Soil Environ. 33(1): 51–58, 2014
www.se.org.pk
Online ISSN: 2075–1141
Print ISSN: 2074–9546

Screening of maize hybrids for enhancing emergence and growth parameters at different soil moisture regimes

Babar Hussain Babar[1*], Mumtaz Akhtar Cheema[2], Muhammad Farrukh Saleem[1] and Abdul Wahid[3]
[1]Department of Agronomy, University of Agriculture, Faisalabad, Pakistam
[2]Memorial University Grenfell campus, Corner Brook,NL, Canada
[3]Department of Botany, University of Agriculture, Faisalabad, Pakistan

Abstract

Water stress is a major constraint in crop production particularly in arid and semiarid regions of the world including Pakistan. Screening of maize germplasm at early stage is an effective tool for successful crop production in these areas. A pot experiment was conducted to screen seven maize hybrids namely 32F10, 32B33, 33H35, 3335, 34N43, 6142, 6525 at 80, 60 and 40% water holding capacities. A completely randomized design (CRD) with four replications was used. Results revealed that hybrid 34N43 recorded maximum emergence index, emergence energy, uniformity of emergence, final emergence percentage, shoot length, plant biomass and leaf area and maintained maximum water potential, osmotic potential, turgor potential and relative water contents whereas mean emergence time and time taken for 50% emergence was minimum for this hybrid under all three water holding capacities. While the performance of hybrid 32F10 was poor with respect to emergence, early growth and water relations under well watered conditions generally and under water stress particularly. Hybrid 32F10 proved to be the most sensitive to drought among the tested germplasm. Hence, it may be concluded that maize hybrid 34N43 would perform better under conditions of poor water supply as in Pakistan.

***Keywords**: Drought, maize hybrid, water potential, osmotic potential, relative water contents*

Introduction

Growth and yield of crops are generally restricted under soil water deficits. Maize (*Zea mays* L.) suffers from soil moisture deficit, which may cause drastic yield reduction, especially if it occurs during the reproductive phase (Basseti and Westgate, 1994). Water resources have become meager due to climate change, population growth and competition from other water users (Farahani *et al.*, 2007). Water resources for agriculture are decreasing due to increase in demand for irrigation and other non-agricultural water uses (Bacon, 2004). Most climate change methods have predicted an increase in the aridity in many areas of the globe due to change in environmental conditions. So, the interest in the research on plant responses to shortage of water is gaining considerable ground (Araus *et al*., 2008; Ashraf, 2010). On a global basis, it has been reported that shortage of water in conjunction with radiation, and high temperature poses the most important environmental constraint to plant survival and final crop yield (Tollenaar and Lee, 2006; Araus *et al*., 2008). As agriculture is a major user of land water resources in many regions of the world, so, with increasing aridity in conjunction with a fast increase in human population, water will become a scarce commodity in the near future, particularly in the third world countries like Pakistan. Faced with scarcity of water resources, drought is the single most critical threat to world food security. It was the catalyst of the great famines of the past. Because the world's water supply is limiting, future food demand for rapidly increasing population pressures is likely to further aggravate the effects of drought (Somerville and Briscoe, 2001).

Water stress affects plant growth in different ways. The first and foremost effect of water stress is impaired germination and poor stand establishment (Harris *et al.,* 2002). Drought stress has been reported to severely reduce germination and seedling stand (Kaya *et al.,* 2006). Among the stages of the plant life cycle, seed germination, seedling emergence and establishment are key processes in the survival and growth of plants (Hadas, 2004). Water stress not only affects seed germination but also increases mean germination time in maize plants (Willanborb *et al.,* 2004). Cell growth is one of the most drought-sensitive physiological processes due to the reduction in turgor pressure (Taiz and Zeiger, 2010). Under severe water deficiency, cell elongation of higher plants can be inhibited by interruption of water flow from the xylem to the surrounding elongating cells (Nonami, 1998). Drought stress creates a wide array of biochemical and physiological changes, beginning from a variable decline in leaf relative water content (RWC) as a better indicator of plant water

*Email: babarhbabar@gmail.com

status (Seghatoleslami *et al.*, 2008). Water potential (ψ_w) is considered to be a reliable parameter for measuring plant water stress response. It varies greatly, depending on the type of plant and environmental conditions (Saini and Westgate, 2000). In drought tolerant plants, there are many defense mechanisms such as osmoregulation, antioxidant and hormonal systems, helping plants to stay alive and develop earlier to their reproductive stages (Reddy *et al.*, 2004; Ashraf, 2010). It is imperative to improve the drought tolerance of crops under the changing circumstances. Currently, there are no economically viable technological means to facilitate crop production under drought. However, selection of crop plants tolerant to drought stress might be a promising approach.

Maize (*Zea mays* L.) is an important crop grown all over the world and is the third most important cereal grain after wheat and rice. It contributes 62% in the total cereal production (Farhad *et al.*, 2011). Maize is one of the major world food crops. However, in areas where water availability is limited, maize grain losses may reach up to 24 million tons per year that is equivalent to 17% of well watered production in the world (Edmeades *et al*., 1999). In Pakistan, water stress is also a major obstacle for maize production. Approximately, 35% of the maize in Pakistan strictly depends on natural rain (Arora *et al.*, 2002).

Variation in sensitivity of maize hybrids towards water stress (Mostafavi *et al.*, 2011) is reflected from adverse effects of water shortage on germination and seedling growth (Khodarahmpour, 2011), water potential (Medici *et al.*, 2003), osmotic potential and turgor potential (Claudio *et al.*, 2006)

Maize genotypes vary to different agro-management practices, particularly water and nutrient. These variable responses differ mainly due to differences in plant morphology (Benga *et al.*, 2001), crowding stress tolerance (Tollenaar and Lee, 2006), intraspecific competition in maize plants for water (Maddonni and Otegui, 2006), plant growth rate (Aslam *et al*., 2006) and crop duration (Echarte *et al.*, 2006). Physiological and morphological characteristics such as osmotic adjustment, stomatal behavior, leaf water potential, root volume, root weight, leaf area and dry matter production were different in maize cultivars grown under limited water supply (Farhad *et al.*, 2011). To cope with drought, genotypes can be identified that can survive during moisture stress and/or recover after such stress. This can be done by comparing genotype performance under well-watered and moisture-stressed conditions. An alternative but equally effective approach is to subject genotypes to induced moisture stress at specific growth stages. The objectives of this study were to determine their efficiency in water use for emergence, growth and dry matter production under different moisture regimes, and also gain information on relative yield loss of the genotypes under moisture deficit conditions. It is believed that understanding of their response to soil-water deficits through measurement of crop-water status and associated morpho-physiological responses (Cox and Jolliff, 1987) will help identify populations that could be used to develop drought-tolerant maize varieties. So this study was conducted to find a drought tolerant hybrid, which can survive under limited water conditions.

Materials and Methods

A pot experiment was conducted in Research Area of Agronomy Department of University of Agriculture, Faisalabad to screen the maize hybrids for drought tolerance. Seven locally available maize hybrids viz. 32F1, 32B33, 33H35, 3335, 34N43, 6142 and 6525 were screened for drought tolerance in wire house. The water stress treatments (80%, 60% and 40% water holding capacities) were created by applying measured quantity of water. Screening was done based on the performance of hybrids under drought stress.

Time taken to 50% emergence (E_{50}) [Days]

Time taken to 50% emergence of seedlings (E_{50}) was calculated according to the following formulae of Coolbear *et al.* (1984) modified by Farooq *et al.* (2005):

$$E_{50} = t_i + \left[\frac{N/2 - n_i}{n_j - n_i}\right](t_j - t_i)$$

Where N is the number of final emergence count and n_i, n_j cumulative number of seeds emerged at adjacent days t_i and t_j when $n_i < (N+1)/2 < n_j$.

Mean emergence time (MET) [Days]

Mean emergence time (MET) was calculated according to following equation of Ellis and Roberts (1981):

$$MET = \frac{\sum Dn}{\sum n}$$

Where n is the number of seeds, emerged on day D from the beginning of emergence.

Emergence energy (EE) [%]

Energy of germination was calculated according to the formula as described by Farooq *et al.* (2006):

$$EE\ (\%) = \frac{\text{No. of seedlings emerged 4 days after sowing}}{\text{Total number of seedlings sown}} \times 100$$

Final emergence percentage (FEP) [%]

$$\text{FEP (\%)} = \frac{\text{Final no. of seedlings emerged}}{\text{Total no. of seeds sown}} \times 100$$

Final emergence percentage was calculated as described by Basra *et al.* (2011) using the following formula:

Coefficient of uniformity of emergence (CUE)

The coefficient of uniformity of emergence (CUE) was calculated as described by Bewley and Black (1985) using the following formula:

$$CUE = \sum n / \sum \left[\left(\bar{t} - t \right)^2 . n \right]$$

Where t is the time in days, starting from day 0, the day of sowing, and n is the number of seeds completing emergence on day t and $\bar{t}$ is equal to MET.

Water relations

Leaf water potential (-MPa) was determined with a Scholander type pressure chamber (arimad -2 –Japan, ELE international) by using third leaf from top. Leaf osmotic potential (- MPa) was determined with vapor pressure osmometer (Vapro, 5520) by using sap of leaves frozen at 20 ^{o}C for more than 7 days. The turgor potential was calculated as described by Farhad *et al.* (2011) using following formula:

$$\Psi_p = \Psi_w - \Psi_s$$

Results

Maize emergence

Maize hybrids differed significantly ($p \leq 0.05$) for time taken for 50% emergence (E_{50}), mean emergence time (MET) and final emergence percentage (FEP). Irrigation regimes also differed significantly. Interaction between maize hybrids and irrigation regimes for $E_{50,}$ MET and FEP was also significant (Table 1). Increasing water stress increased $E_{50,}$ MET and decreased FEP as revealed from data. Maize hybrid 32F10 had maximum E_{50}, MET and minimum FEP whereas hybrid 34N43 had minimum E_{50}, MET and more FEP under all three moisture regimes.

As per data given in table 2, maize hybrids differed significantly ($p \leq 0.05$) for emergence energy (EE), coefficient of uniformity of emergence (CUE) and emergence index (EI) under different irrigation regimes. Interaction between maize hybrids and irrigation regimes for these parameters was also significant. Increasing water stress decreased all the parameters under discussion. Maximum values were observed under 80% WHC in hybrid 34N43 against the minimum in hybrid.

Table 1: Effect of irrigation regimes on emergence of maize hybrids

Irrigation regime	**50% emergence**			**Mean emergence time**			**Final emergence**		
Hybrid	**40**	**60**	**80**	**40**	**60**	**80**	**40**	**60**	**80**
32F10	7.36 a	6.71a	6.65 a	10.38 a	8.78 a	8.35 a	70.27 g	74.77 g	75.72 g
32B33	7.30 b	6.53 b	6.18 b	10.28 b	8.13 b	7.53 b	71.14 f	76.97 f	79.34 f
33H25	7.21 c	6.46 c	4.87 d	10.16 c	7.88 c	6.15 d	71.83 e	77.74 e	86.94 d
3335	7.07 d	6.33 d	5.22 c	9.67 d	7.73 d	6.63 c	72.54 d	78.44 d	84.76 e
34N43	5.57 g	4.19 g	3.47 g	6.84 g	5.83 g	5.11 g	81.72 a	88.45 a	92.54 a
6142	6.89 e	5.73 e	4.05 e	9.48 e	7.33 e	5.55 e	73.20 c	81.16 c	89.80 c
6525	6.82 f	5.09 f	3.76 f	9.04 f	6.39 f	5.47 f	73.94 b	85.63 b	90.86 b
LSD (5%)		**0.026**			**0.028**			**0.025**	

Mean having different letters in coulums are significantly different from each other

Table 2: Effect of irrigation regimes on emergence related parameters of maize hybrids

Irrigation regimes	Emergence energy (%)			Uniformity of emergence			Emergence Index		
Hybrids	40	60	80	40	60	80	40	60	80
32F10	18.74 g	27.95 g	29.39 g	0.12 g	0.45 g	0.48 g	3.21 g	4.74 g	4.95 g
32B33	20.13 f	32.16 f	42.76 f	0.16 f	0.52 f	0.63 f	3.51 f	5.43 f	6.65 g
33H25	21.25 e	32.66 e	57.84 d	0.23 e	0.55 e	0.78 d	3.93 e	5.84 e	9.42 d
3335	23.48 d	39.54 d	51.97 e	0.28 d	0.59 d	0.72 e	4.07 d	6.25 d	8.41 e
34N43	48.33 a	60.43 a	66.46 a	0.69 a	0.80 a	0.89 a	7.90 a	9.72 a	10.41 a
6142	24.75 c	45.92 c	61.26 c	0.34 c	0.66 c	0.82 c	4.26 c	7.42 c	10.12 c
6525	26.43 b	54.36 b	65.12 b	0.38 b	0.75 b	0.85 b	5.04 b	8.79 b	10.24 b
LSD (5%)		0.032			0.013			0.025	

Mean having different letters in coulums are significantly different from each other

Table 3: Effect of irrigation regimes on growth of maize hybrids

Irrigation regimes	Root length (cm)			Shoot dry weight (g)			Leaf area (cm^2)		
Hybrids	40	60	80	40	60	80	40	60	80
32F10	17.37 fg	15.80 gh	13.00 c	0.41 d	0.78 f	0.91 d	213.3 e	428.6 g	443.4 g
32B33	18.75 ef	17.75 fg	13.05 c	0.45 d	0.79 f	0.93 d	248.0 d	458.6 f	513.9 f
33H25	18.32 c	17.82 de	13.50 c	0.42 d	0.80 e	1.38 c	258.3 c	512.6 e	623.1 e
3335	20.75 de	18.62 cd	13.87 c	0.56 bc	0.95 d	1.45 c	264.8 c	559.0 d	698.5 d
34N43	34.67 a	24.00 ab	20.70 a	1.05 a	2.09 a	2.94 a	412.5 a	873.9 a	927.1 a
6142	24.37 b	19.42 cd	14.50 b	0.61 b	1.24 b	1.46 c	286.4 b	626.5 c	751.5 c
6525	25.12 b	21.25 bc	14.60 b	0.71 b	1.10 c	2.22 b	304.8 b	701.7 b	849.1 b
LSD(5%)		2.75			0.355			76.71	

Mean having different letters in coulums are significantly different from each other

Maize growth

Maize hybrids differed significantly ($p \leq 0.05$) for root length, shoot length, root dry weight, shoot dry weight and leaf area. Similarly, irrigation regimes had significant effect on growth. Interaction between maize hybrids and irrigation regimes was significant for root length, shoot dry weight and leaf area and non significant for shoot length and root dry weight. Increased moisture stress caused increase in root length while decrease in root dry weight, shoot dry weight, shoot length and leaf area of all maize hybrids. Hybrid 34N43 gained maximum root length and shoot length as well as maximum root dry weight, shoot dry weight and leaf area against minimum values for all these parameters recorded in hybrid 32F10; this was true at all moisture regimes (Table 3 and 4).

Table 4: Effect of irrigation regimes on shoot length and root dry weight of maize hybrids

Factor A: Maize hybrids	Shoot length (cm)	Root dry weight (g)
32F10	14.49 f	0.73 d
32B33	15.84 e	0.83 d
33H25	16.34 de	0.87 d
3335	17.19 cd	1.05 c
34N43	22.81 a	1.58 a
6142	17.87 c	1.08 c
6525	19.58 b	1.31 b
LSD (5%)	**1.341**	**0.173**
Factor B: Irrigation regimes		
I_1 (40 % WHC)	14.55 c	0.61 c
I_2 (60 % WHC)	18.04 b	1.17 b
I_3 (80 % WHC)	20.59	1.41 a
LSD (5%)	**0.878**	**0.113**

Water relations

Maize hybrids differed significantly ($p \leq 0.05$) for water potential (WP), osmotic potential (OP) and turgor potential (TP) under different irrigation regimes (Table 5). Maximum water potential (-0.31MPa) was recorded in hybrid 34N43 under 80% WHC and minimum (-0.54MPa) was recorded in hybrid 32F10 under same WHC. Similar trend was observed under 40% WHC as well as 60% WHC however, increase in moisture level increased osmotic potential. Similarly, maximum osmotic potential was recorded in hybrid 34N43 and minimum was recorded in hybrid 32F10 under all irrigation levels. With respect to TP, performance of maize hybrid 34N43 was statistically superior to other hybrids at all levels of WHC, although a considerable decrease in TP was observed with decrease in percent WHC.

Table 5: Effect of irrigation regimes on water relations of maize hybrids

Irrigation regimes	Water potential (-MPa)			Osmotic potential (-MPa)			Turgor potential (MPa)		
Hybrids	**40**	**60**	**80**	**40**	**60**	**80**	**40**	**60**	**80**
32F10	1.02 a	0.81 a	0.54 a	1.29 a	1.13 a	0.99 a	0.25 f	0.24 g	0.41 g
32B33	1.00 b	0.79 b	0.51 b	1.25 b	1.10 b	0.98 b	0.26 e	0.32 f	0.48 f
33H25	0.96 c	0.74 c	0.45 c	1.24 c	1.08 c	0.98 b	0.29 d	0.36 e	0.52 e
3335	0.93 d	0.69 d	0.41 d	1.22 d	1.07 d	0.97 c	0.29 d	0.37 d	0.55 d
34N43	0.85 g	0.59 g	0.31 g	1.19 g	0.99 g	0.93 f	0.34 a	0.45 a	0.64 a
6142	0.90 e	0.66 e	0.40 e	1.21 e	1.02 e	0.95 d	0.30 c	0.40 c	0.62 b
6525	0.89 f	0.62 f	0.33 f	1.20 f	1.01 f	0.94 e	0.32 b	0.42 b	0.57 c
LSD (5%)		**0.003**			**0.002**			**0.003**	

Mean having different letters in coulums are significantly different from each other

Discussion

Water stress reduced the germination efficiency of maize hybrids. Under 80% WHC, minimum time for 50% emergence and mean emergence time was recorded and water availability increased emergence energy, coefficient of uniformity of emergence, emergence index and final emergence percentage. However, increase rate was different for different hybrids (Tables 1 and 2). There are many biochemical and physiological processes involved in seed germination i.e. a) imbibition of seed with water which helps in making seed coat soft and facilitates the emergence of embryo parts. b) activation of hydrolysis enzymes i.e., α- and β- amylase which play a key role in conversion of complex sugars to simpler ones and c) mobilization of food reserves from storage parts to embryo. And for all these processes, availability of adequate water is obligatory (Taiz and Zeiger, 2010; Wahid and Farooq, 2012). But response to drought stress was different in different hybrids due to their different genetic makeup. Different genotypes respond differently to availability of water and water stress so that some are more sensitive to water stress and some are relatively tolerant (Farhad *et al.*, 2011).

More root length was observed under drought stress as compared to well watered conditions. Plants when face water stress, root to shoot ratio is increased. Root proliferation is an important parameter to assess drought tolerance in different genotypes as tolerant genotypes under drought stress have more root penetration to explore water from more depth as compared to sensitive ones (Farooq *et al.*, 2009). More shoot length was recorded under well watered condition as compared to water stress. Hybrids also differed in their root length. Changes in morphological characters reflect the effects of drought stress on plants (Farooq *et al.*, 2009; Jaleel *et al.*, 2009). Olaoye (2009) reported that water stress decreased the plant height of maize hybrids whereas more height of maize hybrids was recorded under well watered conditions. Both root dry weight (RDW) and shoot dry weight (SDW) were increased at 80% WHC in all hybrids. Water stress disrupts homeostasis in plants. Major changes in water status can cause molecular damage, growth inhibition and resultantly death of plant cells. It is already accepted that different crop cultivars hold different responses to different level of water stress in view of water status and plant growth (Li Xin *et al.*, 2011). Leaf area (LA) of maize hybrids varied significantly under varying water stress levels. Intensity of soil water deficit largely influences LA of a genotype. (Abo-El-Kheir and Mekki, 2007; Farhad *et al.*, 2011). In consonance with growth as a function of moisture availability, increase in seedling growth and leaf area under favorable moisture conditions in this study corroborating earlier report of Bazinger *et al.* (2000) that leaf area affects water use in plants by reducing evaporation/transpiration ratio and weed competition especially at full canopy.

Maximum water potential (WP) was recorded in maize hybrids under well watered conditions and it decreased significantly under water stress. The primary and most important effect of water deficits in plants is hampered water status (Farooq *et al.*, 2010; Taiz and Zeiger, 2010). Medici *et al.* (2003) observed that maize hybrid P-6875 showed a WP of -0.78MPa under controlled condition and WP of this hybrid decreased to -0.96MPa under water stress conditions. Osmotic potential (OP) of leaves is decreased with decrease in water content of soil. Claudio *et al.* (2006) reported that OP of leaves increased upto -0.90 MPa under normal water availability and it decreased to -1.20 MPa under water stress conditions. Turgor potential (TP) of maize hybrids was increased under well watered conditions. The first response of plants to water stress is that cells lose turgidity so that cell size is reduced resultantly decreasing leaf area. As a result of this adaptation, less surface is available for water loss and plants maintain minimum water status for survival (Taiz and Zeiger, 2010). Claudio *et al.* (2006) found that leaf TP was decreased from 0.54 MPa to 0.18 MPa under water stress. Maximum relative water contents (RWC) were recorded at 80% WHC (Table 4.15). Decrease in RWC indicates a loss of turgor that results in limited water availability for the cell extension process in crop plants (Li Xin *et al.*, 2011).

Conclusion

Water holding capacity below 80% has negative effects on emergence and growth of maize plants. From the above study, it is concluded that different maize hybrids showed variable response to water stress and the hybrid 34N43 performed better at 40 and 60% water holding capacity as compared to other hybrids. So, it can be recommended to grow in water scarce area.

References

Abo-El-Kheir, M.S.A. and B.B. Mekki. 2007. Response of maize single cross-10 to water deficits during silking and grain filling stages. *World Journal of Agricultural Science* 3: 269–272.

Araus, J.L., G.A. Slafer, C. Royo and M.D. Serret. 2008. Breeding for yield potential and stress adaptation in cereals. *Critical Reviews in Plant Science* 27: 377–412.

Arora, A., R.K. Sairam and G.C. Srivastava. 2002. Oxidative stress and antioxidative systems in plants. *Current Science* 82: 1227–1238.

Ashraf, M. 2010. Inducing drought tolerance in plants: some recent advances. *Biotechnology Advances* 28:169–183.

Aslam, M., I.A. Khan, M. Saleem and Z. Ali. 2006. Assessment of water stress tolerance in different maize accessions at germination and early growth stage. *Pakistan Journal of Botany* 38: 1571–1579.

Bacon, M.A. 2004. Water Use Efficiency in Plant Biology. Blackwell publishing, Oxford, UK. 327p.

Basra, S.M.A., M.N. Iftikhar and I. Afzal. 2011. Potential of moringa (*Moringa oleifera*) leaf extract as priming agent for hybrid maize seeds. *International Journal of Agriculture and Biology* 13: 1006–1010.

Basseti, P. and M.E. Westgate. 1994. Floral asynchrony and kernel set in maize quantified by image analysis. *Agronomy Journal* 86: 699–703.

Bazinger, M., G.O. Edmeades, D. Beck and M. Bellon. 2000. Breeding for drought and nitrogen stress tolerance in maize: From theory to practice. CIMMYT, Mexico. 68p.

Benga, S.H., R. Hamilton, L.M. Dwyer, D.W. Stewrart, D. Cloutier, L. Assemat, K. Foroutan and D.L. Smith. 2001. Morphology and yield response to weed pressure by corn hybrids differing in canopy architecture. *European Journal of Agronomy* 14: 293–302.

Bewley, J.D. and M. Black. 1985. Seeds: Physiology of Development and Germination. Plenum Press, New York. 445p.

Chimenti, C.A., M. Marcantonio and A.J. 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: 305–315.

Coolbear, P., A. Francis and D. Grierson. 1984. The effect of low temperature pre-sowing treatment on the germination performance and membrane integrity of artificially aged tomato seeds. *Journal of Experimental Botany* 35:1609–1617.

Cox, J.W. and G.D. Jolliff. 1987. Crop-water relations of sunflower and soybean under irrigated and dryland conditions. *Crop Science* 27:553–557.

Echarte, L., F.H. Andrade, V.O. Sadras and P. Abbate. 2006. Kernel weight and its response to source manipulations during grain filling in Argentinean maize hybrids released in different decades. *Field Crops Research* 96: 307-312.

Edmeades, G.O., J. Bolaoos, M. Hernandez and S. Bello. 1999. Causes for silk delay in a low land tropical maize population. *Crop Science* 33: 1029–1035.

Ellis, R.A. and E.H. Robert. 1981. The quantification of ageing and survival in orthodox seeds. *Seed Science* and *Technology* 9: 373–409.

Farahani, H.J., T.A. Howell, W.J. Shuttleworth and W.C. Bausch. 2007. Evapotranspiration progress in measurement and modeling in agriculture. *Transactions of the American Society of Agricultural and Biological Engineers* 50: 1627–1638.

Farhad, W., M.A. Cheema, M.F. Saleem and M. Saqib. 2011. Evaluation of drought tolerance in maize hybrids. *International Journal of Agriculture and Biology* 13: 523–528.

Farooq, M., A. Wahid, N. Kobayashi, D. Fujita and S.M.A. Basra. 2009. Plant drought stress: effects, mechanisms and management. *Agronomy for Sustainable Development* 28: 185–212.

Farooq, M., A. Wahid, S.A. Cheema, D.J. Lee and T. Aziz. 2010. Comparative time course action of foliar applied glycinebetaine, salicyclic acid, nitrous oxide, brasinosteroids and spermine in improving drought resistance of rice. *Journal of Agronomy and Crop Science* 196: 336–345.

Farooq, M., S.M.A. Basra, K. Hafeez, S.A. Asad and N. Ahmad. 2005. Use of Commercial fertilizers as osmotica for rice priming. *Journal of Agriculture and Social Sciences*1:172–175.

Farooq, M., S.M.A. Basra, M. Khalid, R. Tabassum and T. Mehmood. 2006. Nutrietn homeostasis, reasrvers metabolism and seedling vigor as affected by seed priming in coarse rice. *Candadian Journal of Botany* 84: 1196–1202.

Hadas, A. 2004. Seedbed preparation: the soil physical environment of germinating seeds. p. 3-–36. *In:* Handbook of Seed Physiology: Applications to Agriculture. R.L. Benech-Arnold and R.A. Sanchez (eds.). Food Product Press, New York, USA.

Harris D., R.S. Tripathi, A. Joshi. 2002. On-farm seed priming to improve crop establishment and yield in dry direct-seeded rice. p. 231–240. *In:* Direct seeding: Research Strategies and Opportunities. S. Pandey, M. Mortimer, L. Wade, T.P. Tuong, K. Lopes and B. Hardy (eds.). International Rice Research Institute, Manila, Philippines. 383p.

Jaleel, C.A., P. Mannivannan, A. Wahid, M. Farooq, H.J. Aljuburi, R. Somasundaram and R. Panneerselvan. 2009. Drought stress in plants: A review on morphological characteristics and pigments composition. *International Journal of Agriculture and Biology* 11: 100-105.

Kaya, M.D., G. Okcub, M. Ataka, Y. Cikilic and O. Kolsarcia. 2006. Seed treatments to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). *European Journal of Agronomy* 24: 291–295.

Khodarahmpour, Z. 2011. Effect of drought stress induced by polyethylene glycol on germination indices in corn (*Zea mays* L.) hybrids. *African Journal of Biotechnology* 10(79): 18222–18227.

Li Xin, Z., M. Gao, S. Li and Z. Liang. 2011. Modulation of plant growth, water status and antioxidant system of two maize cultivars induced by *Glycine betaine* under long term mild drought stress. *Pakistan Journal of Botany* 33: 1587–1594.

Maddonni, G.A. and M.E. Otegui. 2006. Intra-specific competition in maize: Contribution of extreme plant hierarchies to grain yield, grain yield components and kernel composition. *Field Crops Research* 97: 155–166.

Medici, L.O., A.T. Machado, R.A. Azevedo and C. Pimentel. 2003. Glutamine synthetase activity, relative water content and water potential in maize submitted to drought. *Biology of Plant* 47: 301–304.

Mostafavi, K.H., G.H. Sadeghi, M. Dadresan and M. Zarabi. 2011. Effects of drought stress on germination indices of corn hybrids (*Zea mays* L.). *International Journal of Agricultural Science* 1(2): 10–18.

Nonami, H. 1998. Plant water relations and control of cell elongation at low water potentials. *Journal of Plant Research* 111: 373–382.

Olaoye, G.L. 2009. Screening for moisture deficit tolerance in four maize populations derived from drought tolerant inbred x adapted cutivar crosses. *Tropical and Subtropical Agro ecology* 10: 237–251.

Reddy, A.R., K.V. Chaitanya and M. Vivekanandan. 2004. Drought - induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of Plant Physiology* 161: 1189–1202.

Saini, H.S. and M.E. Westgate. 2000. Reproductive development in grain crops during drought. *Advances in Agronomy* 68: 61–95.

Seghatoleslami, M.J., M. Kafi and E. Majidi. 2008. Effect of drought stress at different growth stages on yield and water use efficiency of five proso millet *(Panicum Miliaceum* L.*)* genotypes. *Pakistan Journal of Botany* 40(4): 1427–1432.

Somerville, C. and J. Briscoe. 2001. Genetic engineering and water. *Science* 292: 2217.

Taiz, L. and E. Zeiger. 2010. Plant Physiology. 5th Ed. Sinauer Associates Sunderland, Massachusetts. 782p.

Tollenaar, M. and E.A. Lee. 2006. Dissection of physiological processes underlying grain yield in maize by examining genetic improvement and heterosis. *Maydica* 51: 399–408.

Wahid, A. and M. Farooq. 2012. Is seed invigoration economical and practical? *Journal of Agriculture and Social Sciences* 8: 79–80.

Willanborb, C.J., R.H. Gulden, E.N. Jhonson and S.J. Shirtliffe. 2004. Germination characteristics of polymer-coated canola (*Brassica napus* L.) seeds subjected to moisture stress at different temperatures. *Agronomy Journal* 96:786–791.