

DROUGHT AND SALINITY STRESS IN CROP PLANTS

Ravi Kumar^{1*} and Lakshyadeep²¹Research scholar, Department of Plant Breeding and Genetics, SKNCOA, Jobner.² Department of Plant Breeding and Genetics, MPUAT, Udaipur.

Email: bishnoiravi@gmail.com

Received-02.07.2017, Revised-18.08.2017

Abstract: Abiotic stress is a condition deviated from normal conditions which is mainly produced from the abiotic environmental factors or non living components. These factors affect the crop plants adversely via reducing growth and production. These non living components of environment are drought (water stress), water logging, extremes of temperature (high and low), high salinity/alkalinity, high acidity nutrient toxicity *etc.* Temperature (high and low), salinity stress and drought are major abiotic factor which affect much as compare to others non living factors. Abiotic stress severely limits plant growth and development, due to that final yield is reduced.

Keywords: Drought, Crop plants, Abiotic factor, Production

REFERENCES

- Abd EL-Azim, W.M. and Ahmed, S.Th.** (2009). Effect of salinity and cutting date on growth and chemical constituents of *Achillea fragratissima* Forssk, under Ras Sudr conditions. *Research Journal of Agriculture and Biological Sciences*, 5(6): 1121-9.
- Abd El-Wahab, M.A.** (2006). The efficiency of using saline and fresh water irrigation as alternating methods of irrigation on the productivity of *Foeniculum vulgare* Mill subsp. *vulgare* var. *vulgare* under North Sinai conditions. *Research Journal of Agriculture and Biological Sciences*, 2(6): 571-577.
- Abdel Latef, A.A. and Chaoxing, H.** (2011). Effect of arbuscular mycorrhizal fungi on growth, mineral nutrition, antioxidant enzymes activity and fruit yield of tomato grown under salinity stress. *Scientia Horticulturae*, 127: 228–233.
- Abdel Latef, A.A. and Chaoxing, H.** (2014). Does inoculation with *Glomus mosseae* improve salt tolerance in pepper plants? *Journal of Plant Growth Regulation*, 33(3): 644-653.
- Aggarwal, A., Kadian, N., Neetu, K., Tanwar, A. and Gupta, K.K.** (2012). Arbuscular mycorrhizal symbiosis and alleviation of salinity stress. *J Appl Nat Sci* 4: 144–155.
- Ahmad, P., Prasad, M.N.V.** (2012a). *Environmental Adaptations and Stress Tolerance in Plants in the Era of Climate Change*. Springer, New York.
- Ahmad, P., Prasad, M.N.V.** (2012b). *Abiotic Stress Responses in Plants: Metabolism, Productivity and Sustainability*. Springer, New York.
- Anjum, F., Yaseen, M., Rasul, E., Wahid, A. and Anjum, S.** (2003b). Water stress in barley (*Hordeum vulgare* L.). II. Effect on chemical composition and chlorophyll contents. *Pakistan Journal of Agricultural Sciences*, 40: 45–49.
- Anonymous** (2015). Turning Basaltic Terrain into Model Research Farm: Chronicle Description. ICAR-National Institute of Abiotic Stress Management (NIAM), Pune 8: 1-64.
- Anonymous** (2015). Vision-2050. ICAR-National Institute of Abiotic Stress Management (NIAM), Pune: 1-27.
- Araus, J.L., Slafer, G.A., Reynolds, M.P. and Royo, C.** (2002). Plant breeding and drought in C₃ cereals: what should we breed for?. *Annals of Botany*, 89: 925–940.
- Arrese-Igor, C., Gordon, C., Gonzalez, E.M., Marino, D., Ladrera, R., Larrainzer, E., Gil-Quintana, E.** (2011). Physiological response of legume nodules to drought. *Plant Stress*, 5 (special issue 1): 24–31.
- Ashraf, M., and Orooj, A.** (2006). Salt stress effects on growth, ion accumulation and seed oil concentration in an arid zone traditional medicinal plant ajwain (*Trachyspermum ammi* [L.] Sprague). *Journal of Arid Environments*, 64(2): 209-220.
- Ashraf, M., Athar, H.R., Harris, P.J.C. and Kwon, T.R.** (2008). Some prospective strategies for improving crop salt tolerance. *Advances in Agronomy*, 97: 45–110.
- Baghalian, K., Haghiry, A., Naghavi, M.R., Mohammadi, A.** (2008). Effect of saline irrigation water on agronomical and phytochemical characters of chamomile (*Matricaria recutita* L.). *Scientia Horticulturae*, 116: 437-441.
- Ben Salah, I., Albacete, A., Andújar, C.M., Haouala, R., Labidi, N., Zribi, F., Martínez, V., Perez-Alfocea, F., Abdelly, C.** (2009). Response of nitrogen fixation in relation to nodule carbohydrate metabolism in *Medicago ciliaris* lines subjected to salt stress. *J Plant Physiol* 166: 477–488.
- Bhatt, R.M. and Rao, S.N.K.** (2005). Influence of pod load response of okra to water stress. *Indian Journal of Plant Physiology*, 10: 54– 59.
- Bilal, M., Rashid, R.M., Rehman, S.U., Iqbal, F., Ahmed, J., Abid, M.A., Ahmed, Z. and Hayat, A.** (2015). Evaluation of wheat genotypes for drought tolerance. *Journal of Green Physiology, Genetics and Genomics*, 1: 11–21.

*Corresponding Author

- Blum, A. and Pnuel, Y.** (1990). Physiological attributes associated with drought resistance of wheat cultivars in a mediterranean environment. *Australian Journal of Agricultural Research*, 41: 799–810.
- Charlson, D.V., Bhatnagar, S., King, C.A., Raj, J.D., Sneller, C.H., Carter, T.E.Jr., and Purcell, L.C.** (2009). Polygenic inheritance of canopy wilting in soybean [*Glycine max* (L.) Merr.]. *Theoretical and Applied Genetics*, 119: 587–594.
- Chaves, M.M., Maroco, J.P., Pereira, J.S.** (2003). Understanding plant responses to drought – from genes to the whole plant. *Functional Plant Biology*, 30: 239–264.
- Choudhary, A.K., Sultana, R., Chaturvedi, S.K., Sharma, R., Bhatt, B.P. and Singh, S.P.** (2014). Breeding strategies to mitigate abiotic stresses in pulses. *ECOBASM*, pp. 16-21.
- Craig, J., Barratt, P., Tatge, H., Dejardin, A., Handley, L., Gardner, G.D., Barber, L., Wang, T., Hedley, C., Martin, C. and Smith, A.M.** (1999). Mutations at the *rug4* locus alter the carbon and nitrogen metabolism of pea plants through an effect on sucrose synthase. *The Plant Journal*, 17: 353–362.
- Davenport, R., James, R., Zakrisson-Plogander, A., Tester, M. and Munns, R.** (2005). Control of sodium transport in durum wheat. *Plant Physiology*, 137: 807-818.
- Delgado, M.J., Ligerio, F. and Lluch, C.** (1994). Effects of salt stress on growth and nitrogen fixation by pea, faba-bean, common bean and soybean plants. *Soil Biol Biochem*, 26: 371–376.
- Dencic, S., Kastori, R., Kobiljski, B. and Duggan, B.** (2000). Evaluation of grain yield and its components in wheat cultivars and landraces under near optimal and drought conditions. *Euphytica*, 113(1): 43–52.
- Djanaguiraman, M. and Prasad, P.V.V.** (2013). Effects of salinity on ion transport, water relations and oxidative damage. In: Ahmad P, Azooz MM, Prasad MNV (eds), *Ecophysiology and Responses of Plants under Salt Stress*. Springer Science+Business Media, pp. 89–114.
- Djibril, S., Mohamed, O.K., Diaga, D., Diégane, D., Abaye, B.F., Maurice, S. and Alain, B.** (2005). Growth and development of date palm (*Phoenix dactylifera* L.) seedlings under drought and salinity stresses. *African J. Biotechnol.*, 4: 968–972.
- Edward, D. and Wright, D.** (2008). The effects of winter water-logging and summer drought on the growth and yield of winter wheat (*Triticum aestivum* L.). *European J. Agron.*, 28: 234–244.
- Egamberdieva, D. and Lugtenberg, B.** (2014). Use of plant growth-promoting rhizobacteria to alleviate salinity stress in plants. In: Miransari M (ed.), *Use of Microbes for the Alleviation of Soil Stresses*. Springer Science+Business Media, New York, pp. 73–96.
- Elsheikh, E.A. and Wood, E.M.** (1990). Effect of salinity on growth, nodulation and nitrogen yield of chickpea (*Cicer arietinum* L.). *J Exp Bot.* 41: 1263–1269.
- Elsheikh, E.A. and Wood, E.M.** (1995). Nodulation and N fixation by soybean inoculated with salt tolerant *Rhizobia* or salt sensitive *Bradyrhizobia* in saline soil. *Soil Biol Biochem*, 27: 657–661.
- Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. and Basra, S.M.A.** (2009). Plant drought stress: effects, mechanisms and management. *Agron. Sustain. Dev.*, 29: 185–212.
- Fischer, R., Turner, N. and Kramer, P.** (1980). Influence of water stress on crop yield in semiarid regions. In: Turner NC & Kramer PJ (eds) *Adaptation of plants to water and high temperature stress*. Wiley, New York, pp. 323–339.
- Fricke, W., Akhiyarova, G., Veselov, D. and Kudoyarova, G.** (2004). Rapid and tissue-specific changes in ABA and in growth rate response to salinity in barley leaves. *J. Exp. Bot.* 55: 1115–1123.
- Galvez, L., Gonzalez, E.M. and Arrese-Igor, C.** (2005). Evidence for carbon flux shortage and strong carbon/nitrogen interactions in pea nodules at early stages of water stress. *J Exp Bot.*, 56: 2551–2561.
- Gonzalez, E.M., Aparicio-Tejo, P.M., Gordon, A.J., Minchin, F.R., Royuela, M. and Arrese-Igor, C.** (1998.) Water-deficit effects on carbon and nitrogen metabolism of pea nodules. *J Exp Bot.*, 49: 1705–1714.
- Gonzalez, E.M., Gordon, A.J., Hames, C.L. and Arrese-Igor, C.** (1995). The role of sucrose synthase in the response of soybean nodules to drought. *J Exp Bot.*, 46: 1515–1523.
- Gordon, A.J., Minchin, F.R., James, C.L. and Komina, O.** (1999). Sucrose synthase in legume nodules is essential for nitrogen fixation. *Plant Physiol.*, 120: 867–877.
- Grattan, S.R. and Grieves, C.M.** (1999). Salinity-nutrient relations in horticultural crops. *Scientia Horticulturae*, 78: 127-57.
- Gupta, N., Gupta, S. and Kumar, A.** (2001). Effect of water stress on physiological attributes and their relationship with growth and yield of wheat cultivars at different stages. *Journal of Agronomy and Crop Science* 186: 55–62.
- Gursoy, M., Balkan, A. and Ulukan, H.** (2012). Ecophysiological responses to stresses in slants: A general approach. *Pak J Biol Sci.*, 15: 506–516.
- Hameed, A., Dilfuza, E., Abd-Allah, E.F., Hashem, A., Kumar, A. and Ahmad, P.** (2014). Salinity stress and arbuscular mycorrhizal symbiosis in plants. In: Miransari M (ed.), *Use of Microbes for the Alleviation of Soil Stresses*. Springer Science+Business Media New York pp. 139–159.
- Hasanuzzaman, M., Gill, S.S. and Fujita, M.** (2013). Physiological role of nitric oxide in plants grown under adverse environmental conditions. In: Tuteja N, Gill SS (eds), *Plant Acclimation to Environmental Stress*. Springer Science + Business Media, New York, pp. 269–322.

- Hasegawa, P.M., Bressan, R.A., Zhu, J.K. and Bohnert, H.J.** (2000). Plant cellular and molecular responses to high salinity. *Ann Rev Plant Physiol Plant Mol Biol.*, 51: 463–499.
- Hawes, M. C., Gunawardena, U., Miyasaka, S. and Zhao, X.** (2000). The role of root border cells in plant defense. *Trends in Plant Science*, 5(3): 128–133.
- Heuer, B. and Nadler, A.** (1995). Growth, development and yield of potatoes under salinity and water deficit. *Australian Journal of Agricultural Research*, 46: 1477–1486.
- Hu, Y., Burucs, Z., von Tucher, S., and Schmidhalter, U.** (2007). Short-term effects of drought and salinity on mineral nutrient distribution along growing leaves of maize seedlings. *Environmental and Experimental Botany*, 60(2): 268–275.
- Hussain, N., Sarwar, G., Schmeisky, H., Al-Rawahy, S. and Ahmad, M.** (2011). Salinity and drought management in legume crops. In: Yadav SS, McNeil DL, Redden R, Patil SA (eds), *Climate Change and Management of Cool Season Grain Legume Crops*. Springer, Dordrecht, pp: 171–192.
- ICAR** (2010). Degraded and Wastelands of India Status and Spatial Distribution. Indian Council of Agricultural Research, KAB-I, Pusa, New Delhi.
- Impa, S.M., Nadaradjan, S., Jagadish, S.V.K.** (2012). Drought stress induced reactive oxygen species and anti-oxidants in plants. In: Ahmad P, Prasad MNV (eds), *Abiotic Stress Responses in Plants: Metabolism, Productivity and Sustainability*. Springer Science + Business Media, pp. 131–147.
- James, R. A., Blake, C., Byrt, C. S. and Munns, R.** (2011). Major genes for Na⁺ exclusion, Nax1 and Nax2 (wheat HKT1;4 and HKT1;5), decrease Na⁺ accumulation in bread wheat leaves under saline and waterlogged conditions. *Journal of Experimental Botany*, 62(8): 2939–2947.
- James, R. A., von Caemmerer, S., Condon, A. G., Zwart, A. B. and Munns, R.** (2008). Genetic variation in tolerance to the osmotic stress component of salinity stress in durum wheat. *Functional Plant Biology*, 35(2): 111–123.
- Johansen, C., Baldev, B., Brouwer, J.B., Erskine, W., Jermyn, W.A., Li- Juan, L., Malik, B.A., Ahad Miah, A. and Silim, S.N.** (1992). Biotic and abiotic stresses constraining productivity of cool season food legumes in Asia, Africa and Oceania. In: Muehlbauer, F.J., W.J. Kaiser (eds.), *Expanding the Production and Use of Cool Season Food Legumes*, pp: 75–194. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Kage, H., Kochler, M. and Stutzel, H.** (2004). Root growth and dry matter partitioning of cauliflower under drought stress conditions: measurement and simulation. *European J. Agron.*, 20: 379–394.
- Kahlow, M. A., Raof, A., Zubair, M. and Kemper, W.D.** (2007). Water use efficiency and economic feasibility of growing rice and wheat with sprinkler irrigation in the Indus Basin of Pakistan. *Agricultural Water Management*, 87(3): 292–298.
- Kamara, A.Y., Menkir, A., Badu-Apraku, B. and Ibikunle, O.** (2003). The influence of drought stress on growth, yield and yield components of selected maize genotypes. *J. Agric. Sci.*, 141: 43–50.
- Kapoor, R., Evelin, H., Mathur, P. and Giri, B.** (2013). Arbuscular mycorrhiza: Approaches for abiotic stress tolerance in crop plants for sustainable agriculture. In: Tuteja N, Gill SS (eds), *Plant Acclimation to Environmental Stress*. Springer Science+Business Media, pp. 359–401.
- Kaur, H., Gupta, A.K., Kaur, N. and Sandhu, J.S.** (2009). Differential response of the antioxidant system in wild and cultivated genotypes of chickpea. *Plant Growth Regul* 57: 109–114.
- Kavar, T., Maras, M., Kidric, M., Sustar-Vozlic, J. and Meglic, V.** (2007). Identification of genes involved in the response of leaves of *Phaseolus vulgaris* to drought stress. *Molecular Breeding*, 21: 159–172.
- Khan, H.R., Paull, J.G., Siddique, K.H.M. and Stoddard, F.L.** (2010). Faba bean breeding for drought-affected environments: A physiological and agronomic perspective. *Field Crops Res*, 115: 279–286.
- Kiani, S.P., Maury, P., Sarrafi, A. and 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.
- Kilic, H. and Yagbasanlar, T.** (2010). The effect of drought stress on grain yield, yield components and some quality traits of durum wheat (*Triticum turgidum*) cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 38: 164–170.
- Kosova, K., Vitamvas, P., Urban, M.O., Kholova, J. and Prasil, I.T.** (2014). Breeding for enhanced drought resistance in barley and wheat – drought-associated traits, genetic resources and their potential utilization in breeding programmes. *Czech Journal of Genetics and Plant Breeding*, 50: 247–261.
- Kumar, J., and Abbo, S.** (2001). Genetics of flowering time in chickpea and its bearing on productivity in the semi-arid environments. *Advances in Agronomy*, 72: 107–138.
- Ladrera, R., Marino, D., Larrainzar, E., Gonzalez, E.M. and Arrese-Igor, C.** (2007). Reduced carbon availability to bacteroids and elevated ureides in nodules, but not in shoots, are involved in nitrogen fixation response to early drought in soybean. *Plant Physiol* 145: 539–546.
- Lafitte, H.R., Yongsheng, G., Yan, S. and Li, Z.K.** (2007). Whole plant responses, key processes and adaptation to drought stress: the case of rice. *J. Exp. Bot.*, 58: 169–175.
- Larcher, W.** (2003). *Physiological Plant Ecology*. 4th Ed. Springer Verlag, Berlin–Heidelberg.
- Lawlor, D.W. and Cornic, G.** (2002). Photosynthetic carbon assimilation and associated

- metabolism in relation to water deficits in higher plants. *Plant Cell Environ.*, 25: 275–294.
- Lonbani, M. and Arzani, A.** (2011). Morpho-physiological traits associated with terminal drought stress tolerance in triticale and wheat. *Agronomy Research*, 9(1-2): 315–329.
- Ludlow, M.M. and Muchow, R.C.** (1990). A critical evaluation of traits for improving crop yields in water-limited environments. *Advances in Agronomy*, 43: 107–153.
- Manivannan, P., Jaleel, C.A., Kishorekumar, A., Sankar, B., Somasundaram, R., Sridharan, R. and Panneerselvam, R.** (2007a). Changes in antioxidant metabolism of *Vigna unguiculata* (L.) Walp. by propiconazole under water deficit stress. *Colloids and Surfaces. B: Biointerfaces*, 57: 69–74.
- Massacci, A., Nabiev, S.M., Pietrosanti, L., Nematov, S.K., Chernikova, T.N., Thor, K. and Leipner, J.** (2008). 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.*, 46: 189–195.
- Materne, M. and McNeil, D.L.** (2007). Breeding methods and achievements. In: Yadav SS, McNeil DL, Stevenson PC (eds), *Lentil: An Ancient Crop for Modern Times*. Springer, Dordrecht, pp. 241–253.
- Mohammadian, R., Moghaddam, M., Rahimian, H. and Sadeghian, S.Y.** (2005). Effect of early season drought stress on growth characteristics of sugar beet genotypes. *Turkisk J. Bot.*, 29: 357–368.
- Monneveux, P., Sanchez, C., Beck, D. and Edmeades, G.O.** (2006). Drought tolerance improvement in tropical maize source populations: evidence of progress. *Crop Sci.*, 46: 180–191
- Morgan, J. M.** (1984). Osmoregulation and water stress in higher plants. *Annual Review of Plant Physiology*, 35: 299–319.
- Mozaffari, K., Arshi, Y. and Zeinali-Khanghaa, H.** (1996). Research on the effects of water stress on some morphophysiological traits and yield components of sunflower (*Helianthus annuus* L.). *Seed Plant*, 12: 24–33.
- Mudgal, V.** (2004). Physiological studies on growth and nitrogen metabolism in *Cicer arietinum* L. undersaline conditions. Ph.D. Thesis. Rohilkhand University, India.
- Munns, R.** (1993). Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. *Plant Cell Environ.* 16: 15–24.
- Munns, R.** (2002). Comparative physiology of salt and water stress. *Plant Cell Environ.* 25: 239–250.
- Munns, R. and Tester, M.** (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59: 651–681.
- Nicholas, S.** (1998). Plant resistance to environmental stress. *Current Opinion in Biotechnology*, 9: 214–219.
- Noctor, G. and Foyer, C. H.** (1998). Ascorbate and glutathione: keeping active oxygen under control. *Annual Review of Plant Physiology and Plant Molecular Biology*, 49: 249–279.
- Pagano, M.C.** (2014). Drought stress and mycorrhizal plants. In: Miransari M (ed.), *Use of Microbes for the Alleviation of Soil Stresses*. Springer Science + Business Media, New York, pp. 97–110.
- Passioura, J. B.** (1996). Drought and drought tolerance, In: *Drought Tolerance in Higher Plants: Genetical, Physiological and Molecular Biological Analysis*, E. Belhassen, Ed., pp. 3–12, Kluwer Academic, Dordrecht, The Netherlands.
- Passioura, J.B. and Munns, R.** (2000). Rapid environmental changes that affect leaf water status induce transient surges or pauses in leaf expansion rate. *Aust. J. Plant Physiol.* 27: 941–948.
- Petropoulos, S.A., Daferera, D., Polissiou, M.G. and Passam, H.C.** (2008). The effect of water deficit stress on the growth, yield and composition of essential oils of parsley. *Scientia Horticulturae*, 115: 393–397.
- Porcel, R., Aroca, R. and Ruiz-Lozano, J.M.** (2012) Salinity stress alleviation using arbuscular mycorrhizal fungi. A review. *Agron Sustain Dev*, 32: 181–200.
- Rabie, G.H. and Almadini, A.M.** (2005). Role of bioinoculants in development of salt-tolerance of *Vicia faba* plants under salinity stress. *Afr J Biotech* 4: 210–222.
- Rajendran, K., Tester, M. and Roy, S. J.** (2009). Quantifying the three main components of salinity tolerance in cereals. *Plant, Cell and Environment*, 32(3), 237–249.
- Ramos, M.L.G., Gordon, A.J., Michin, F.R., Sprent, J.I. and Parsons, R.** (1999). Effect of water stress on nodule physiology and biochemistry of a drought tolerant cultivar of common bean (*Phaseolus vulgaris* L.). *Annals Bot* 83: 57–63.
- Rane, J. M. and Maheshwari, S. N.** (2001). Effect of pre-anthesis water stress on growth, photosynthesis and yield of six wheat cultivars differing in drought tolerance. *Indian Journal of Plant Physiology*, 6: 53–60.
- Rao, R. C. N., Williams, J. H., Wadia, K. D. R., Hubikk, K. T. and Fraquhar, G. D.** (1993). Crop growth, water use efficiency and carbon isotope discrimination in groundnut genotypes under end season drought conditions. *Annals of Applied Biology*, 122: 357–367.
- Rasool, S., Ahmad, A., Siddiqi, T.O. and Ahmad, P.** (2013). Changes in growth, lipid peroxidation and some key antioxidant enzymes in chickpea genotypes under salt stress. *Acta Physiol Plant*, 35: 1039–1050.
- Reddy, A.R., Chaitanya, K.V. and Vivekanandan, M.** (2004). Drought induced responses of photosynthesis and antioxidant metabolism in higher plants. *J. Plant Physiol.*, 161: 1189–1202.

- Richards, R.A., Rawson, H.M. and Johnson, D.A.** (1986). Glaucousness in wheat: its development, and effect on water-use efficiency, gas exchange and photosynthetic tissue temperatures. *Australian Journal of Plant Physiology*, 13: 465–473.
- Rucker, K. S., Kevin, C. K., Holbrook, C. C. and Hook, J. E.** (1995). Identification of peanut genotypes with improved drought avoidance traits. *Peanut Science*, 22: 14–18.
- Sacks, M.M., Silk, W.K. and Burman, P.** (1997). Effect of water stress on cortical cell division rates within the apical meristem of primary roots of maize. *Plant Physiol.*, 114: 519–527.
- Saha, P., Chatterjee, P. and Biswas, A.K.** (2010). NaCl pretreatment alleviates salt stress by enhancement of antioxidant defense system and osmolyte accumulation in mungbean (*Vigna radiata* L. Wilczek). *Indian J Exp Biol*, 48: 593–600.
- Sankar, B., Jaleel, C.A., Manivannan, P., Kishorekumar, A., Somasundaram, R. and Panneerselvam, R.** (2007). Effect of paclobutrazol on water stress amelioration through antioxidants and free radical scavenging enzymes in *Arachis hypogaea* L. *Colloids Surface B: Biointerfaces*, 60: 229–235.
- Sankar, B., Jaleel, C.A., Manivannan, P., Kishorekumar, A., Somasundaram, R. and Panneerselvam, R.** (2008). Relative efficacy of water use in five varieties of *Abelmoschus esculentus* (L.) Moench. under water-limited conditions. *Colloids Surface B: Biointerfaces*, 62: 125–129.
- Sassi, S., Gonzalez, E.M., Aydi, S., Arrese-Igor, C. and Abdely, C.** (2008). Tolerance of common bean to long-term osmotic stress is related to nodule carbon flux and antioxidant defenses; evidence from two cultivars tolerance. *Plant Soil.*, 312: 39–48.
- Saxena, N.P., Johansen, C., Saxena, M.C. and Silim, S.N.** (1993). Selection for drought and salinity tolerance in cool-season food legumes. In: Singh KB, Saxena MC (eds), *Breeding for Tolerance in Cool Season Food Legumes*. John Wiley & Sons, Ltd, Chichester, UK, pp. 245–270.
- Shanker, A.K. and Venkateswarlu, B.** (2011). *Abiotic Stress in Plants – Mechanisms and Adaptations*. InTech Publisher, Janeza Tridne Rijeka, Croatia.
- Shao, H.B., Chu, L. Y., Jaleel, C. A. and Zhao, C. X.** (2008). Water-deficit stress-induced anatomical changes in higher plants. *Comptes Rendus*, 331(3): 215–225.
- Sharp, R. E. and Davis, W. J.** (1989). Regulation of growth and development of plants growing with a restricted supply of water, in *Plant under Stress*, H. G. Jones, T. J. Flowers, and M.B. Jones, Eds., pp. 71–93, Cambridge University Press, Cambridge, UK.
- Sharp, R.E. and LeNoble, M.E.** (2002). ABA, ethylene and the control of shoot and root growth under water stress. *J. Exp. Bot.*, 53: 33–37
- Shimazaki, Y., Ookawa, T. and Hirasawa, T.** (2005). The root tip and accelerating region suppress elongation of the decelerating region without any effects on cell turgor in primary roots of maize under water stress. *Plant Physiology*, 139(1): 458–465.
- Siddique, K.H.M., Loss, S.P. and Thomson B.D.** (2003). Cool season grain legumes in dryland Mediterranean environments of Western Australia: Significance of early flowering, in: Saxena N.P. (Ed.), *Management of Agricultural Drought*. Science Publishers, Enfield (NH), USA, pp. 151–161.
- Sinclair, T.R. and Serraj, R.** (1995). Legume nitrogen fixation and drought. *Nature*, 378: 344.
- Singh, B.B., Mai-Kodomi, Y. and Terao, T.** (1999). Relative drought tolerance of major rainfed crops of the semi-arid tropics. *Ind J Gene*, 59: 1–8.
- Singh, T. N. Paleg, L. G. and Aspinall, D.** (1973). Stress metabolism. I. Nitrogen metabolism and growth in the barley plant during water stress. *Australian Journal of Biological Sciences*, 26: 45–56.
- Specht, J.E., Chase, K., Macrander, M., Graef, G.L., Chung, J., Markwell, J.P., Germann, M., Orf, J.H. and Lark, K.G.** (2001). Soybean response to water. A QTL analysis of drought tolerance. *Crop Science*, 41: 493–509.
- Spollen, W. G., Sharp, R. E., Saab, I. N. and Wu, Y.** (1993). Regulation of cell expansion in roots and shoots at low water potentials, in *Water Deficits, Plant Responses From Cell to Community*, J. A. C. Smith and H. Griffiths, Eds., pp. 37–52, Bios Scientific Publishers, Oxford, UK.
- Streeter, J.G.** (2003). Effects of drought on nitrogen fixation in soybean root nodules. *Plant Cell Environ*, 26: 1199–1204.
- Subbarao, G.V., Johansen, C., Slinkard, A.E., Rao, R.C.N., Saxena, N.P. and Chauhan Y.S.** (1995). Strategies and scope for improving drought resistance in grain legumes. *Critical Reviews in Plant Sciences*, 14: 469–523.
- Sudhakar, C., Reddy, P. S. and Veeranjanyulu, K.** (1993). Effect of salt stress on the enzymes of proline synthesis and oxidation in green gram *Phaseolus aureus* roxb seedlings. *Journal of Plant Physiology*, 141: 621–623.
- Tabatabaie, S.J. and Nazari, J.** (2007). Influence of nutrient concentration and NaCl salinity on growth, photosynthesis and essential oil content of peppermint and lemon verbena. *Turk J Agric.*, 31: 245–253.
- Tahir, M.H.N. and Mehid, S.S.** (2001). Evaluation of open pollinated sunflower (*Helianthus annuus* L.) populations under water stress and normal conditions. *Int. J. Agric. Biol.*, 3: 236–238.
- Tahir, M.H.N., Imran, M. and Hussain, M.K.** (2002). Evaluation of sunflower (*Helianthus annuus* L.) inbred lines for drought tolerance. *Int. J. Agric. Biol.*, 3: 398–400.
- Tahkokorpi, M., Taulavuori, K., Laine, K. and 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.
- Toker, C. and Mutlu, N.** (2011). Breeding for abiotic stress. In: Pratap A, Kumar J (eds) *Biology and Breeding of Food Legumes*. CAB International, pp. 241–260.
- Toker, C. and Yadav, S.S.** (2010). Legume cultivars for stress environments. In: Yadav SS, McNeil DL, Redden R, Patil SA (eds), *Climate Change and Management of Cool Season Grain Legume Crops*. Springer, Dordrecht, pp. 351–376.
- Toker, C., Canci, H. and Yildirim, T.** (2007b). Evaluation of perennial wild *Cicer* species for drought resistance. *Gen Res Crop Evol.*, 54: 1781–1786.
- Toker, C., Lluch, C., Tejera, N.A. and Siddique, K.H.M.** (2007a). Abiotic stresses. In: Yadav SS, Redden R, Chen W, Sharma B (eds) *Chickpea Breeding and Management*. CAB International, Wallingford, UK, pp. 474–496.
- Turner, N.C., Wright, G.C. and Siddique, K.H.M.** (2001). Adaptation of grain legumes (pulses) to water-limited environments. *Advances in Agronomy*, 71: 123–231.
- Vadez, V., Sinclair, T.R. and Serraj, R.** (2000). Asparagine and ureide accumulation in nodules and shoot as feedback inhibitors of N₂ fixation in soybean. *Physiol Plant* 110: 215–223.
- Valentine, A.J., Benedito, V.A. and Kang, Y.** (2011). Legume nitrogen fixation and soil abiotic stress: From physiology to genomic and beyond. *Annual Plant Rev* 42: 207–248.
- Verdoy, D., Coba del Pena, T., Redondo, F.J., Lucas, M.M. and Pueyo, J.J.** (2006). Transgenic *Medicago truncatula* plants that accumulate proline display nitrogen-fixing activity with enhanced tolerance to osmotic stress. *Plant Cell Environ* 29: 1913–1923.
- Wang, F. Z., Wang, Q. B., Kwon, S. Y., Kwak, S. S. and Su, W. A.** (2005). Enhanced drought tolerance of transgenic rice plants expressing a pea manganese superoxide dismutase. *Journal of Plant Physiology*, 162(4): 465–472.
- Wang, W., Vinocur, B. and Altman, A.** (2007). Plant responses to drought, salinity and extreme temperatures towards genetic engineering for stress tolerance. *Planta*. 218: 1-14.
- Watson, D. J.** (1952). The physiological basis of variation in yield. *Advances in Agronomy*, 4: 101–144.
- Webber, M., Barnett, J., Finlayson, B. and Wang, M.** (2006). *Pricing China's Irrigation Water*. Working Paper, School of Anthropology, Geography and Environmental Studies, The University of Melbourne, Victoria, Australia.
- Wu, Q.S., Xia, R.X. and Zou, Y.N.** (2008). Improved soil structure and citrus growth after inoculation with three arbuscular mycorrhizal fungi under drought stress. *European Journal of Soil Biology*, 44: 122–128.
- Wullschleger, S.D., Yin, T.M., DiFazio, S.P., Tschaplinski, T.J., Gunter, L.E., Davis, M.F. and Tuskan, G.A.** (2005). Phenotypic variation in growth and biomass distribution for two advanced-generation pedigrees of hybrid poplar. *Canadian J. For. Res.*, 35: 1779–1789
- Xue, Q. W., Zhu, Z. X., Musick, J. T., Stewart, B. A. and Dusek, D. A.** (2006). Physiological mechanisms contributing to the increased water-use efficiency in winter wheat under deficit irrigation. *Journal of Plant Physiology*, 163(2): 154–164.
- Yeo, A.** (1999). Prediction of the interaction between the effects of salinity and climate change on crop plants. *Scientia Horticulturae*, 78: 159–174.
- Zhang, M., Duan, L., Zhai, Z., Li, J., Tian, X., Wang, B., He, Z. and Li, Z.** (2004). Effects of plant growth regulators on water deficit-induced yield loss in soybean. Proceedings of the 4th International Crop Science Congress, Brisbane, Australia.
- Zhu, J.K.** (2007). *Plant Salt Stress*: John Wiley & Sons, Ltd.