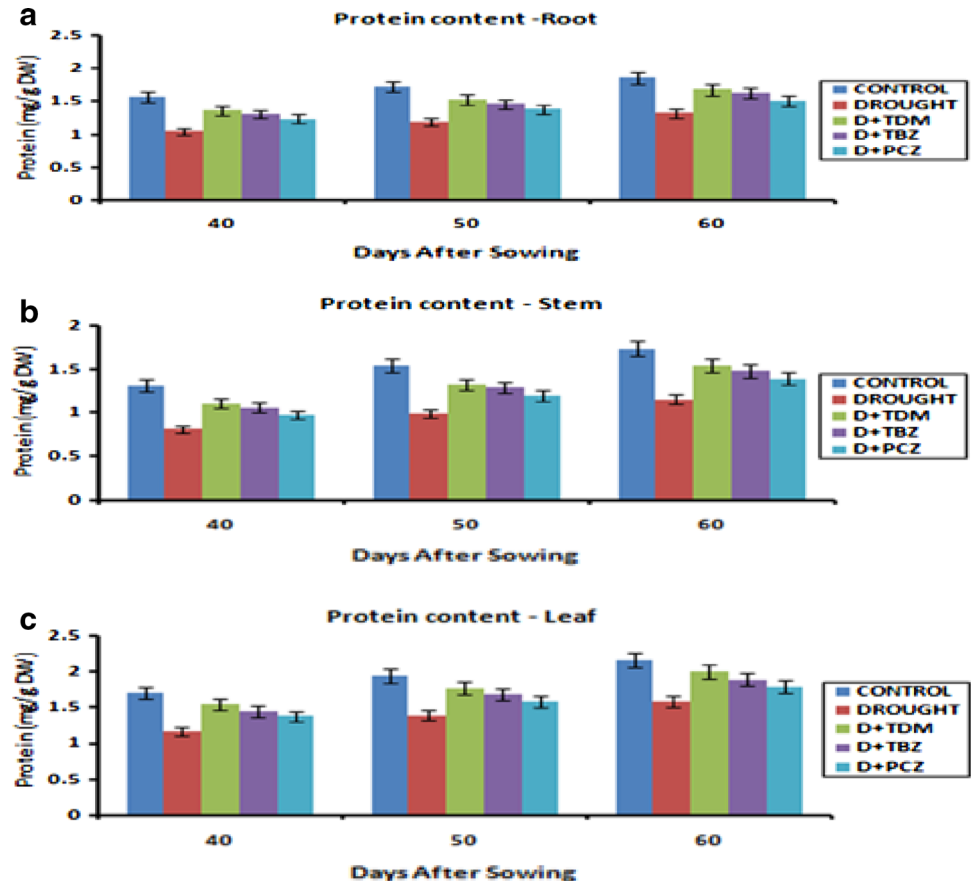


Fig. 4 Effect of drought stress and drought with triazole combination on the protein content of *Zea mays* (Expressed in mg/g dry weight)



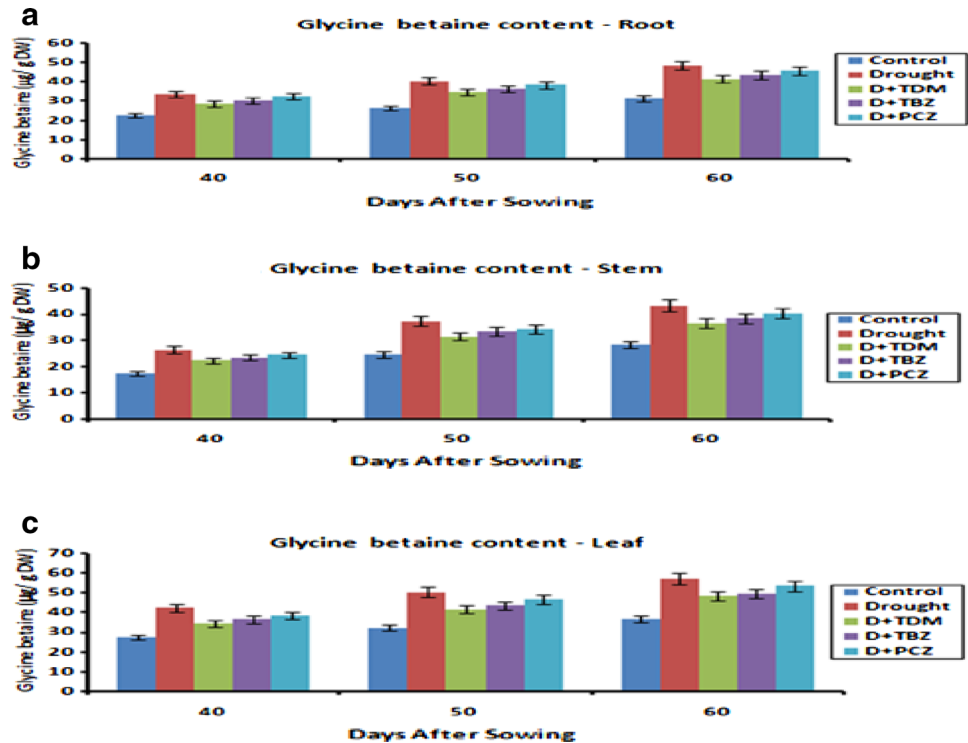
Gupta 2006). Similar results were observed in cherry (Centritto 2005). Triazole treatment to the drought-stressed maize plants increased the chlorophyll content when compared to control. Paclobutrazol and drought stress treatment increased the pigments in olive (Thakur et al. 1998). Similar increased results were observed in through difenoconazole and tricyclazole treatments in *Lycopersicon esculentum* (Mohamadi and Rajaei 2013).

Drought induced a reduction in chlorophyll 'b' content in leaves of maize when compared to control plants. Similar results were observed in rice (Farooq et al. 2009). A reduction in chlorophyll content was reported in drought-stressed *Vaccinium myrtillus* (Tahkokorpi et al. 2007) and sunflower plants (Kiani et al. 2008). Triazole treatment to the drought-stressed maize plants increased

the chlorophyll 'b' content when compared to control. Triazole with drought stress treatment increased the pigments in rose (Jenks et al. 2001). Similar results were observed in maize (Ren et al. 2007) and in *Lycopersicon esculentum*. (Shanmugapriya et al. 2013). Drought stress decreased the total chlorophyll content to a larger extent when compared to control. A reduction in chlorophyll content was reported in drought-stressed soybean plants (Zhang et al. 2006). Triazole treatment to the drought-stressed maize plants increased the total chlorophyll content when compared to drought stress. Triazole-treated leaves were dark green due to high chlorophyll a and b in *Chrysanthemum* (Wood 1984).

In maize, the carotenoid content decreased significantly in all the treatments when compared to control.

Fig. 5 Effect of drought stress and drought with triazole combination on the glycine betaine content of *Zea mays* (Expressed in $\mu\text{g/g}$ dry weight)



Among the drought treatments, the highest reduction was observed in carotenoid content when compared to other treatments. Carotenoids are a large class of isoprenoid molecules that are synthesized *de novo* by all photosynthetic and many non-photosynthetic organisms. They are divided into the hydrocarbon carotenes, such as lycopene and β -carotene, or into xanthophylls, typified by lutein. Carotenoids are also exploited as coloring agents, furnishing distinctive yellow, orange, and red colors to flowers, fruits, and roots, where they probably act as attractants to pollinators and for seed dispersal. The colors provided by the pigments are of important agronomical value in many horticultural crops (Shao et al. 2009). Reduced carotenoid content under drought was reported in sunflower (Gimenez et al. 1992). Triazoles treatment increased the carotenoid content in maize when compared to control and drought-stressed plants. Paclobutrazol with drought stress treatment increased the pigments in olive (Thakur et al. 1998), Triamidefon and tricyclazole applications raised the pigment content in *Lycopersicon esculentum* (Mohamadi and Rajaei 2013). The anthocyanin content was decreased by drought stress treatment in maize. In drought-stressed plants, the anthocyanin content was low as compared to control plants. Similar results were observed in tomato (Still and Pill 2004). Triazole treatment increased the anthocyanin content in maize plants, but drought stress has no significant effect upon this. Triadimefon increased the

chlorophyll and anthocyanin content in radish cotyledons (Lichtenthaler 1979).

Drought stress caused decrease in protein content of all the parts maize plants to a large extent. Similar results were observed in wheat (Gong et al. 2005). The reduction in protein content in the chilling-stressed plants of maize was correlated with increased proline accumulation (Cheng et al. 1999). This may be due to the hydrolysis of protein or the inhibition of protein synthesis by oxidative stress, leading to the accumulation of proline (Feng et al. 2003). Protein metabolism has been associated with adaptation of plants to environment changes. Only a few reports discussing the leaf proteins of sunflower are available. Rodriguez et al. (2002) reported a decrease in leaf soluble proteins in sunflower due to water stress. However, the nature of plant species (Terri et al. 1986) and the types of tissue modulate the concentration of soluble proteins under water stress (Irigoyen et al. 1992; Shao et al. 2009). Triazole with drought stress treatment resulted in increased protein content in maize when compared to drought stress but it was lower than that of control. Paclobutrazol-treated wheat seedlings had more soluble protein (Kraus et al. 1995).

Drought stress caused an increase in the content of glycine betaine in all parts of the maize plant when compared to control. Betaines are known to be one of the major osmoregulating compounds, forming inner salts with quaternary ammonium groups and a carboxyl group. Among

them, glycine betaine is the most familiar and widespread in plants and bacteria. The accumulation of glycine betaine occurs in some, but not in all, higher plants, and most of the glycine betaine is synthesized in chloroplasts by two enzymes, viz. choline monoxygenase (CMO) and betaine aldehyde dehydrogenase, responsible for glycine betaine synthesis chloroplastically. Glycine betaine synthesis can be induced by both drought and salt stress by the overexpression of CMO, and by betaine aldehyde dehydrogenase in barley (Nakamura et al. 2001) and stress tolerance in plants (Jun et al. 2000). The glycine betaine content increased under drought stress in sunflower (Manivannan et al. 2007). Glycine betaine is considered to be one of the most abundant quaternary ammonium compounds produced in higher plants under stressful environments (Shao et al. 2009). Triazole treatment to the drought-stressed plants decreased glycine betaine content, but it was higher than that of control. Similar results were observed in *Abelmoschus esculentus* (Rabert et al. 2013).

Acknowledgments The authors are grateful to thank the University Grants Commission for providing financial assistance [F.No.F.42-958/2013 (SR) Dated: 14-03-2013] for the execution of the project. The authors also acknowledge the Professor and Head, Department of Botany, Annamalai University, Annamalaiagar, for providing necessary facilities to carry out the work.

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References

- Anjum SA, Wang LC, Farooq M, Hussain M, Xue LL, Zou CM (2011) Brassinolide application improves the drought tolerance in maize through modulation of enzymatic antioxidants and leaf gas exchange. *J Agron Crop Sci* 197:177–185
- Aron DI (1949) Copper enzymes in isolated chloroplasts, polyphenol oxidase in *Beta vulgaris* L. *Plant Physiol* 24:1–15
- Boudsocq M, Lauriere C (2005) Osmotic signaling in plants. Multiple pathways mediated by emerging kinase families. *Plant Physiol* 138:1185–1194
- Bradford MM (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein dye binding. *Ann Biochem* 72:248–253
- Cabello JV, Lodeyro AF, Zurbriggen MD (2014) Novel perspectives for the engineering of abiotic stress tolerance in plants. *Curr Opin Biotechnol* 26:62–70
- Casati P, Walbot V (2004) Rapid transcriptome responses of maize (*Zea mays*) to UV-B irradiated and shielded tissues. *Genome Biol* 5:R16
- Casson SA, Lindsey K (2003) Genes and signaling in root development. *New Phytol* 158(1):11–34
- Centritto M (2005) Photosynthetic limitations and carbon partitioning in cherry in response to water deficit and elevated [CO₂]. *Agric Ecosyst Environ* 106:233–242
- Cheng WH, Taliercio EW, Chourey PS (1999) Sugar modulate an unusual mode of the cell-wall invertase gene (Incw1) through its 3' untranslated region in a cell suspension culture of maize. *Proc Natl Acad Sci USA* 96:10512–10517
- Correia MJ, Coelho D, David MM (2001) Response to seasonal drought in three cultivars of *Ceratonia siliqua*: leaf growth and water relation. *Tree Physiol* 21:645–653
- Du H, Wu N, Chang Y, Li X, Xiao J, Xiong L (2013) Carotenoid deficiency impairs ABA and IAA biosynthesis and differentially affects drought and cold tolerance in rice. *Plant Mol Biol* 83:475–488
- FAOSTAT (2013) FAOSTAT Production database. Statistics Division of the Food and Agriculture Organization of the United Nations. <http://faostat3.fao.org/home/index.html>. Accessed 16 May 2013
- Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA (2009) Plant drought stress: effects, mechanisms and management. *Agron Sustain Dev* 29:185–212
- Feng Z, Guo A, Feng Z (2003) Amelioration of chilling stress by triadimefon in cucumber seedlings. *Plant Growth Regul* 39:277–283
- Fletcher RA, Gilley A, Sankhla N, Davis TM (2000) Triazoles as plant growth regulators and stress protectants. *Hort Rev* 24:56–138
- Gimenez K, Mitchell V, Lawlor D (1992) Regulation of photosynthetic rate of two sunflower hybrids under water stress. *Plant Physiol* 98:516–524
- Gong H, Zhu X, Chen K, Wang S, Zhang C (2005) Silicon alleviates oxidative damage of wheat plants in pots under drought. *Plant Sci* 169:313–321
- Grieve CM, Grattan SR (1983) Rapid assay for determination of water soluble quaternary ammonium compounds. *Plant Soil* 70:303–307
- Huang GT, Ma SL, Bai LP, Zhang L, Ma H, Jia P, Liu J, Zhong M, Guo ZF (2012) Signal transduction during cold, salt, and drought stresses in plants. *Mol Biol Rep* 39:969–987
- Humphreys MW, Yadav RS, Cairns AJ et al (2006) A changing climate for grassland research. *New Phytol* 169:9–26
- Irigoyen JJ, Emerich DW, Sanchez-Diaz M (1992) Water stress induced changes in concentration of proline and total soluble sugars in nodulated alfalfa (*Medicago sativa*) plants. *Physiol Plant* 84:55–60
- Ismail A, Takeda S, Nick P (2014) Life and death under salt stress: same players, different timing? *J Exp Bot*. doi:10.1093/jxb/eru159
- Jaleel CA, Sankar B, Murali PV, Gomathinayagam M, Lakshmanan GMA, Panneerselvam R (2008) Water deficit stress effects on reactive oxygen metabolism in *Catharanthus roseus*; impacts on ajmalicine accumulation. *Colloids Surf B* 62:105–111
- Jenks MA, Andersen L, Teusink RS, Williams MH (2001) Leaf cuticular waxes of potted rose cultivars as affected by plant development, drought and paclobutrazol treatments. *Physiol Plant* 112:62–70
- Jiang MY, Zhang JH (2004) Abscisic acid and antioxidant defense in plant cells. *Acta Bot Sin* 46(1):1–9
- Jirschitzka J, Mattern DJ, Gershenzon J, D'Auria JC (2013) Learning from nature: new approaches to the metabolic engineering of plant defense pathways. *Curr Opin Plant Biotech* 24:320–328
- Jun Hariji HR, Adam L, Rozwadowski KL, Hammerlineli JL, Keller WA, Selvaraj G (2000) Genetic engineering of glycinebetaine production towards enhancing stress tolerance in plants. *Plant Physiol* 122:747–756

- Kiani SP, Maury P, Sarrafi A, Grieu P (2008) QTL analysis of chlorophyll fluorescence parameters in sunflower (*Helianthus annuus* L.) under well watered and water stressed conditions. *Plant Sci* 175:565–573
- Kirk JTO, Allen RL (1965) Dependence of chloroplast pigment synthesis on protein synthesis: effect of actidione. *Biochem Biophys Res Commun* 21:530–532
- Kraus TE, Mc Kersie BD, Fletcher RA (1995) Paclobutrazol induced tolerance of wheat leaves to paraquat may involve increased antioxidant enzyme activity. *J Plant Physiol* 145:570–576
- Kresovic B, Matovic G, Gregoric E, Djuricin S, Bodroza D (2014) Irrigation as a climate change impact mitigation measure: an agronomic and economic assessment of maize production in Serbia. *Agric. Water Manage* 139:7–16
- Li C (2000) Population differences in water use efficiency of *Eucalyptus microtheca* seedlings under different watering regimes. *Physiol Plant* 108:134–139
- Li SK, Wang CT (2010) Potential and ways to high yield in maize [M]. Science Press, Beijing
- Lichtenthaler HK (1979) Effect of biocides on the development of the photosynthetic apparatus of radish seedlings grown under strong and weak high conditions. *Z Naturforsch* 34:936–940
- Liu Y, Hou P, Xie R, Li S, Zhang H, Ming B, Ma D, Liang S (2013) Spatial adaptabilities of spring maize to variation of climatic conditions. *Crop Sci* 53:1–11
- Manivannan P, Jaleel CA, Sankar B, Kishorekumar A, Somasundaram R, Alagu Lakshmanan GM, Panneerselvam R (2007) Growth, biochemical modifications and proline metabolism in *Helianthus annuus* L. as induced by drought stress. *Colloids Surf B* 59:141–149
- Mathews MA, Nanvolkenburg E, Boyer JS (1984) Acclimatization of leaf growth to low water potentials in sunflower. *Plant Cell Environ* 7:199–206
- Mittler R (2006) Abiotic stress, the field environment and stress combination. *Trends Plant Sci* 11(1):15–19
- Mohamadi N, Rajaei P (2013) Effect of triamidefon fungicide on some growth parameters and antioxidant enzymes activity in tomato (*Lycopersicon esculentum* Mill.) plant under drought stress. *Int J Adv Biol Biom Res* 1(4):341–350
- Munns R (2002) Comparative physiology of salt and water stress. *Plant Cell Environ* 25(2):239–252
- Munns R (2005) Genes and salt tolerance: bringing them together. *New Phytol* 167:645–663
- Nakamura T, Nomura M, Mori H, Jagendorf AT, Ueda A, Takabe T (2001) An isozyme of betaine aldehyde dehydrogenase in barley. *Plant Cell Physiol* 42:1088–1092
- Nayyar H, Gupta D (2006) Differential sensitivity of C3 and C4 plants to water deficit stress: association with oxidative stress and antioxidants. *Environ Exp Bot* 58:106–113
- Pane JA, Goldstein AH (2001) Response of stomatal conductance to drought in ponderosa pine: implications for carbon and ozone uptake. *Tree Physiol* 21:377–394
- Pita P, Pardes JA (2001) Growth, leaf morphology, water use and tissue water relation of *Eucalyptus globules* clones in response to water deficit. *Tree Physiol* 21:599–607
- Qin F, Shinozaki K, Yamaguchi-Shinozaki K (2011) Achievements and challenges in understanding plant abiotic stress responses and tolerance. *Plant Cell Physiol* 52:1569–1582
- Rabert GA, Rajasekar M, Manivannan P, Somasundaram R, Panneerselvam R (2013) Effect of triazole fungicide on biochemical and antioxidant enzymes activity in okra (*Abelmoschus esculentus* L.) plant under drought stress. *Int J Agri Food Sci* 3(3):100–107
- Ren J, Dai W, Xuan Z, Yao Y, Korpelainen H, Li C (2007) The effect of drought and enhanced UV-B radiation on the growth and physiological traits of two contrasting Poplar species. *Forest Eco Manag* 239:112–119
- Rhodes D (1987) Metabolic response to stress. In: Davis DD (ed) *Biochemistry of plants*. Academic Press, New York, pp 201–241
- Rodriguez D, Romero-Garcia J, Rodriguez-Garcia R, Sanchez JLA (2002) Characterization of proteins from sunflower leaves and seeds: relationship of biomass and seed yield. In: Janick J, Whipkey A (eds) *Trends in new crops and new uses*. ASHS Press, Alexandria
- Rose R, Gleenson FG, Atkinson M (1993) Morphological and water stress characteristics of three Douglas fir stock types in relation to seedling performance under different soil moisture condition. *New For* 7:1–17
- Shanmugapriya AK, Sivakumar T, Panneerselvam R (2013) Difenoconazole and Tricyclazole induced changes in photosynthetic pigments of *Lycopersicon esculentum* L. *Int J Agri Food Sci* 3(2):72–75
- Shao HB, Chu LY (2005) Plant molecular biology in China: opportunities and challenges. *Plant Mol Biol Repr* 23:345–358
- Shao HB, Shao MA, Liang ZS (2003) Roles of ABA signal transduction during higher plant seed maturation and germination. *For Stud China* 5(4):54–62
- Shao HB, Liang ZS, Shao MA (2005) Adaptation of higher plants to environmental stresses and stress signal transduction. *Acta Ecol Sin* 25(7):1871–1882
- Shao HB, Chu LY, Zhao CX, Guo QJ, Liu XA, Ribaut J-M (2006a) Plant gene regulatory network system under abiotic stress. *Acta Biol Sezeged* 50:1–9
- Shao HB, Liang ZS, Shao MA (2006b) Osmotic regulation of 10 wheat (*Triticum aestivum* L.) genotypes at soil water deficits. *Biointerfaces* 47:132–139
- Shao HB, Chu LY, Wu G, Zhang JH, Lu ZH, Hu YC (2007a) Changes of some antioxidative physiological indices under soil water deficits among 10 wheat (*Triticum aestivum* L.) genotypes at tillering stage. *Biointerfaces* 54:143–149
- Shao HB, Jiang SY, Li FM, Chu LY, Zhao CX, Shao MA, Zhao XN, Li F (2007b) Some advances in plant stress physiology and their implications in the systems biology era. *Biointerfaces* 54:33–36
- Shao HB, Chu LY, Lu ZH, Kang CM (2008a) Primary oxidant scavenging and redox signaling in higher plants. *Int J Biol Sci* 4:8–14
- Shao HB, Chu LY, Shao MA, Zhao CX (2008b) Progress in plant aquaporin structure—function relationships. *Mol Membr Biol* 25:179–191
- Shao HB, Guo XL, Chu LY, Shao MA, Liu ZH (2008c) Bioengineering plant resistance to abiotic stresses by the global calcium signal system. *Biotech Adv* 26:503–510
- Shao HB, Chu LY, Abdul Jaleel C, Manivannan P, Panneerselvam R, Shao MA (2009) Understanding water deficit stress-induced changes in the basic metabolism of higher plants—biotechnologically and sustainably improving agriculture and the environment in arid regions of the globe. *Crit Rev Biotechnol* 29(2):131–151
- Shi H, Ye T, Zhong B, Liu X, Chan Z (2014) Comparative proteomic and metabolomic analyses reveal mechanisms of improved cold stress tolerance in bermudagrass (*Cynodon dactylon* (L.) Pers.) by exogenous calcium. *J Integr Plant Biol*. doi:10.1111/jipb.12167
- Still JR, Pill WG (2004) Growth and stress tolerance of tomato seedlings (*Lycopersicon esculentum* Mill.) in response to seed treatment with paclobutrazol. *Hort Sci* 79:197–203
- Sun GR, Peng YZ, Shao HB, Chu LY et al (2005) Does *Puccinia tenuiflora* have the ability of salt exudation? *Colloids Surf B: Biointerf* 46(4):197–203



- Tahkokorpi M, Taulavuori K, Laine K, Taulavuori E (2007) After-effects of drought related winter stress in previous and current year stems of *Vaccinium myrtillus* L. *Environ Exp Bot* 61:85–93
- Terri JA, Turner M, Gurevitch J (1986) The response of leaf water potential and crassulacean acid metabolism to prolonged drought in *Sedum rubrotinctum*. *Plant Physiol* 81:678–680
- Thakur A, Thakur PS, Singh RP (1998) Influence of paclobutrazol and triacontanol on growth and water relations in olive varieties under water stress. *Indian J Plant Physiol* 3:116–120
- Weber JA, Gates DM (1990) Gas exchange in *Quercus rubra* during a drought: analysis of relation among photosynthesis, transpiration and conductance. *Tree Physiol* 7:215–225
- Weigh M (2001) Evidence for increased sensitivity to nutrient and water stress in a fast-growing hybrid willow compared with a natural willow clone. *Tree Physiol* 21:1141–1148
- Wood BW (1984) Influence of paclobutrazol on selected growth and biochemical characteristics of young pecan seedlings. *Hort Sci* 19:834–839
- Yang J, Zhang N, Mi X, Wu L, Ma R, Zhu X, Yao L, Jin X, Si H, Wang D (2014) Identification of miR159s and their target genes and expression analysis under drought stress in potato. *J compbiolchem* 53:204–213
- Yue Y, Zhang M, Zhang J, Tian X, Duan L, Li Z (2012) Overexpression of the *AtLOS5* gene increased abscisic acid level and drought tolerance in transgenic cotton. *J Exp Bot* 63:3741–3748
- Zhang D, Quantick PC (1997) Effects of chitosan coating on enzymatic browning and decay during postharvest storage of litchi (*Litchi chinensis* Sonn.) fruit. *Post Harvest Biol Technol* 12:195–202
- Zhang J, Jia W, Yang J, Ismail AM (2006) Role of ABA in integrating plant responses to drought and salt stresses. *Field Crops Res* 97:111–119
- Zhao Y, Du H, Wang Z, Huang B (2011) Identification of proteins associated with water-deficit tolerance in C4 perennial grass species, *Cynodon dactylon* × *Cynodon transvaalensis* and *Cynodon dactylon*. *Physiol Plant* 141:40–55
- Zhu JK (2002) Salt and drought stress signal transduction in plants. *Annu Rev Plant Biol* 53:247–273