Bulgarian Journal of Agricultural Science, 26 (No 2) 2020, 299–308

The response of durum wheat varieties from semi-arid environment to drought stress on germination and at the seedling stage

Adel H. Abdel-Ghani[1], Saddam A. Al-Dalain[2], Nael H. Thaher[3*], Saed J. Owais[1], Shahed I. Sarayrh[1], Raeda Mayta[4] and Mahmud A. Duwayri[5]

[1]*Mutah University, Faculty of Agriculture, Department of Plant Production, 61710 Alkarak, Jordan*
[2]*Al-Balqa Applied University, Al-Shoubak University College, 19117 Alsalt, Jordan*
[3]*National Agricultural Research Center, Directorate of Intellectual Property Management and Protection, 19381 Baqaa, Jordan*
[4]*Ministry of Agriculture, Al-Karak Directorate, 61671 Alkarak, Jordan*
[5]*University of Jordan, Faculty of Agriculture, Department of Horticulture and Agronomy, 11942 Amman, Jordan*
[*]*Corresponding author:* n1thaher@gmail.com

Abstract

Abdel-Ghani, A. H., Al-Dalain, S. A., Thaher, N. H., Owais, S. J., Sarayrh, S. I., Mayta, R. & Duwayri, M. A. (2020). The response of durum wheat varieties from semi-arid environment to drought stress on germination and at the seedling stage. *Bulg. J. Agric. Sci., 26 (2)*, 299–308

Early drought is a major constraint for cultivating wheat crop in the semi-arid region resulted in poor emergence and weak seedlings and might lead to a complete crop failure under severe drought. The response of eight wheat varieties to simulated osmotic stress was assessed using 10% and 15% polyethylene glycol (PEG-6000), in addition to the control treatment (no stress). Water stress during germination had no effect on the final germination percentages, but it delayed germination with significant differences among genotypes. Results showed that severe osmotic stress (15% PEG) substantially delayed germination; however, mild osmotic stress (10% PEG) had a little effect on germination rate. Furthermore, the results of this study showed that the fastest germinating varieties regardless of osmotic stress level were Acsad 65, Cham I and Ammon. Assessment of coleoptiles and seminal roots demonstrated that HoraniNawawi and Omqais varieties had the longest coleoptiles while Acsad 65 and BaniSuef 6 had the longest seminal roots. The pattern of response of wheat genotypes to osmotic water stress showed substantial differences at the early stage of plant development. Genotypes with a fast germination and a more vigorous root system are very desirable for the rapid establishment of seedlings and their early vigor in the dry areas.

*Keywords***:** drought stress; germination rate; osmotic stress; polyethyleneglycol; seedling traits; water stress; wheat

Introduction

Durum (*Triticum durum* L.) is a major cultivated field crop in West Asia and North Africa (WANA) and semi-arid areas with more than 300 mm rainfall. Drought caused by low and irregular rainfall in the growing seasons is a major constraint, facing small grain winter cereals in this region (Lakew et al., 1997; Abdel-Ghani et al., 2004; Parzies et al., 2008)we estimated the outcrossing rate of 12 barley landraces (Hordeum vulgare ssp. vulgare, in short H. vulgare. In the semi-arid regions, seedlings that are exposed to early drought can result in poor emergence and growth (Grando & Ceccarelli, 1995; Al-Karaki, 1998; Sahnoune et al., 2004). In addition, severe drought with a high evaporation rate at early growth stages may cause a complete failure of seedlings and therefore a total loss of the crop (Al-Karaki, 1998;

Abdel-Ghani et al., 2012). Selection of genotypes with a fast and high percentage of germination is desirable for a rapid establishment of seedlings and their strong early vigor in the dry areas (Haddadin et al., 2013; Abdel-Ghani et al., 2014b). As well as selection of vigorous roots is critical for the evaluation of drought-tolerance (Sahnoune et al., 2004; Kumar et al., 2012; Abdel-Ghani et al., 2013; Haddadin et al., 2013). The early embryonic roots in wheat are called seminal roots. Indirect selection of traits for long and high number of seminal roots can potentially be useful to enhance the growth of wheat seedling under the drought stress conditions (Grando & Ceccarelli, 1995; Kumar et al., 2012; Abdel-Ghani et al., 2013).

Although a considerable variation exists in the root architecture (Wang et al. 2006; Kumar et al., 2012; Abdel-Ghani et al., 2013), root traits are not often studied by plant breeders for yield improvement in such crops (Tuberosa et al., 2003; Kumar et al., 2012; Abdel-Ghani et al., 2013). This is mainly due to the difficulties to access roots that are hidden in the soil. Recently, Abdel-Ghani et al. (2015) reported an extensive genetic variation in the barley root morphology using 233 genotypes of barley from the barley core collection (BCC), and recommended selection for seminal root as a potential selection criterion under drought.

Selection for drought tolerance and/or high nutrient use efficiency can be performed by either assessing grain yield *per se* or identifying of secondary traits associated with grain yield that positively enhances grain yield under drought. In the recent past, many studies revealed positive correlations between vigorous seedling roots, tolerance to water stress and the efficiency in absorbing nutrients (Soto-Cerda & Cloutier, 2012; Abdel-Ghani et al., 2013). Evaluation of the variation in root traits as selection criteria could open the opportunity for using this technique to improve wheat performance under drought stress and in soils with deficient nutrients. The objectives of the current study were to (i) evaluate the effect of induced drought stress in eight wheat varieties using polyethylene glycol (PEG) on germination, germination rate and seedling traits, and (ii) set recommendations for plant breeders to use genotypes that can tolerate drought at least at early stages of seedling development.

Materials and Methods

Plant materials and germination test

Seven durum wheat varieties (HoraniNawawi, DairAlla 6, Cham 1, Omqais, Acsad 65, BaniSuef 4, BaniSuef 6) and one bread wheat variety (Ammon) were obtained from the National Agricultural Research Centre nurseries in Jordan and used in this study (Table 1). The eight varieties of wheat were exposed to different polyethylene glycol (PEG-6000) treatments to assess the influence of different osmotic potential on the final germination percentage, germination rate and root and shoot traits at seven days old seedlings germinating in the dark under controlled conditions. Briefly, germination tests were carried out in a germination chamber following the International Seed Testing Association (ISTA) rules for germination of wheat seeds (ISTA, 2015). Ten seeds of each variety of wheat were sown in 13 cm diameter Petri dishes above what mangemination paper, using five Petri dishes per genotype. Seeds were exposed to drought using PEG-6000. Two concentrations of PEG-6000 (10% and 15% w/v) were prepared for this assessment. Following treatments, Petri dishes were placed in a growth chamber for seven days at a constant temperature of 20°C and at 80% relative humidity (RH). Treated Petri dishes with sterile distilled water were included as a control. The experimental design was a randomized complete block design (RCBD) with five replicates arranged in split plots, where the main plots were water stress treatments, and the sub-plots were the wheat varieties.

The effect of induced drought stress using PEG

Germinated seeds were counted at eight hours intervals for seven days. Seeds with 2 mm radicle lengths were considered germinated. The collected data then were used to determine the final germination percentage (FGP), mean germination time (MGT) and the time required to reach 10% (t_{10}) and 50% (t_{50}) germination as follows:

Table 1. The names, types, pedigrees, sources and year of release of the eighth wheat varieties used in the study

No.	Name	Type	Pedigree	Source	Year of release
1	Horani Nawawi	Durum	Landrace	Jordan	1976
2	Dair Alla 6	Durum	Yemen X Cr’s’X PLc’s’/’Gto’s CM 18687-D85-D11	Jordan	1974
3	Cham 1	Durum	‘Waha = plc’s’-ruff’s’X gta’s’-rtte	ICARDA	1988
4	Omqais	Durum	Um Rabi 6	ICARDA	2004
5	Acsad 65	Durum	Stork CM470-1M-2Y-CM × GDAV2 469-AA’S” STORK’S	CIMMYT	1988
6	Ammon	Bread	Tsi/Vee’s’	ICARDA	2004
7	Bani Suef 4	Durum	IANZEN1	Egypt	2008
8	Bani Suef 6	Durum		Egypt	

1. FGP was calculated by dividing the total number of germinated seeds by the total number of seeds exist in the Petri dish (in this case 10):

$$FGP = \frac{\sum n}{nt},$$

where n is the number of germinated seeds in each Petri dish after seven days, and nt is the total number of seeds exist in the Petri dish.

2. MGT was calculated according to Lafond & Baker (1986):

$$MGT = \frac{\sum n \times x}{\sum n},$$

where n is the number of newly germinated seeds at each time point (8, 16, 24 h…etc.) and x is the time point of counting.

2. t_{10}: the time takes for 10% of the seeds to germinate,

4. t_{50}: the time takes for 50% of the seeds to germinate.

The following root traits were recorded on seven days of seedlings: the maximum seminal root length (MSRL), the number of seminal roots (NSR), the total seminal root length (TSRL) and the seminal root dry weight (SRDW). Moreover, the following shoot traits were recorded at the same time point: coleoptile length (CL), shoot length (SL) and shoot dry weight (SDW). The ratio between root and shoot dry weights were used to estimate the ratio of root to shoot (RSR).

Data analysis

Data were assessed using a mixed model analysis of variance with PROC MIXED in SAS 9.1. Differences are significant at $P = 0.05$ unless otherwise stated. RCBD design with split arrangement was analyzed using the following linear model:

$$y_{jki} = \mu + B_{k(i)} + T_i + v_{ij} + V_j + VT_{ji} + \varepsilon_{jki},$$

where y_{jki} represents the individual observation of the jki^{th} experimental unit (i.e. Petri dish), μ is the grand mean, T_i is the effect of i^{th} stress treatment, $B_{k(l)}$ is the effect of k^{th} block nested in i^{th} stress treatment, V_k is the effect of k^{th} variety, VT_{ji} is the interaction effect of the i^{th} treatment with k^{th} variety, and v_{ij} and ε_{jki} are main plots and sublopts errors, respectively. The phenotypic variance (was estimated according to the following formula:

$$\sigma_p^2 = \sigma_g^2 + \frac{\sigma_{g\times ex}^2}{n} + \frac{\sigma_e^2}{n \times r},$$

where σ_g^2 is the variance due to genotype, $\sigma_{g\times ex}^2$ is the genotype × treatment variance, is the residual variance component, r is the number of replicates and n is the stress treatments. The broad-sense heritability (h^2) estimates were calculated on plot basis by dividingon (Hallauer & Miranda, 1981). Phenotypic correlations (r_g) between different traits were estimated using variance and covariance for the two traits according to Mode & Robinson (1959). Significant differences among the mean values were compared by LSD test ($P = 0.05$).

Phenotypic and genetic correlation coefficients were calculated to assess any possible relationships amongst different parameters of germination rate and seedling related traits over different parameters of osmotic potential. Coefficients of phenotypic (r_p) and genetic correlation (r_g) were estimated according to the standard procedure of Mode and Robinson (1959), analysis of variance and covariance for different pairs of traits (i.e. parameters) were analyzed in this study. The significance of r_g was considered when the standard errors of the coefficients greater than the standard error by one (+) or two times (Baker, 1986).

Results

Effect of different treatments of osmotic potential on final germination percentage and germination rate

Final germination percentage was not significantly affected by the treatments of PEG osmotic stress, varieties and their interaction (Table 2). Full germination percentage was recorded in all wheat varieties at different levels of osmotic water stress, whereas a delay in initiation (t_{10}) and the time required to reach 50% germination (t_{50}) were observed. The final germination percentage of the control and PEG treatments (10% and 15% PEG) reached 100%for all varieties (Table 2). The parameters of germination rate showed that the seeds germinated faster under control than under osmotic stress (10% and 15% PEG) treatments. Severe osmotic stress (15%) delayed germination to a greater extent than mild osmotic stress treatment (10%). Under 10% PEG and 15% PEG as compared to control, MGT was delayed by 4.78 and 8.99 h, t_{10} by 2.65 and 7.14 h and t_{50} by 4.56 and 8.83 h, respectively.

There was a substantial variation in germination rate among varieties as shown in Table 2, even though all varieties reached 100% in the final germination percentage. The result showed that the fastest germinating varieties over different treatments of osmotic stress were Acsad 65 followed by Cham I and Ammon, while BaniSuef 6 and Omqais varieties were the slowest in germination. For example, the values of germination rate for Acsad 65 were 18.89, 13.73 and 18.40 h for MGT, t_{10} and t_{50}, while the corresponding values for BaniSuef 6 were 24.28, 17.76 and 23.57 h. Varieties that displayed lowest values for MGT, t_{10} and t_{50} could be

Table 2. Main effects of varieties and osmotic stress on final germination percentage, mean germination time (day), the time (day) required to reach 10% and 50% germination (t_{10} and t_{50}, respectively)

Treatment	FGP%	MGT	t_{10}	t_{50}
Variety (V)				
Horani Nawawi	100	21.39c	13.39b	20.43c
Dair Alla 6	100	22.18bc	15.01b	21.37bc
Cham 1	100	20.72bc	14.26b	20.00cd
Omqais	100	23.94a	19.07a	23.19a
Acsad 65	100	18.89d	13.73b	18.40d
Ammon	100	21.32c	14.17b	20.56c
Bani Suef 4	100	23.50ab	15.45b	22.76ab
Bani Suef 6	100	24.28a	17.76a	23.57a
LSD (0.05)	–	1.66	1.85	1.63
Osmotic treatment (OT)				
Control	100	17.44c	12.16c	16.82c
10%PEG	100	22.22b	14.81b	21.38b
15%PEG	100	26.43a	19.30a	25.65a
LSD (0.05)	–	1.03	1.55	1.07
V×OT	ns	ns	ns	ns

Mean values within a column followed by the same letter do not differ based on Least Significant Difference test at $P = 0.05$

suggested as tolerant varieties because they could germinate faster under water stress.

There was a slight increase in CL when varieties exposed to PEG stress (Table 3). This increase was about 0.1 and 0.2 cm under 10% and 15% PEG, respectively. There were no significant differences in MRL between control (13.36 cm) and 10% PEG (13.80 cm), while the MRL was significantly decreased to 12.10cm when exposed to 15% PEG (Table 3). There was not any change in the NSR under all treatments. The root dry weight decreased by increasing PEG stress (Table 3). The root dry weight decreased from 7.25 mg/seedling to 7.10 and 6.64 mg/seedling under 10% and 15% PEG, respectively.

There was a high variation in seedling traits (Table 3). The longest coleoptile averaged over all treatments was observed in HoraniNawawi (7.43 cm), followed by Omqais (6.5 cm). However, the coleoptile lengths ranged from 4.54 to 5.22 cm in all other varieties. The longest seminal roots were observed in Acsad 65 (15.45 cm), followed by BaniSuef 6 (14.96 cm), while MRL ranged in other varieties from 9.90 to 14.71 cm. The variation in NSR was narrow and ranged from 4.71 in BaniSuef 6 to 5.48 in DairAlla6. In regard to the RDW, the heaviest roots were observed in DairAlla 6 (8.20 mg/seedling), followed by Ammon (7.41 mg/seedling), Acsad65 (7.38 mg/seedling) and BaniSuef6 (7.13 mg/seedling), while other varieties showed values ranged from 6.10 to 6.93 mg/seedling (Table 3).

Table 3. Main effects of varieties and osmotic potentials on coleoptiles length (CL), maximum root length (MRL), number of seminal roots (NSR) and root dry weight (RDW)

Varieties and osmotic potentials on coleoptiles length (CL), maximum root length (MRL), number of seminal roots (NSR) and root dry weight (RDW).Treatment	CL	MRL	NSR	RDW
Variety (V)				
HoraniNawawi	7.43 a	14.71 cd	4.92 b	6.93 dcb
DairAlla 6	5.10 cd	13.61 cd	5.48 a	8.20 a
Cham 1	4.54 e	12.90 d	4.30 d	6.23 dc
Omqais	6.50 b	9.90 f	5.01 b	6.54 dcb
Acsad 65	4.90 d	15.45 a	5.01 b	7.38 ab
Ammon	4.92 d	11.73 e	4.92 b	7.41 ab
BaniSuef 4	5.20 c	11.70 e	4.90 b	6.10 d
BaniSuef 6	5.22 c	14.95 ab	4.71 c	7.13 cb
LSD (0.05)	0.102	0.96	0.126	0.58
Osmotic treatment (OT)				
Control	5.40 b	13.36 a	4.98 a	7.25 a
10%PEG	5.60 a	13.80 a	4.93 a	7.10 ab
15%PEG	5.50 a	12.10 b	4.80 b	6.64 b
LSD (0.05)	0.10	0.97	0.13	0.59
V×OT	ns	ns	ns	Ns

Mean values within a column followed by the same letter do not differ based on Least Significant Difference test at $P = 0.05$

Correlations for different traits

Phenotypic genotypic correlation coefficients among different traits were estimated in this study and are presented in Table 4. There were strong and highly significant positive correlations amongst the parameters of seed germination (MGT, t_{10} and t_{50}). The genetic correlation between MGT and both t_{10} and t_{50} were 0.84++ and 1.00++, respectively. The times required to reach t_{10} and t_{50} were significantly and positively correlated (r_g = 0.84++). The parameters of MGT, t_{10} and t_{50} were positively correlated with SL (r_g = 0.53+, 0.47+ and 0.53+, respectively), while they were negatively correlated with MRL and RSR (r_g = -0.57+, -0.60 and -0.57+ and -0.65++, -0.69++ and -0.70++, respectively). The SL was positively correlated with CL and NSR (r_g = 0.69++), while it was negatively correlated with RSR (r_g = -0.54+). The CL showed positive correlation with SFW, SDW and RFW (r_g = 0.57++, 0.66++ and 0.44+, respectively), while it was negatively correlated with RSR on dry basis (r_g = 0.68++). The SFW was positively correlated with NSR, RFW and RSR on fresh basis (r_g = 0.34+, 0.97++ and 0.77++, respectively). The SDW was negatively correlated with MRL (r_g = -1.03++), RSRF (r_g = -0.43+) and RSRD (r_g = -1.30++). The MRL and RSRF were positively and significantly correlated with RSRD (r_g = 0.800++ and 0.55+, respectively). The RFW was positively correlated with RSRF (r_g = 0.90++) (Table 4).

MGT, mean germination time; t_{10} & t_{50}, the time required to reach 10% & 50% germination respectively; SL, seedling length; CL, coleoptile length, SFW, shoot fresh weight; SDW, shoot dry weight; MRL, maximum root length; NSR, number of seminal roots; RFW, root fresh weight; RDW, root dry weight; RSRF, root to shoot ratio on fresh basis; RSRD, root to shoot ratio on dry basis.

Interactive effect of genotypes and water stress

The results of this study showed significant interactions for all traits except for NSR, RFW, RSRF and SFW. The interactive effect of water stress and varieties on MGT was significant (*P* = 0.05) as shown in Table 5. Under different treatments of osmotic, the fastest germination was observed in Acsad65 (MGT = 14.6, 19.8 and 22.3 h under control, 10% PEG and 15% PEG, respectively), followed by Ammon (MGT = 15.7, 22.0 and 26.1h, respectively), Cham1 (MGT = 16.1, 20.1 and 25.9 h, respectively) and Horani Nawawi (MGT = 16.7, 21.9 and 25.6 h, respectively). Furthermore, the germination for other varieties ranged from 17.1 to 22.7, 22.1 to 25.3 h and 26.1 to 29.8 h. In general, genotypes with low MGT and under different treatment of osmotic demonstrated minimum values for t_{10} and t_{50} as shown in Table 5.Under the three treatments of osmotic stress, the longest coleoptiles were observed in HoraniNawawi (CL = 7.7, 7.8

Table 4. Genetic correlation (below diagonal) and phenotypic correlation (below diagonal) coefficients among various pairs of 13 recorded traits

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	MGT		0.80*	1.00**	-0.07	-0.11	-0.24	0.03	-0.52	-0.1	-0.24	-0.72*	-0.32	-0.51
2	t_{10}	0.77++		0.84**	-0.06	0.04	-0.3	0.53	-0.62	0.01	-0.29	-0.58	-0.31	-0.57
3	t_{50}	1.01++	0.80++		-0.07	-0.11	-0.27	0.08	-0.54	-0	-0.26	-0.7	-0.32	-0.52
4	SL	0	0	0		0.98**	0.21	0.43	0.01	0.22	0.37	0.33	1.00**	0.94**
5	CL	-0.96	-0.24	-0.79	1.34		0	0.47	-0.01	0.25	0.46	0.26	0.98**	0.90**
6	SFW	-0.36	-0.38+	-0.35	3.99	2.05		-0.27	0.22	0.29	0.96**	0.02	0.28	0.28
7	SDW	-0.23	0.60+	-0.11	-1.53	-0.45	0.43		-0.4	0.21	-0.23	0.01	0.38	0.23
8	MRL	0	0	0	0	0	0	0		0.37	0.38	0.77*	0.05	0.2
9	NSR	-0.82	-0.39	-0.69	-3.09	-0.89	3.21	-2.17	0		0.31	0.16	0.22	0.11
10	RFW	-0.37	-0.3	-0.34	1.17	0.70+	1.52++	-0.58	0	1.28		0.26	0.44	0.48
11	RDW	-1.32++	-0.98++	-1.20++	0.53	0.18	0.2	-0.93	0	-1	0.37		0.36	0.54
12	RSRF	-0.44	-0.26	-0.39	0	0	0	0	0	0	0	0		0.96**
13	RSRD	-0.58+	-0.66+	-0.59+	0.91++	0.98++	2.63	-1.24	0	-2.7	1.02	0.93+	0	

MGT, mean germination time; t_{10} & t_{50}, the time required to reach 10% & 50% germination respectively; SL, seedling length; CL, coleoptile length, SFW, shoot fresh weight; SDW, shoot dry weight; MRL, maximum root length; NSR, number of seminal roots; RFW, root fresh weight; RDW, root dry weight; RSRF, root to shoot ratio on fresh basis; RSRD, root to shoot ratio on dry basis

Table 5. The interactive effect of genotype and water stress (PEG) on mean germination time (MGT), the time (t_{10}) and (t_{50})

Treatments	Variety	MGT	t_{10}	t_{50}
Control	HoraniNawawi	16.71 bc	9.40 d	15.60 c
	DairAlla 6	17.23 bc	11.12 cd	16.50bc
	Cham 1	16.10 c	11.11 cd	15.58 c
	Omqais	19.20 b	14.83 ab	18.72 b
	Acsad 65	14.60 c	12.80bc	14.90 c
	Ammon	15.70 c	10.60 cd	15.22 c
	BaniSuef 4	17.13 bc	10.25 cd	16.13 bc
	BaniSuef 6	22.70 a	12.20 a	21.98 a
	LSD (0.05)	2.88	3.21	2.83
10% PEG	HoraniNawawi	21.92 bcd	13.80bc	20.95 bc
	DairAlla 6	22.12 bcd	13.70bc	21.10bc
	Cham 1	20.10 cd	12.80 c	19.21 c
	Omqais	22.80bc	17.62 a	22.15 ab
	Acsad 65	19.80 d	12.40 c	18.77 c
	Ammon	22.03 bcd	14.15 bc	21.14 bc
	BaniSuef 4	25.30 a	16.43 ab	24.73 a
	BaniSuef 6	23.70 ab	17.70 a	23.02 ab
	LSD (0.05)	2.88	3.21	2.83
15% PEG	HoraniNawawi	25.60 b	18.60bc	24.74 b
	DairAlla 6	27.20 ab	20.30 b	26.58 ab
	Cham 1	25.98 b	18.90bc	25.22 b
	Omqais	29.83 a	24.80 a	28.71 a
	Acsad 65	22.30 c	16.03 c	21.54 c
	Ammon	26.10 b	17.80bc	25.31
	BaniSuef 4	28.04 ab	19.70 b	27.40 ab
	BaniSuef 6	26.50 b	18.42 bc	25.71 b
	LSD (0.05)	2.88	3.21	2.83

Mean values within a column followed by the same letter do not differ based on Least Significant Difference test at $P = 0.05$

Table 6. The interactive effect of genotype and water stress (PEG) on coleoptile length (CL), maximum roots length (MRL) and shoot length (SL)

Treatments	Variety	CL	MRL	SL
Control	HoraniNawawi	7.71 a	13.7 bc	11.44 a
	DairAlla 6	4.81 cd	12.23 c	9.81 b
	Cham 1	4.63 d	12.99 c	8.26 c
	Omqais	6.40 b	9.99 d	11 a
	Acsad 65	4.59 d	15.30 ab	9.78 b
	Ammon	4.75 cd	13.10 c	9.52 b
	BaniSuef 4	5.14 c	13.15 c	10.04 b
	BaniSuef 6	4.98 cd	16.42 a	9.97 b
	LSD (0.05)	0.40	1.64	0.86
10% PEG	HoraniNawawi	7.78 a	15.88 ab	9.90 a
	DairAlla 6	5.30 c	14.30bc	10.10 a
	Cham 1	4.60 e	14.14 c	7.30 d
	Omqais	6.62 b	10.90 d	9.70 ab
	Acsad 65	4.75 e	17.30 a	9.03 bc
	Ammon	4.81 de	10.48 d	8.73 c
	BaniSuef 4	5.17 cd	11.28 d	9.51 abc
	BaniSuef 6	5.44 c	15.80 ab	10.10 a
	LSD (0.05)	0.40	1.64	0.86
15% PEG	HoraniNawawi	6.80 a	13.57 ab	7.97 abc
	DairAlla 6	5.12 b	14.30 a	7.81 abc
	Cham 1	4.44 c	11.58 cd	6.15 d
	Omqais	6.45 a	8.80 e	7.26 c
	Acsad 65	5.24 b	13.80 ab	8.13 ab
	Ammon	5.20 b	11.56 cd	6.22 d
	BaniSuef 4	5.33 b	10.54 d	8.67 a
	BaniSuef 6	5.24 b	12.66 bc	7.70bc
	LSD (0.05)	0.40	1.64	0.86

Mean values within a column followed by the same letter do not differ based on Least Significant Difference test at $P = 0.05$

and 6.8 cm under control, 10% PEG and 15% PEG, respectively), followed by Omqais (Cl = 6.4, 6.6 and 6.5 cm, respectively). Furthermore, the coleoptile length for other varieties ranged from 4.6 to 5.1 cm, 4.6 to 5.4 cm and 4.4 to 5.1 cm, respectively as shown in Table 6.

Under control, the longest seminal roots (MRL) were observed in Bani Suef6 (16.4 cm), followed by Acsad 56 (15.3 cm), while other varieties ranged from 12.2 to 13.7 cm. Under 10% PEG, the longest seminal roots were observed in Acsad 65 (17.3 cm), followed by HoraniNawawi (15.9 cm) and BaniSuef 6 (15.8 cm), while other varieties ranged from 10.5 to 14.1cmas shown in Table 7. Under 15% PEG, the maximum seminal root length was observed in DairAlla 6 (14.3 cm), followed by Acsad 56 (13.8 cm) and HoraniNawawi (13.6 cm), while other varieties ranged from 8.8 to 12.7 cm.

The interactive effect of water stress and varieties on SL were significant ($P < 0.001$) (Table 6). Under control, the longest shoots were observed in HoraniNawawi (11.4 cm) followed by Omqais (11 cm), while other varieties ranged from 8.3 to 10.0 cm. Under 10% PEG, the longest shoots were observed in BaniSuef 6 and DairAlla 6 (10.1 cm), followed by HoraniNawawi (9.9 cm), while other varieties ranged from 7.3 to 9.7 cm. Under 15% PEG, the longest shoots were observed in BaniSuef 4 (8.7 cm), followed by Acsad 56 (8.1 cm), while other varieties ranged from 6.2 to 8.0 cm.

The interactive effect of water stress and varieties on RDW were significant ($P < 0.001$; Table 7). The heaviest roots were observed in Ammon (13.2 mg), followed by Omqais (7.3 mg) under control treatments. Other varieties ranged from 5.3 to 7.0 mg. DairAlla 6 (9.0 mg), followed by HoraniNawawi (8.0 mg) showed the heaviest roots, while

Table 7. The interactive effect of genotype and water stress (PEG) on root dry weight (RDW), shoot dry weight (SDW; mg/seedling) and root to shoot ratio on a dry basis (RSRD)

Treat-ments	Variety	RDW	SDW	RSRD
Control	HoraniNawawi	6.98 b	9.24 b	0.80abc
	DairAlla 6	6.65 bc	6.81 b	0.97 a
	Cham 1	5.33 c	7.40 b	0.72 bcd
	Omqais	7.30 b	13.72 a	0.53 d
	Acsad 65	5.91 bc	6.94 b	0.90abc
	Ammon	13.20 a	14.30 a	0.92 ab
	BaniSuef 4	6.90bc	8.74 b	0.81 abc
	BaniSuef 6	5.80bc	8.40 b	0.70 cd
	LSD (0.05)	1.64	2.70	0.22
10% PEG	HoraniNawawi	7.99 ab	12.20 a	0.70 c
	DairAlla 6	9.04 a	8.60bcd	1.10 ab
	Cham 1	7.18 bcd	9.13 bcd	1.30 a
	Omqais	6.22 cd	11.13 ab	0.60 c
	Acsad 65	7.97 ab	8.32 cd	0.95 b
	Ammon	4.26 e	10.20abc	0.50 c
	BaniSuef 4	5.95 d	10.96 abc	0.60 c
	BaniSuef 6	7.80abc	6.80 d	1.20 a
	LSD (0.05)	1.65	2.70	0.22
15% PEG	HoraniNawawi	5.84 c	7.20bc	0.80 c
	DairAlla 6	8.80 a	7.30bc	1.22 ab
	Cham 1	6.18 bc	4.60 c	1.40 a
	Omqais	6.12 c	15.24 a	0.40 d
	Acsad 65	8.26 a	8.01 b	1.04 b
	Ammon	4.68 c	7.30bc	0.64 c
	BaniSuef 4	5.50 c	7.20bc	0.80 c
	BaniSuef 6	7.80 ab	6.80bc	1.20 ab
	LSD (0.05)	1.65	2.70	0.22

Mean values within a column followed by the same letter do not differ based on Least Significant Difference test at $P = 0.05$

other varieties ranged from 4.3 to 8.0 mg. Under 15% PEG, the heaviest roots were observed in DairAlla 6 (8.8 mg), followed by Acsad 65 (8.3 mg), while other varieties ranged from 4.7 to 7.8 mg.

The interactive effect of water treatments and varieties on SDW were significant, ($P < 0.001$; Table 7). Under control, the heaviest shoots were observed in Ammon (14.3 mg), followed by Omqais (13.7 mg), while other varieties ranged from 6.8 to 9.2 mg. Under, 10% PEG, the heaviest shoots were observed in HoraniNawawi (12.2mg), followed by Omqais (11.1 mg), while other varieties ranged from 6.8 to 11.0 mg. Under 15% PEG, the heaviest shoots were observed in Omqais (15.2 mg), followed by Acsad 65 (8.0 mg), while other varieties ranged from 4.6 to 7.3 mg.

The interactive effect of water stress and varieties on RSRD were significant ($P < 0.001$; Table 7). The RSRD were observed in DairAlla6 (0.97) followed by Ammon (0.92) under control treatments, and other varieties ranged from 0.53 to 0.9 under 10% PEG. The RSRD was observed in Cham1 (1.3), followed by BaniSuef6 (1.2), and other varieties ranged from 0.5 to 1.1. Under 15% PEG, the RSRD were observed in Cham1 (1.4), followed by DairAlla6 (1.2), and BaniSuef6 (1.2) while other varieties ranged from 0.4 to 1.0.

Variance components and heritability estimates

Heritability estimates (h^2) and confidence interval of h^2 for germination rate and seedling of the eight wheat varieties combined across osmotic potential treatments are presented in Table 8. Genetic variance was highly significant ($P<0.01$) for the recorded parameters except for RDW which demonstrated a non-significant genetic variation with high genotype by osmotic potential interaction. The effects of osmotic potential treatments were highly significant ($P = 0.01$) for all traits. Genotype × osmotic potential interaction was significant ($P < 0.01$) for most traits. The results demonstrated that heritability was extremely high ranging from 0.7 for SDW to 1.0 RFW.

Discussion

Germination is an important stage for the formation of wheat crop, which usually interacts with seedbed environment (i.e. drought and other stresses) and kernel size (Naylor, 1993; Khajeh-Hosseini et al., 2003; Toklu & Yagbasanlar, 2007). Germination and seedling growth can be delayed when seeds expose to drought conditions, however, this depends on the severity of drought stress (Heikal et al., 1982; Mensah et al., 2006). Germination and seedling stage are the most weakest stage in the plant life cycle (Nevo et al., 1984; Kigel, 1995). Therefore, selection for genotypes with high germination percentage and fast germination rate is essential to minimize the effect of drought on seedling growth.

The results of this study demonstrated that PEG simulated drought stress has adverse effect on germination rate. Genetic variation among wheat varieties was demonstrated by the results of this study, more specifically, the germination rate related parameters (MGT, t_{10} and t_{50}) displayed a delay in germination and seedling traits were retarded when they exposed to PEG stress. High PEG concentration (15%) substantially delayed the germination with substantial differences among the eighth genotypes of wheat. All varieties reached t_{10} and t_{50} at different time points. PEG can simulate drought by hampering water imbibition and decreasing water uptake of seeds from surrounding environment. Consequently, simulated drought stress using PEG is the main reason for the delay in germination as reflected in higher values

Table 8. Estimates of variance components, broad sense heritability h^2andconfidence interval (CI) of h^2in some agronomical traits in the tested wheat

Trait	Variance components				h^2	Confidence interval C.I.(h^2)
	Treatment (T)	Genotype (G)	T×G	Error		
Mean germination time	19.98**	2.64**	1.04*	1.05	0.79	4.06-93.83
t_{10}	12.6**	2.8*	1.9**	1.3	0.73	-25.92-91.90
t_{50}	19.2**	2.44**	1.2*	1.009	0.77	-6.74-93.14
Shoots length	1.6**	0.6**	0.2**	0.1	0.86	36.79-95.94
Coleoptile length	-0.002	0.9**	0.06**	0.02	0.97	87.03-99.17
Shoot fresh weight	223.1**	1517.9**	21.45	78.8	0.98	90.1-99.36
Shoot dry weight	0.4	3.3*	2.96**	0.92	0.72	-29.66-91.66
Maximum roots length	0.6*	3.1**	1.2**	0.33	0.86	35.71-95.87
Number of seminal root	0.01+	0.1**	0.006	0.02	0.93	68.80-97.99
Roots fresh weight	141.3**	2080.8**	-24.3	50.5	0.99	98.07-99.88
Roots dry weight	-0.5	-1.1	4.3**	0.34	0.00	0.00-0.00
Root shoot ratio fresh	0.004**	0.03**	0.002	0.004	0.95	77.99-98.59
Root shoot ratio dry	0.0005	0.04*	0.03**	0.005	0.75	-15.22-92.59

**significant at $P < 0.01$; * significant at $P < 0.05$; ns, not significant. t_{10}& t_{50}, the time required to reach 10% & 50% germination respectively

of MGT, t_{10} and t_{50} (Murillo-Amador et al., 2002; Sayar et al., 2010b; Ghanifathi et al., 2011). Selection of genotypes under drought conditions with a high germination percentages and high values of MGT, t_{10} and t_{50} are critical to obtain a vigorous seedling and coping early drought stress (Al-Karaki, 1998; Abdel-ghani & Al-majali, 2013; Abdel-Ghani et al., 2014a). In the current study, Cham I and Ammon germinated faster with short MGR, t_{10} and t_{50}periods under PEG stress which allows the use of these wheat varieties in arid areas that are suffering from frequent early drought stress. Interestingly, there was not any significant effect by the osmotic stress on the FGP which indicates the high adaptability of these varieties to water stress conditions. In contrast, previous studies showed that PEG stress decreased FGP when it compared to non-stress conditions (Almansouri et al., 2001; Jajarmi, 2009; Sayar et al., 2010a)especially drought stress, can play an important role in the reduction of the plant growth stage, specifically during germination in arid and semi arid regions in Iran.. In order to study the effects of drought stress on germination indices in wheat cultivars, an experiment was conducted in factorial form, using a completely randomized design of four replications. In this experiment, seven wheat cultivars (azar, omid, dorom, tabaci, keraceharvand, arvand, Gv 3-20.

Plant breeders and research scientists in the semi-arid areas attempt to improve wheat yields and develop new wheat varieties that tolerate drought. Managing the risk of drought is a very complex process that requires interactive effect of many traits with biochemical processes and polygenic inheritance combined with a high genotype by environment interaction (Ceccarelli, 1996; Zhu, 2002; Tuberosa & Salvi, 2007) detoxification (i.e., damage control and repair. Susceptibility to drought depends on its intensity and duration, as well as, the growth stage of the crop at which the drought is imposed (Szira et al., 2008; Haddadin et al., 2013)the physiological and quantitative genetic bases of drought tolerance are still poorly understood. The comparison of results obtained from different sources is also complex, because different testing methods may lead to controversial conclusions. This report discusses various drought stress experiments (hydroponics and in soil. The tolerance of genotypes at a particular growth stages not necessarily correlated with the level of tolerance at other growth stages (Szira et al., 2008; Nezhadahmadi et al., 2013; Acuña-Galindo et al., 2015)the physiological and quantitative genetic bases of drought tolerance are still poorly understood. The comparison of results obtained from different sources is also complex, because different testing methods may lead to controversial conclusions. This report discusses various drought stress experiments (hydroponics and in soil. Plant breeders often aim to select high yielding genotypes by either direct selection for grain yield *per se* or indirect selection of traits that are related to drought. In this study, the results demonstrate considerable variations among seedling traits. Traits such as coleoptiles length and seminal roots can be very useful in the indirect selection traits to improve the adaptation to drought at the seedling stage. For example, selection of long coleoptiles and a more vigorous root can improve adaptation under drought, this also includes more vigorous seedlings, erect growth habit, long coleoptiles, tallness and long peduncles, long and high number of seminal roots and nodal roots with high volume and density (Almansouri et al., 2001; Ceccarelli et al., 2004). In the current study, there were high and significant genetic differences in the length of coleoptiles and seminal roots which indicate the possibility of improving wheat performance (Grando & Ceccarelli, 1995; Haddadin et al., 2013; Abdel-Ghani et al., 2014a).

In addition, selection of genotypes with vigorous roots can enhance the grain yield. The results of previous studies showed that a more vigorous root system in cereals was positively correlated with plant biomass (Pandey et al., 2000; Kanbar et al., 2009; Chloupek et al., 2010; Sayed, 2011; Ehdaie et al., 2012; Xie et al., 2017)maize was grown under five irrigation treatments, providing deficit irrigation during vegetative and reproductive periods at five N levels on a Tropudalph clay loam soil. The purpose of this study was to (i. Similarly, a recent study by Abdel-Ghani et al. (2014) indicated that selection for a more vigorous root system can improve barley performance under drought conditions.

The results of the current study indicate that the heritability estimate was generally high for most traits ranged from 0.72 to 1.00 with significant interactions between genotype × osmotic potential treatments. Furthermore, there was a high and significant interaction between genotype × osmotic potential on the RDW, which indicates that the genotypes of wheat varieties responded differently to osmotic stress. The high heritability combined with high and low genetic × treatments interaction for both germination rate and seedling traits indicates a high potential for using these traits as indirect selection criteria to improve the yield of wheat crop. This result supports previous reports (Ceccarelli, 1996; Abdel-Ghani et al., 2014a) which indicated indirect selection for drought related trait might be an efficient approach to enhance yield, especially, when such traits are positively correlated with yield and displayed high heritability estimates.

Conclusions

Osmotic stress had no effect on the final germination percentage. All varieties reached full germination under different osmotic potentials which indicates the high potential of these varieties under drought stress. Osmotic stress delayed the initiation (t_{10}) and the time needed to reach 50% germination (t_{50}) with substantial variation among tested varieties. The fastest germinating varieties over different osmotic potential treatments were Acsad 65 followed by Cham I and Ammon, while BaniSuef 6 and Omqais varieties were the slowest in germination. Therefore, using varieties with fast germination under drought would be advantageous to get more vigorous seedlings and consequently might result in high yield. Long coleoptiles and deep and vigorous seminal roots are desirable traits under drought and can be exploited further to enhance seedling vigorous. Horani Nawawi and Omqais displayed the longest coleoptiles, while the longest seminal roots were observed in Acsad 65 and BaniSuef 6. The variation in seminal roots was narrow. The heaviest roots were observed in DairAlla 6, followed by Ammon, Acsad65 and BaniSuef6. The heritability estimate was generally high for most traits ranged from 0.70 to 1.0, which might indicate a high potential for using these traits as indirect selection criteria to improve seedling growth and consequently wheat yield.

References

Abdel-Ghani, A. H., Kumar, B., Reyes-Matamoros, J., Gonzalez-Portilla, P. J., Jansen, C., Martin, J. P. S., Lee, M. & Lübberstedt, T. (2013). Genotypic variation and relationships between seedling and adult plant traits in maize (*Zea mays* L.) inbred lines grown under contrasting nitrogen levels. *Euphytica*, *189*, 123-133.

Abdel-Ghani, A., Neumann, K., Wabila, C., Sharma, R., Dhanagond, S., Owais, S. J., Börner, Graner, A. & Kilain, B. (2014). Diversity of germination and seedling traits in a spring barley collection under drought simulated conditions. *Genet. Resour. Crop Evol.*, *62*(2), 275-292.

Abdel-Ghani, A. H., Parzies, H. K., Omary, A. & Geiger, H. H. (2004). Estimating the outcrossing rate of barley landraces and wild barley populations collected from ecologically different regions of Jordan. *Theor. Appl. Genet.*, *109*, 588-95.

Acuña-Galindo, M. A., Mason, R. E., Subramanian, N. K. & Hays, D. B. (2015). Meta-analysis of wheat QTL regions associated with adaptation to drought and heat stress. *Crop Sci.*, *55*, 477-492.

Al-Karaki, G. N. (1998). Response of wheat and barley during germination to seed osmopriming at different water potential. *J. Agron. Crop Sci.*, *181*, 229-235.

Almansouri, M., Kinet, J. M. & Lutts, S. (2001). Effect of salt and osmotic stresses on germination in durum wheat (*Triticum durum* Desf.). *Plant Soil*, *231*, 243-254.

Baker, R. J. (1986). Selection indices in plant breeding. CRC Press, Inc., Boca Raton, Florida.

Ceccarelli, S. (1996) Adaptation to low/high input cultivation. *Euphytica*, *92*, 203-214.

Ceccarelli, S., Grando, S. & Baum, M. (2004). Breeding for drought resistance in a changing climate. In: *Challenges and strategies for dryland agriculture. CSSA Special Publication No. 3.* Crop Science Society of America and American Society of Agronomy, Segoe Rd. Madison. WI 53711, USA, 677 S.

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

Chloupek, O., Forster, B. P. & Thomas, W. T. B. (2006). The effect of semi-dwarf genes on root system size in field-grown barley. *Theor. Appl. Genet.*, *112*, 779-786.

Ehdaie, B., Layne, A. P. & Waines, J. G. (2012). Root system plasticity to drought influences grain yield in bread wheat. *Euphytica*, *186*, 219-232.

Ghanifathi, T., Valizadeh, M., Shahryari, R. & Shahbazi, H. (2011). Effect of drought stress on germination indices and seedling growth of 12 bread wheat genotypes. *Adv. Environ. Biol.*, *5*, 1034-1039.

Grando, S. & Ceccarelli, S. (1995). Seminal root morphology and coleoptile length in wild (*Hordeum vulgare* ssp. *spontaneum*) and cultivated (*Hordeum vulgate* ssp.*vulgare*) barley. *Euphytica*, *86*, 73-80.

Haddadin, M. F., Abdel-Ghani, A. H. & Al-Majali, N. F. (2013). Response of barely varieties to drought stress imposed at different developmental stages. *Jordan J. Agric. Sci., 9*, 507-524.

Hallauer, A. M. & Miranda, J. B. (1981). Quantitative genetics in maize breeding, 2nd ed. Iowa State University Press, Ames, Iowa.

Heikal, M. M., Shaddad, M. A. & Ahmed, A. M. (1982). Effect of water stress and gibberellic acid on germination of flax, sesame and onion seeds. *Biol. Plant.*, *24*, 124–129.

ISTA (2015). ISTA Rules Full Issue. Int. Rules Seed Test.

Jajarmi, V. (2009). Effect of water stress on germination indices in seven wheat cultivar. *World Acad. Sci. Eng. Tech., 49*, 105-106.

Kanbar, A., Toorchi, M. & Shashidhar, H. E. (2009). Relationship between root and yield morphological characters in rainfed low land rice (*Oryza sativa* L.). *Cereal Res. Commun.*, *37*, 261-268.

Khajeh-Hosseini, M., Powell, A. A. & Bingham, I. J. (2003). The interaction between salinity stress and seed vigor during germination of soybean seeds. *Seed Sci. Technol.*, *31*, 715-725.

Kigel, J. (1995). Seed germination in arid and semiarid regions, in: Kigel, J., Galili, G. (Eds.), Seed Development and Germination. New York: *Marcel Dekker*, 645-697.

Kumar, B., Abdel-Ghani, A. H., Reyes-Matamoros, J., Hochholdinger, F. &Lübberstedt, T. (2012). Genotypic variation for root architecture traits in seedlings of maize (*Zea mays* L.) inbred lines. *Plant Breed.*, *131*, 465-478

Lakew, B., Semeane, Y., Alemayehu, F., Gebre, H., Grando, S., Van Leur, J. A. G. & Ceccarelli, S. (1997). Exploiting the diversity of barley landraces in Ethiopia. *Genet. Resour. Crop Evol.*, *44*, 109-116.

Mensah, J. K., Obadoni, B. O. & Eruotor, P. G. (2006). Simulated flooding and drought effects on germination, growth, and yield parameters of sesame (*Sesamum indicum* L.). *African J. Biotechnol*., *5*, 1249-1253.

Mode, C. J. & Robinson, H. F. (1959). Pleiotropism and the genetic variance and covariance. *Biometrics*, *15*, 518-537.

Murillo-Amador, B., López-Aguilar, R., Kaya, C., Larrinaga-Mayoral, J. & Flores-Hernández, A. (2002). Comparative effects of NaCl and polyethylene glycol on germination, emergence and seedling growth of cowpea. *J. Agron. Crop Sci.*, *188*, 235-247.

Naylor, R. E. L. (1993). The effect of parent plant nutrition on seed size, viability and vigour and on germination of wheat and triticale at different temperatures. *Ann. Appl. Biol.*, *123*, 379-390.

Nevo, E., Beiles, A., Gutterman, Y., Storch, N. & Kaplan, D. (1984). Genetic resources of wild cereals in Israel and vicinity II. Phenotypic variation within and between populations of wild barley (*Hordeum sponataneum*). *Euphytica*, *33*, 737-756.

Nezhadahmadi, A., Prodhan, Z. H. & Faruq, G. (2013). Drought tolerance in wheat. *Sci. World J.*, 610721. doi:10.1155/2013/610721

Pandey, R. K., Maranville, J. W. & Admou, A. (2000). Deficit irrigation and nitrogen effects on maize in a Sahelian environment I. Grain yield and yield components. *Agric. Water Manag., 46,* 1-13. doi:10.1016/S0378-3774(00)00073-1

Parzies, H. K., Nke, C. F., Abdel-Ghani, A. H. &Geiger, H. H. (2008). Outcrossing rate of barley genotypes with different floral characteristics in drought-stressed environments in Jordan. *Plant Breed.*, 127, 536-538.

Sahnoune, M., Adda, A., Soualem, S., Harch, M. K. & Merah, O. (2004). Early water-deficit effects on seminal roots morphology in barley. *C. R. Biol.*, *327*, 389-398.

Sayar, R., Bchini, H., Mosbahi, M. & Ezzine, M. (2010). Effects of salt and drought stresses on germination, emergence and seedling growth of Durum wheat (*Triticum durum* Desf.). *J. Agric. Res.*, *5*, 2008-2016. doi

Sayar, R., Bchini, H., Mosbahi, M. & Khemira, H. (2010). Response of Durum wheat (*Triticum durum* Desf.) growth to salt and drought stresses. *Czech J. Genet. Plant Breed.*, *46*, 54-63.

Sayed, M. (2011). QTL Analysis for Drought Tolerance Related to Root and shoot traits in barley (*Hordeum vulgare* L.). der Rheinischen Friedrich-Wilhelms-Universität Bonn, Germany.

Soto-Cerda, B. J. & Cloutier, S. (2012). Association mapping in plant genomes, In: *Genetic Diversity in Plants,* 29–54.

Szira, F., Bálint, A. F., Börner, A. & Galiba, G. (2008). Evaluation of drought-related traits and screening methods at different developmental stages in spring barley. *J. Agron. Crop Sci.*, *194*, 334-342.

Toklu, F. & Yagbasanlar, T. (2007). Genetic analysis of kernel size and kernel weight in bread wheat (*T. aestivum* L.). *Asian J. Plant Sci.*, *6*, 844-848.

Tuberosa, R. & Salvi, S. (2007). From QTLs to genes controlling root traits in maize, in: Scale and complexity in plant system research: *Gene-Plant-Crop Relations*, 15-24.

Tuberosa, R., Salvi, S., Sanguineti, M. C., Maccaferri, M., Giuliani, S. &Landi, P. (2003). Searching for quantitative trait loci controlling root traits in maize: A critical appraisal, in: *Plant and Soil*, 35-54.

Wang, Y., Yao, J., Zhang, Z. & Zheng, Y. (2006). The comparative analysis based on maize integrated QTL map and meta-analysis of plant height QTLs. *Chinese Sci. Bull.*, 51, 2219-2230.

Xie, Q., Fernando, K. M. C., Mayes, S. & Sparkes, D. L. (2017). Identifying seedling root architectural traits associated with yield and yield components in wheat. *Ann. Bot.*, *119*, 1115-1129.

Zhu, J. K. (2002). Salt and drought stress signal transduction in plants. *Annu. Rev. Plant Biol.*, *53*, 247-273.

Received: March, 27, 2019; *Accepted:* August, 21, 2019; *Published:* April, 30, 2020