OPEN ACCESS J. Plant Environ. 04 (01) 2022. 09-17 DOI: 10.33687/jpe.004.01.3995

Check for updates

Available Online at EScience Press
Journal of Plant and Environment
ISSN: 2710-1665 (Online), 2710-1657 (Print)
https://esciencepress.net/journals/JPE

Comparative Screening of Hybrids and Synthetic Maize (*Zea mays* L.) Cultivars for Drought-Sensitive and Drought-Tolerant Under Different Irrigation Regimes

Muhammad Nadeem Shah[1,2*], Shabir Hussain[2*], Hakoomat Ali[2], Mehrab Khan[2], Humaira Jamil[3], Anum Bukhari[2], Shahkar Ali[2], Muhammad Naveed[2], Muhammad Sohail[4,5]

[1]North Florida Research and Education Centre (NFREC), Univer. of Florida, 155 Research Road, Quincy, FL, 32351, USA.
[2]Department of Agronomy, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Punjab, Pakistan.
[3]Department of Plant Breeding & Genetics, University of Agriculture Faisalabad, Pakistan.
[4]Department of Horticulture, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Punjab, Pakistan.
[5]UMR Agap _ Universite' de Montpellier, TA A108/03, Avenue Agropolis, F-34398, Montpellier Codex 05, France.

ARTICLE INFO

Article History
Received: February 13, 2022
Revised: April 17 2022
Accepted: April 26, 2022

Keywords
Maize hybrids
Drought-sensitive
Drought-tolerant
Osmotic potential
Plant-water status

ABSTRACT

Water scarcity is the most serious issue in crop production around the globe. Because of less water availability, various breeding and agronomic management techniques are being used to cope with this issue. For this purpose, a pot experiment was performed to screen hybrids and synthetic maize cultivars for drought-tolerance under various irrigation regimes at green-house of Agronomic Research Farm, Bahauddin Zakariya University, Multan, Pakistan during 2017. Experimental treatments comprise five maize hybrids *viz*. H_1=DK-6317, H_2=DK-6724, H_3=P-1543, H_4=P-1429, and H_5= P-1574 and three locally synthetic maize cultivars *viz*. S_1= Neelum, S_2= Pak- Afghoi, and S_3= Sadaf and three irrigation regimes *viz*. Control (CK) =80%WHC (water holding capacity), low drought (LD) =60% WHC and severe drought (SD) =40% WHC. It was resulted that irrigation regimes significantly affect growth and plant water relation. Results regarding maize hybrids growth showed that maximum plant height (5.20, 46.8, and 38.77 cm), number of leaves (6.41, 6.19, and 5.65), leaf area per plant (415.5, 361.5 and 305.8 cm^2), dry weight of shoot per plant (6.09, 5.09, and 4.39 g) and dry weight of root per plant (0.85, 0.82, and 0.78 g) was obtained from DK-6724 under CK, LD and SD, respectively. While the minimum plant height (45.23, 36.47 and 28.87 cm), number of leaves (5.38, 5.05, and 4.79), leaf area per plant (11.87, 10.99, and 10.01 cm^2), dry weight of shoot per plant (5.71, 4.75, and 4.02 g) and dry weight of root per plant (0.66, 0.63 and 0.61 g) was measured in P-1429 under CK, LD and SD, respectively. Likewise, in synthetic cultivars, Neelum performed well followed by Pak-Afghoi and Sadaf in all irrigation regimes. Results regarding plant water relation revealed that DK-6724 and Neelum maintained their osmotic potential and are considered as drought-tolerant. While P-1429 and Sadaf could not maintain their osmotic potential and were considered as drought-sensitive under normal and drought stress.

Corresponding Author: Muhammad Nadeem Shah; Shabir Hussain
Email: agrariansmnsb@yahoo.com; shabirhussain@bzu.edu.pk

INTRODUCTION

Maize (*Zea mays* L.) is an essential 3rd main cereal crop after wheat and rice and also staple food that provide food to a large number of populations in the world. It is also a vital fodder crop because it feeds livestock, and it gives the raw material for agro-based industries as well as a series of products, *i.e.*, starch, fiber, malt dextrin, glucose and gluten-free products for the production of alcohol, pharmaceuticals, cosmetics, edible oil, textile paper, and organic chemicals (Aziz *et al*., 2010). Maize has greater nutritional values as it contains about 10% proteins, 72% starch, 3% sugar, 8.5% fiber, 4.8% oil, and 1.7% ash (Chaudhary *et al*., 1998). In underdeveloped nations, maize is a key source of revenue and employment (Tagne *et al*., 2008). Inputs can be used efficiently because of the crop's short lifetime, and they can produce huge quantities of food grains per unit area. In Pakistan, maize has become a significant component in agriculture, contributing 0.5 % to GDP and 2.4% to value-added in agriculture. It may be grown effectively as an autumn and spring crop twice a year in Pakistan. It was cultivated on an average area of 0.94 Mha with a total annual production of 6.99 Mt during 2019-2020 (Government of Pakistan 2021).

We depend heavily on cereals in our food sources, yet agricultural production of grains is greatly affected due to drought stress (Elliott *et al*., 2014; Kadam *et al*., 2014). It was estimated that approximately 3% of cereal production was lost due to drought disasters worldwide during 2000-2007 (Lesk *et al*., 2016). In the last few decades, many drought events conducted and are anticipated some countries where farming will be challenging, like Asia and beyond (Lobell *et al*., 2011). Except in the United States (USA), significant maize production (China, Brazil, France) is intensified to experience low production due to changing climate (Lobell *et al*., 2011). Water-holding capacity, soil compositions regarding organic carbon compound's aggregation, and moisture availability are the key factors for drought severity. However, due to long-lasting drought on agro ecosystem causes severe threats to the economy of different nations (Lal, 2009).

Water is the most critical limiting factor in the natural environment for plant growth and limiting agriculture productivity (Siddique *et al*., 2000; Tang *et al*., 2017) and with about 45% of arable land located in semiarid and arid areas restricted globally (Farooq *et al*., 2009; Hou *et al*., 2014). Water supply is as vital as nitrogen for successful crop and crop production (Mansouri-Far *et al*., 2010). However, irrigation is the only solution to solve this issue, but it faces a shortage problem day by day. Now a days, water scarcity has become a significant problem for crop production worldwide (Abbasi *et al*., 2016; Hussain *et al*., 2018). Drought effects on change in enzyme activity, disruption of metabolism, reduce photosynthesis, enhance respiration (Aslam *et al*., 2015; Guo *et al*., 2018; Ibrahim *et al*., 2001), damage ecological environment, and also effect on development and growth of the plant (Anjum *et al*., 2011; Liu *et al*., 2012; Peñuelas *et al*., 2001). Statistics of the last three years showed that drought reduced food production 15.6% - 48.5% (Ashraf *et al*., 2006; Zheng *et al*., 2017). All the biochemical reactions of plants are affected by drought conditions. Due to water scarcity, the efficiency of plants is also severely influenced by the crop yield by low stomatal performance during the respiration process (Yordanov *et al*., 2000). A plant's performance as sub-stomatal conductance is also influenced under drought stress by preventing the photosynthetic electron transport rate from increasing (Chakir & Jensen, 1999). Water stress reduces plant height (Soler *et al*., 2007) and leaf area (Pandey *et al*., 2000) by limiting cell division and leaf growth (Reymond *et al*., 2003). Depending upon climate conditions, maize requires about 600-700 mm water for optimum crop yield and growth (Reddy & Nayak, 2018). Drought conditions affect the growth and production of maize crops at any stage of their development (Paudyal, 2001). Plant under Drought stress attempt adaptive mechanisms and uptake water through the osmotic adjustment to adjust and maintain cell turgor and aid them to tolerate, avoid or escape moisture stress by increasing protoplasmic resistance (Ahanger *et al*., 2014; Aslam *et al*., 2015; Basu *et al*., 2016).

Developing drought-tolerant hybrids and progressive agronomic practices over the last few decades have improved corn yield gradually worldwide (Kucharik, 2008). So, by adopting some strategies, like screening drought-tolerant maize hybrids, the decline of yield due to drought stress can be minimized.

MATERIALS AND METHODS

Experimental site and soil

A set of pot experiments (hybrids versus synthetic maize cultivars) was conducted comparatively at greenhouse of Agronomic Research Area, Department of Agronomy, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan. Soil samples were collected from the research area of 0-20 cm top soil. Soil samples were air-dried and crushed to sieve through 0.2 mm mesh to analyze the soil. The soil analysis is given in Table 1.

Table 1. Pre experiment soil analysis.

Determination	pH	EC (dSm^{-1})	N (mg/kg)	P (mg/kg)	K (mg/kg)	Organic matter (%)
Value	7.92	2.1	0.54	5.08	178	0.8

Greenhouse environment

Seedlings of the maize were sown under an average day and night temperature in the range of 21-23 °C with a 14 h photoperiod.

Experimental treatments

Experimental treatments comprise of five maize hybrids *viz*. H_1=DK-6317, H_2=DK-6724, H_3=P-1543, H_4=P-1429 and H_5= P-1574 Vs three synthetic maize cultivars *viz*. S_1= Neelum, S_2= Pak- Afghoi, and S_3= Sadaf and three levels of drought stress concerning water holding capacity *viz*. Control (Ck) 80% WHC, Low drought (LD) 60% WHC and severe drought (SD) 40% WHC. Complete randomized design (CRD) factorial design was used. Maize hybrids and synthetic cultivars were suggested by agronomic scientists and were high-yielding in southern Punjab, Pakistan.

The sowing was done on 1st February 2017. 22×50 cm diameter earthen pots were filled by 20 kg experimental soil, and five seeds in each pot were sown. Before sowing seed, treatment with Thiophanate Methyl @2g/kg was done to prevent disease attack. Pots were placed equally with the same distance to remove border distance. A recommended dose of N:P:K was also applied at the rate of 80:46:33 kg/Acre. Pots were irrigated usually for seed germination till 15 days after sown (DAS). Drought stress was applied accordingly after 15 DAS. Carbofuran was also applied at the 4th leaf stage to prevent stem borer. Field capacity (FC) was maintained by rinsing the pot three times a day. Thinning was done 15 DAS, and three plants were left to grow. Weeds were also removed from pots by hand pulling. Harvesting was done after 35 DAS. Three plants were randomly selected from each replication to collect data.

Observations

A measuring tape was used to determine plant height. Roots were taken out to measure plant biomass, washed to remove soil particles, and stored in a paper bag. Fresh weight and dry plant biomass were recorded using a digital balance. Water potential (-MPA) was measured from the top 3rd leaf at morning time with Scholander type pressure chamber. The selected leaf was frozen for seven days to measure osmotic potential (-MPA) at below -20°C. The osmotic potential (-MPA) of the leaf in a vapor pressure osmometer was determined by extracting the sap after seven days. At the same time, the difference between water potential and osmotic potential was used to compute turgor potential (MPA). The 4th leaf from the top was collected to measure relative saturation deficit (RSD %) in the morning. Immediately, fresh weight of the leaf was recorded after cleaning the upper surface of the leaf with tissue papers. After this leaf was left over a night at room temperature placed in a test tube containing 10 ml distilled water. On the next day, the leaf was taken to record the saturated weight of samples. For this purpose, the leaf's upper surface was cleaned with the tissue papers, and a digital balance was used to determine the saturated leaf weight as fellow relative saturation deficit (RSD %) was calculated.

RSD= (saturated weight (g) – fresh weigh (g)/saturated weight (g)) × 100

Statistical Analysis

Fisher's analysis of variance approach was used to statistically examine the collected data (d Steel and Torrie, 1986). Least significant difference (LSD) test was used to compare the treatment mean at 5% probability level. Values recorded are the means of three plants and were analyzed statistically using Statistic 8.1.

RESULTS

Agronomic traits

Various hybrids and synthetic cultivars were tested under multiple irrigation schemes to determine which hybrid and cultivar shows more resistant to drought or more susceptible to drought. This experiment showed that drought showed a significant difference in both hybrids and synthetic maize cultivars. With increasing drought conditions, the growth of maize traits was affected dramatically compared to control treatment. A significant decrease in plant height of maize traits was found under drought stress as compared to control (CK). Similar plant height, other agronomic traits like root length (RL), number of leaves (NL), leaf area (LA), and plant biomass of hybrids and synthetic cultivars of maize were also showed a negative effect with increasing drought stress. In maize hybrids, the performance of DK-6724 was significant as compared to other maize hybrids under low drought (LD) and severe drought (SD). While, in maize synthetic cultivars, the performance of Neelum was significantly when compared with Sadaf and Pak. Afghoi cultivars under normal and drought conditions. Meanwhile, P-1429 in maize hybrids and Sadaf in maize synthetic cultivars performed poorly under control (CK) and also under low drought (LD) and severe drought (SD) among the maize genotypes. Hence, maize DK-6724 and Neelum showed tolerance under drought stress while P-1429 and Sadaf showed sensitivity against drought stress.

Plant-water relation

Water potential (-MPA), turgor potential (MPA), osmotic potential (-MPA), and Relative saturation deficit (RSD) are the most often used indicators for evaluating the water condition of plants (Kiani *et al*., 2007). Results showed that drought stress has a significant effect on plant-water status. In maize hybrids and synthetic cultivars, with increasing drought stress, water potential also decreased compared with control irrigation (Ck). In DK-6724 and Neelum, maximum water potential was noticed, and with increasing drought stress, they also showed maximum water potential compared to other hybrids and synthetic cultivars (Fig. 1). Likewise, water potential maximum osmotic potential and turgor potential were also observed in DK-6724 and Neelum cultivars with increasing drought stress. At the same time, minimum water potential, osmotic potential, and turgor potential were observed in P-1429 and Sadaf under every day and drought stress. As well as it is a concern with relative saturation deficit, maximum relative saturation deficit was observed in DK-6724 and Neelum under drought stress and normal irrigation. While a minimum relative saturation deficit was observed in P-1429 and Sadaf with increasing drought stress also in normal irrigation (Fig. 1).

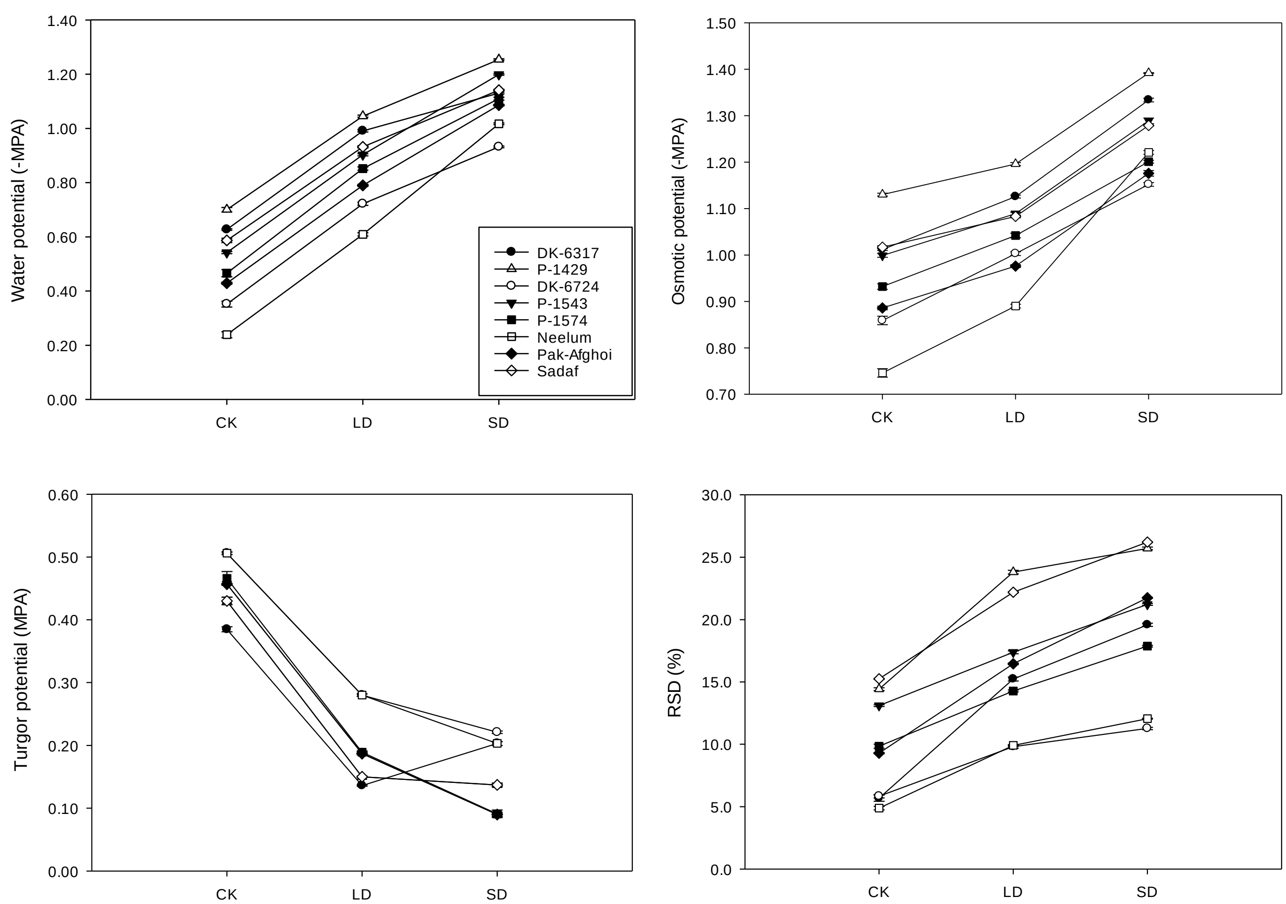

Figure 1. Plant-water relationship of maize hybrids and synthetic cultivars affected by drought stress at p≤0.05, CK= control (80% WHC), LD= low drought (60% WHC) and SD=severe drought (40% WHC).

DISCUSSION

Agronomic and plant-water status data showed that drought stress significantly influences the growth of maize seedlings. Agronomic and plant water status data show that drought stress greatly affects the development of maize seedlings. Drought stress in maize reduced cell elongation and cell division (Anjum *et al*., 2017; Shao *et al*., 2008). Change in morphological attributes of plants is the definitive result of drought (Farooq *et al*., 2009; Jaleel *et al*., 2009). The plant height (PH) of maize hybrids decreased with decreasing FC (Olaoye *et al*., 2009). It was resulted that plant height is being affected when water deficit conditions were applied (Abo-El-Kheir, 2007; Aslam *et al*., 2013; Golbashy *et al*., 2010). Leaf area (LA) is affected mainly by soil moisture (Abo-El-Kheir, 2007; Granier *et al*., 2006; Olaoye *et al*., 2009). So, maize genotypes leaf area decreased with increasing drought stress compared to controlled treatment. A lack of water in the root zone has previously limited leaf area in maize (Ashraf *et al*., 2006). It was resulted that soil water intensity significantly influenced a genotype's leaf area (Olaoye *et al*., 2009). In addition to the growth of l roots characters, drought stress significantly reduced the root length by inhibiting the lateral root meristems' activity (Deak & Malamy, 2005). Water deficit conditions significantly affected the root length of maize (Li *et al*., 2002) and depressed it up to 45 and 33% compared to normal irrigation (Vamerali *et al*., 2003). Several seedling features are affected by drought, including shoot length and fresh and dried plant parts (Yang *et al*., 2004). In cereals, growth performance is directly linked with well-developed root systems to improve drought stress tolerance (Ahmed *et al*., 2019; Avramova *et al*., 2016; Chloupek *et al*., 2010; Sayed, 2011). However, dry root biomass and root length reduced significantly under drought stress. Similarly, in plant biomass components, (Baiyeri *et al*., 2009) reported maximum fresh root and dry weight under normal irrigation compared to drought conditions. Some researchers (Baiyeri *et al*., 2009; Vamerali *et al*., 2003) noticed that maize leaves with different irrigation regimes have different leaf fresh and dry weights. Some researcher (Ahmad *et al*., 2004) observed the minimum stem dry weight in drought conditions compared to normal irrigation. Dehydration has the most significant and immediate consequences for plants, primarily on the state of leaf water (Farooq *et al*., 2009; Taiz & Zeiger, 2006). Moreover, (Chimenti *et al*., 2006; Farhad *et al*., 2011; Medici *et al*., 2003) support our results in plant water relations. (Medici *et al*., 2003) resulted that water potential showed significant results under different irrigation regimes (Table 2). It was resulted that leaf water potential of regular irrigation was -0.4 MPa while under drought condition leaf water potential decreased (Westgate & Boyer, 1985). Leaves osmotic potential under water stress decrease while in regular irrigation is increased (Chimenti *et al*., 2006). He also observed that leaf turgor potential increased under regular irrigation. Similarly (Ashraf *et al*., 2006) concluded that RSD % decreased with a decrease in water stress conditions. Many researchers have investigated that under moisture stress, leaves exhibit a significant reduction in relative water content (RWC) and water potential (Deak & Malamy, 2005; Kyparissis *et al*., 1995; Li & Van Staden, 1998; Nayyar & Gupta, 2006; Scarascia-Mugnozza *et al*., 1996).

CONCLUSION

It was concluded that in maize hybrids and synthetic cultivars, DK-6724 and Neelum maintained their osmotic potential and also attained the maximum growth under control and drought stress regimes. While P-1429 and Sadaf could not maintain their osmotic potential and also performed poorly in growth under different irrigation regimes. So, DK-6724 and Neelum are considered as drought-tolerant while P-1429 and Sadaf are considered as drought-sensitive among the maize hybrids and synthetic cultivars.

CONFLICT OF INTEREST

The authors declares that they have no conflict of interest.

 DOI: 10.33687/jpe.004.01.3995

Table 2. Physical parameters of maize hybrids and synthetic cultivars influenced by different irrigation regimes.

	Treatments		Agronomic observations					
	Maize genotypes	Drought stress (%)	Plant height (cm)	Number of leaves per plant	Root length(cm)	Leaf area per plant(cm²)	Dry weight of shoot per plant(g)	Dry weight of root per plant(g)
Maize hybrids	DK-6317	CK	52.40b	6.25b	13.01b	409.4b	5.99b	0.80c
		LD	44.47g	5.99d	12.25e	354.6f	4.99g	0.77e
		SD	36.87k	5.65f	11.38i	299.4k	4.31l	0.74d
	DK-6724	CK	55.20a	6.41a	13.32a	415.5a	6.09a	0.85a
		LD	46.87e	6.19c	12.48d	361.5e	5.09f	0.82b
		SD	38.77j	5.65f	11.62g	305.8i	4.39k	0.78d
	P-1543	CK	50.10c	5.92e	12.65c	410.2b	5.90c	0.76f
		LD	42.37h	5.64f	11.84f	355.7f	4.91h	0.73h
		SD	34.77m	5.32h	10.99j	301.0j	4.22m	0.70j
	P-1429	CK	45.23f	5.38g	11.87f	401.4d	5.71e	0.66l
		LD	36.47l	5.05i	10.99j	347.7h	4.75j	0.63n
		SD	28.87o	4.79k	10.01l	294.6m	4.02o	0.61o
	P-1574	CK	47.67d	5.66f	12.22e	407.2c	5.80d	0.71j
		LD	39.87i	5.32h	11.42h	351.5g	4.84i	0.68k
		SD	32.20n	5.01j	10.54k	297.5l	4.12n	0.64m
Maize synthetic cultivars	Neelum	CK	42.47a	6.38a	13.99a	337.2a	7.27a	0.81a
		LD	39.17b	6.14b	13.31b	315.7d	5.86d	0.75c
		SD	35.87d	5.79d	12.41d	291.0g	4.96g	0.69g
	Pak- Afghoi	CK	38.17c	5.89c	12.71c	335.8b	6.71b	0.78b
		LD	35.43d	5.65e	11.91e	311.4e	5.49e	0.74d
		SD	33.03e	5.29g	11.01g	287.7h	4.62h	0.72e
	Sadaf	CK	35.27d	5.59f	11.19f	331.5c	6.16c	0.74cd
		LD	32.10f	5.19h	10.38h	307.5f	5.21f	0.70f
		SD	30.13g	4.95i	9.49i	284.6i	4.29i	0.67h

REFERENCES

Abbasi, H., M. Jamil, A. Haq, S. Ali, R. Ahmad, Z. Malik and Z. Parveen. 2016. Salt stress manifestation on plants, mechanism of salt tolerance and potassium role in alleviating it: a review. Zemdirbyste-Agriculture, 103(2): 229-238.

Abo-El-Kheir, M. 2007. Response of maize single cross-10 to water deficits during silking and grain filling stages. World Journal of Agricultural Science, 3(3): 269-272.

Ahanger, M.A., S.R. Tyagi, M.R. Wani and P. Ahmad. 2014. Drought tolerance: role of organic osmolytes, growth regulators, and mineral nutrients. In Physiological mechanisms and adaptation strategies in plants under changing environment, (pp. 25-55). Springer.

Ahmad, I., S. Habib, H. Ahmad and M. Ammad. 2004. Comparative evaluation and analysis of seedling traits for drought tolerance in maize. International Journal of Agriculture and Biology, 6, 246-251.

Ahmed, K., S. Shahid, E.-S. Chung, X. -j. Wang and S.B. Harun. 2019. Climate change uncertainties in seasonal drought severity-area-frequency curves: Case of arid region of Pakistan. Journal of Hydrology, 570, 473-485.

Anjum, S.A., U. Ashraf, M. Tanveer, I. Khan, S. Hussain, B. Shahzad, A. Zohaib, F. Abbas, M.F. Saleem and I. Ali. 2017. Drought-induced changes in growth, osmolyte accumulation, and antioxidant metabolism of three maize hybrids. Frontiers in plant science, 8.

Anjum, S.A., X.-y Xie, L.-c Wang, M.F. Saleem, C. Man and W. Lei. 2011. Morphological, physiological, and biochemical responses of plants to drought stress. African journal of agricultural research, 6(9): 2026-2032.

Ashraf, M.Y., K. Akhtar, F. Hussain and J. Iqbal. 2006. Screening of different accessions of three potential grass species from the Cholistan desert for salt tolerance. Pakistan Journal of Botany, 38(5): 1589-1597.

Aslam, M., M.S. Ibni Zamir, I. Afzal and M. Yaseen. 2013. Morphological and physiological response of maize hybrids to potassium application under drought stress. Journal of Agricultural Research, (03681157), 51(4).

Aslam, M., M.A. Maqbool and R. Cengiz. 2015. Effects of drought on maize. In Drought stress in maize (*Zea mays* L.) (pp. 5-17). Springer.

Avramova, V., K.A. Nagel, H. AbdElgawad, D. Bustos, M. DuPlessis, F. Fiorani and G.T. Beemster. 2016. Screening for drought tolerance of maize hybrids by multi-scale analysis of root and shoot traits at the seedling stage. Journal of Experimental Botany, 67(8): 2453-2466.

Aziz, T., S. Ullah, A. Sattar, M. Nasim, M. Farooq and M.M. Khan. 2010. Nutrient availability and maize (*Zea mays* L.) growth in soil amended with organic manures. International Journal of Agriculture and Biology, 12(4): 621-624.

Baiyeri, K., A. Tenkouano and S. Aba. 2009. The residual effect of plantain-targeted manure on substrate fertility and performance of follower maize (*Zea mays* L.) crop. Journal of Animal and Plant Sciences (JAPS), 3(2): 194-204.

Basu, S., V. Ramegowda, A. Kumar and A. Pereira. 2016. Plant adaptation to drought stress. F1000Research, 5.

Chakir, S. and M. Jensen. 1999. How does Lobaria pulmonaria regulate photosystem II during progressive desiccation and osmotic water stress? A chlorophyll fluorescence study at room temperature and 77 K. Physiologia Plantarum, 105(2): 256-264.

Chaudhary, M., M. Shafiq and A. Rehman. 1998. Effect of organic and inorganic fertilizer on maize crop response under eroded loess soil. Pakistan Journal of Soil Science, 15(3-4): 39-43.

Chimenti, C.A., M. Marcantonio and A. Hall. 2006. Divergent selection for osmotic adjustment results in improved drought tolerance in maize (*Zea mays* L.) in both early growth and flowering phases. Field Crops Research, 95(2-3): 305-315.

Chloupek, O., V. Dostál, T. Středa, V. Psota and O. Dvořáčková. 2010. Drought tolerance of barley varieties in relation to their root system size. Plant Breeding, 129(6): 630-636.

d Steel, R.G. and J.H. Torrie. 1986. Principles and procedures of statistics: a biometrical approach. McGraw-Hill.

Deak, K.I. and J. Malamy. 2005. Osmotic regulation of root system architecture. The Plant Journal, 43(1): 17-28.

Elliott, J., D. Deryng, C. Müller, K. Frieler, M. Konzmann, D. Gerten, M. Glotter, M. Flörke, Y. Wada and N. Best. 2014. Constraints and potentials of future irrigation water availability on agricultural production under climate change. Proceedings of the National Academy of Sciences, 111(9): 3239-3244.

Farhad, W., M.A. Cheema, M.F. Saleem and M. Saqib. 2011. Evaluation of Drought Tolerance in Maize Hybrids. International Journal of Agriculture & Biology, 13(4).

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S. Basra. 2009. A. 2009. Plant drought stress: Effects, mechanisms and management. Agronomy for sustainable development, 29(1): 185-212.

Golbashy, M., S. Khavari, M. Ebrahimi and R. Choucan. 2010. Study of response of corn hybrids to limited irrigation. 11th Iranian Crop Science Congress Tehran.

Granier, C., L. Aguirrezabal, K. Chenu, S.J. Cookson, M. Dauzat, P. Hamard, J.J. Thioux, G. Rolland, S. Bouchier-Combaud and A. Lebaudy. 2006. PHENOPSIS, an automated platform for reproducible phenotyping of plant responses to soil water deficit in Arabidopsis thaliana permitted the identification of an accession with low sensitivity to soil water deficit. New phytologist, 169(3): 623-635.

Guo, Y., S. Tian, S. Liu, W. Wang and N. Sui. 2018. Energy dissipation and antioxidant enzyme system protect photosystem II of sweet sorghum under drought stress. Photosynthetica, 56(3): 861-872.

Hou, L., W. Liu, Z. Li, C. Huang, X. Fang, Q. Wang and X. Liu. 2014. Identification and expression analysis of genes responsive to drought stress in peanut. Russian Journal of Plant Physiology, 61(6): 842-852.

Hussain, H.A., S. Hussain, A. Khaliq, U. Ashraf, S.A. Anjum, S. Men and L. Wang. 2018. Chilling and drought stresses in crop plants: implications, cross talk, and potential management opportunities. Frontiers in plant science, 9, 393.

Ibrahim, M., N. Zeid and E. Semary. 2001. Response of two differentially drought. Tolerant varieties of maize to drought stress. Pakistan Journal of Biological Sciences, 4(7): 779-784.

Jaleel, C. A., P. Manivannan, A. Wahid, M. Farooq, H.J. Al-Juburi, R. Somasundaram and R. Panneerselvam. 2009. Drought stress in plants: a review on morphological characteristics and pigments composition. International Journal of Agriculture and Biology, 11(1): 100-105.

Kadam, N.N., G. Xiao, R. J. Melgar, R.N. Bahuguna, C. Quinones, A. Tamilselvan, P.V.V. Prasad and K.S. Jagadish. 2014. Agronomic and physiological responses to high temperature, drought, and elevated CO_2 interactions in cereals. Advances in agronomy, 127, 111-156.

Kiani, S.P., P. Talia, P. Maury, P. Grieu, R. Heinz, A. Perrault, V. Nishinakamasu, E. Hopp, L. Gentzbittel and N. Paniego. 2007. Genetic analysis of plant water status and osmotic adjustment in recombinant inbred lines of sunflower under two water treatments. Plant Science, 172(4): 773-787.

Kucharik, C.J. 2008. Contribution of planting date trends to increased maize yields in the central United States. Agronomy Journal, 100(2): 328-336.

Kyparissis, A., Y. Petropoulou and Y. Manetas. 1995. 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. Journal of Experimental Botany, 46(12): 1825-1831.

Lal, R. 2009. Challenges and opportunities in soil organic matter research. European Journal of Soil Science, 60(2): 158-169.

Lesk, C., P. Rowhani and N. Ramankutty. 2016. Influence of extreme weather disasters on global crop production. Nature, 529(7584): 84-87.

Li, L. and J. Van Staden. 1998. Effects of plant growth regulators on drought resistance of two maize cultivars. *South* African Journal of Botany, 64(2): 116-120.

Li, Y., M. Fuchs, S. Cohen, Y. Cohen and R. Wallach. 2002. Water uptake profile response of corn to soil moisture depletion. Plant, Cell & Environment, 25(4): 491-500.

Liu, J., F. Zhang, J. Zhou, F. Chen, B. Wang and X. Xie. 2012. Phytochrome B control of total leaf area and stomatal density affects drought tolerance in rice. Plant molecular biology, 78(3): 289-300.

Lobell, D.B., W. Schlenker and J. Costa-Roberts. 2011. Climate trends and global crop production since 1980. Science, 333(6042): 616-620.

Mansouri-Far, C., S.A.M.M. Sanavy and S.F. Saberali. 2010. Maize yield response to deficit irrigation during low-sensitive growth stages and nitrogen rate under semiarid climatic conditions. Agricultural Water Management, 97(1): 12-22.

Medici, L., A. Machado, R. Azevedo and C. Pimentel. 2003. Glutamine synthetase activity, relative water content and water potential in maize submitted to drought. Biologia Plantarum, 47(2): 301-304.

Nayyar, H. and D. Gupta. 2006. Differential sensitivity of C3 and C4 plants to water deficit stress: association with oxidative stress and antioxidants. Environmental and Experimental Botany, 58(1-3): 106-113.

Olaoye, G., A. Menkir, S. Ajala and S. Jacob. 2009. Evaluation of local maize (*Zea mays* L.) varieties from Burkina Faso as source of tolerance to drought. Journal of Applied Biosciences, 17, 887-898.

Pandey, R., J. Maranville and A. Admou. 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment: I. Grain yield and yield components. Agricultural Water Management, 46(1): 1-13.

Paudyal, K.R. 2001. Maize in Nepal: production systems, constraints, and priorities for research. Comment.

Peñuelas, J., F. Lloret and R. Montoya. 2001. Severe drought effects on Mediterranean woody flora in Spain. Forest Science, 47(2): 214-218.

Reddy, S. P. Nayak. 2018. Crop production with limited irrigation: A review. *Agricultural Reviews*, *39*(1), 12-21.

Reymond, M., B. Muller, A. Leonardi, A. Charcosset and F. Tardieu. 2003. Combining quantitative trait loci analysis and an ecophysiological model to analyze the genetic variability of the responses of maize leaf growth to temperature and water deficit. Plant Physiology, 131(2): 664-675.

Sayed, M.A.E.-A.A. 2011. QTL analysis for drought tolerance related to root and shoot traits in barley (*Hordeum vulgare* L.).

Scarascia-Mugnozza, G., P. De Angelis, G. Matteucci and R. Valentini. 1996. Long-term exposure to elevated [CO_2] in a natural Quercus ilex L. community: net photosynthesis and photochemical efficiency of PSII at different levels of water stress. Plant, Cell & Environment, 19(6): 643-654.

Shao, H.-B., L.-Y. Chu, C.A. Jaleel and C.-X. Zhao. 2008. Water-deficit stress-induced anatomical changes in higher plants. Comptes rendus biologies, 331(3): 215-225.

Siddique, M., A. Hamid and M. Islam. 2000. Drought stress effects on water relations of wheat. Botanical Bulletin of Academia Sinica, 41.

Soler, C., G. Hoogenboom, P. Sentelhas and A.P. Duarte. 2007. Impact of water stress on maize grown off-season in a subtropical environment. Journal of Agronomy and Crop Science, 193(4): 247-261.

Tagne, A., T. Feujio and C. Sonna. 2008. Essential oil and plant extracts as potential substitutes to synthetic fungicides in the control of fungi. International Conference Diversifying crop protection.

Taiz, L. and E. Zeiger. 2006. Fisiologia vegetal (Vol. 10). Universitat Jaume I.

Tang, G., F. Shao, P. Xu, L. Shan and Z. Liu. 2017. Overexpression of a peanut NAC gene, AhNAC4, confers enhanced drought tolerance in tobacco. Russian Journal of Plant Physiology, 64(4): 525-535.

Vamerali, T., M. Saccomani, S. Bona, G. Mosca, M. Guarise and A. Ganis. 2003. A comparison of root characteristics in relation to nutrient and water stress in two maize hybrids. In Roots: The Dynamic Interface Between Plants and the Earth, (pp. 157-167). Springer.

Westgate, M. and J. Boyer. 1985. Osmotic adjustment and the inhibition of leaf, root, stem and silk growth at low water potentials in maize. Planta, 164(4): 540-549.

Yang, X., J. Liu, W. Wang, Z. Ye and A. Luo. 2004. Potassium internal use efficiency relative to growth vigor, potassium distribution, and carbohydrate allocation in rice genotypes. Journal of Plant Nutrition, 27(5): 837-852.

Yordanov, I., V. Velikova and T. Tsonev. 2000. Plant responses to drought, acclimation, and stress tolerance. Photosynthetica, 38(2): 171-186.

Zheng, Y., C. Liao, S. Zhao, C. Wang and Y. Guo. 2017. The glycosyltransferase QUA1 regulates chloroplast-associated calcium signaling during salt and drought stress in Arabidopsis. Plant and Cell Physiology, 58(2): 329-341.

Publisher's note: EScience Press remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.