EVALUATION OF BREAD AND EINKORN WHEAT UNDER *IN VITRO* DROUGHT STRESS

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ABSTRACT

The purpose of this study was to investigate the resistance of bread and einkorn wheat genotypes under *in vitro* conditions against drought stress during germination. Twelve bread and ten einkorn wheat genotypes were used as plant material and seven drought stress levels were applied based on a three-replicate factorial restricted randomized block design in order to investigate their effects on germination rate (GR), germinating power (GP), coleoptile length (CL), shoot length (SL), root length (RL), shoot root length ratio (SRLR), root fresh weight (RFW), root dry weight (RDW), and root fresh dry weight ratio (RFDWR) during the year 2014-2015. PEG – 6000 was used to evaluate the effect of drought stress under in vitro conditions on the wheat genotypes. The values of all traits were decreased by the increased effect of PEG levels ($p \leq 0.05$). The results of the variance analysis showed that the genotypes had significant statistical differences for the examined traits under drought stress ($p < 0.05$). According to the results of the GGE biplot analysis, of the total variation between the genotypes and traits investigated under drought stress (75.97%), PC1 and PC2 represented 51.51% and 24.47%, respectively. In addition, einkorn wheat populations were located in the sector of GR, GP, and SRL, which means that these populations had a greater performance for these traits under drought stress conditions. Bread wheat and einkorn genotypes behaved differently for the traits under drought stress. It is considered that the results of the field and in vivo experiments for cold and drought stress will contribute to producing reliable suggestions.

Key words: Bread wheat (*Triticum aestivum* L.), drought, einkorn (*Triticum monococcum* ssp. *monococcum*), germination stage.

INTRODUCTION

Wheat is the most widely grown species across the world and feeds more than one - third of the global population (Rahaie *et al.,* 2013; Shahzad *et al.,*2013) through a production of 670.8 million tons undertaken by 200 million farmers. It is widely used as an ingredient in bread, pasta, noodles, cakes, and biscuits (Eren *et al.,* 2015). In developing countries, wheat guarantees human survival and increases the quality of life (Shahzad *et al.,* 2013; Baloch *et al*., 2017).

The ancestor of wheat, einkorn (*Triticum monococcum spp. monococcum*), has long contributed to the human nutrition and health (Karakaş, 2015). However, it is only grown in limited areas of Turkey, such as the provinces of Kastamonu, Bolu, and Bilecik. It is resistant to cold, drought, and salinity stress (Karagöz and Zencirci, 2005; Zencirci and Karagöz, 2005; Aslan *et al.,* 2016a; Aslan *et al.,* 2016b). Arzani and Ashraf (2017) also reported that einkorn, emmer, and spelt are potential sources for drought, salinity, cold, and several biotic stress factors and should be used as parents in wheat breeding programs. Furthermore, einkorn wheat can be used to improve genetic diversity on the 'A' genome of bread and durum wheat (Aktaş, 2007).

Bread wheat depends on rainfall for its production and 37% of it is cultivated in semi - arid areas of developing countries (Baloch *et al*., 2016); therefore, its yield and production fluctuate frequently due to highly restrictive non - environmental and environmental stresses including diseases, insects, drought, high temperature and cold. Drought stress, which widely differs across the world, reduced the quality of wheat at varying levels depending upon the degree and duration of drought and drought stress in different growth stage of the plant. Wheat genotypes, which are widely adapted to lower rainfall or drought yield higher (Cattivelli *et al.,* 2008) and stabilize wheat production across many countries (Rajaram, 2001).

Wheat (*Triticum* ssp.) needs different temperatures and water regimes at different growth stages, depending on its growth type, planting season, and production region. In wheat, water stress influences all the stages of development from germination to grain filling through vegetative and reproductive growth. Since this species, which is of great economic importance, has to endure drought conditions in numerous countries where it is cultivated, its future production largely depends on studies devoted to providing a better understanding of this stress. Drought sensitivity in wheat, among other growth stages, occurs especially in the early growth and germination stages (Khodabandeh, 2003). Therefore, characterization of drought tolerance of wheat genotypes at the seedling stage is important for global food safety. In addition, selection of wheat genotypes for drought tolerance under actual field conditions is tedious due to low heritability and time required. Thus, an efficient way is to characterize genotypes under in vitro conditions, particularly drought stress, during the early development stages of wheat. Good seed germination is among the prerequisites for a successful stand establishment and further crop development. Yield improvement should, therefore, combine a reasonably high yield potential and one or more specific growth characters under stress. Otherwise, the attempt to increase genetic yield under stress would not provide a successful outcome (Blum, 2005).

To select genotypes for drought tolerance at the seedling stage, polyethylene glycol (PEG 6000) is used in the medium (Rauf *et al.,* 2007). PEG 6000 molecules are inert, non-ionic and basically impermeable chains and have commonly been used to induce water stress without causing any significant physiological damage to crops (Wani *et al.,* 2010). PEG can be used to change the osmotic potential of nutrient clarification culture and can transfer plant water shortage, in an exact way, properly to untried proprieties (Razmjoo *et al.,* 2015).

Testing, locating, and characterizing of genetic resources against drought are succeeded well by advanced parametric, non - parametric, multi - statistical evaluation methods as well as genotype and genotype by environment interaction (GGE) biplot analyses (Yan, 2001; Yan and Kang, 2003; Mahmoodzadeh *et al.,* 2013; Ali and El - Sadek, 2016) result in better wheat germplasm, thus increase wheat yield. Therefore, this study aimed to investigate the drought tolerance and response of 12 bread wheat (*Triticum aestivum* L.) cultivars and 10 hulled einkorn (*T. monococcum* ssp. *monococcum*) wheat populations in terms of germination rate (GR), germinating power (GP), coleoptile length (CL), shoot length (SL), root length (RL), shoot / root length ratio (SRLR), root fresh weight (RFW), root dry weight (RDW), root fresh weight / root ratio (RFDWR) under in vitro conditions using 7 PEG levels during the season of 2014-2015.

MATERIALS AND METHODS

The plant material consisted of 12 bread wheat cultivars; namely, Gerek - 79, İkizce - 96, Kıraç - 66, Kenanbey, Flamura - 85, Momtchil, Bayraktar - 2000, Tosunbey, Pandas, Pehlivan, Demir - 2000 and Gün - 91), and 10 different einkorn wheat populations (Populations 1to 10). These cultivars were evaluated in terms of their GR (%), GP (%), CL (cm), SL (cm), RL (cm), SRLR, RFW (mg), RDW (mg), and RFDWR under drought stress. The seeds of bread wheat cultivars were provided by different research institutes in Turkey (CRIFC, Ankara; AARI, Eskişehir; TARI, Edirne; and CARI, Adana) and einkorn wheat populations were obtained from the Quality Feed Company in Bolu, Turkey.

Drought stress tests: The seeds (3 X 30 rows of each entry per treatment) were surface - sterilized in 96% ethanol for 30 seconds and 10% sodium hypochlorite for 15 minutes and rinsed twice in distilled water (Baloch *et al.,* 2012). Then, 30 seeds (10 X 3) were germinated on wet filter paper under 7 levels of drought stress. PEG 6000-induced drought levels were PEG 600: 0 (control), 4.57 ml: 0.09M, 9.14 ml: 13.71 ml: 0.17 M, 18.28 ml: 0.25M, 22.85 ml: 0.34M, 25.15 ml: 0.43M, and 27.45 ml: 0.51M. The pH of each petri dish was adjusted to 5.9 ± 1 and germinated for 8 days at 23 ± 1 °C in a dark growth room. GR (%) was measured after 4 days and all other remaining GP (%), CL (cm), SL (cm), RL (cm), SRLR, FRW (mg), DRW (mg), and RFDWR were measured after 8 days.

Statistical analysis: Three replicates of the experiment were performed with a randomized complete block design including factorial restrictions. GGE biplot analyses were carried out using GenStat 12th edition (Genstat, 2009) as described by Yan (2001). The means were compared by an LSD test ($p < 0.01$ and $p < 0.05$) according to Gomez and Gomez (1984) and a cluster analysis was performed using SPSS statistical software (Zobel *et al.,* 1988).

RESULTS AND DISCUSSION

Responses of germination characters (GR, GP, CL, SL, RL, SRLR, RFW, RDW, and RFDWR) under drought stress: The effect of drought stress produced by PEG on bread and einkorn wheat genotypes at the seedling stage was investigated under in vitro drought conditions. According to ANOVA, PEG levels (treatments) were significant for all the traits. The difference between the genotypes was statistically significant for all the traits except GP, SRLR, and RFW, and the cultivar effect was significant for GR, RL, and RDW (Table 1). PEG that was used to induce drought stress by adjusting concentrations resulted in a statistically significant decrease in the traits under investigation for all the genotypes ($p \leq 0.05$; Table 2): SL (100 %), SRLR (100 %), RL (99.07 %), RFW (98.87 %), CL (98.69 %), RDW (97.60 %), GR (72.89 %), RFDWR (64.13 %), and GP (55.90 %). The relationship between the PEG levels and the examined traits was analyzed by a regression analysis (Figures 1- 4). The results revealed that as the PEG level increased, GP, GR, CL, and RL decreased. In other words, there was a negative and statistically significant relationship between the PEG levels and GR (R^2=0.76; $p < 0.01$), GP ($R^2 = 0.94$; $p < 0.01$), CL ($R^2 = 0.86$; $p < 0.01$), and RL ($R^2 = 0.94$; $p < 0.01$).These findings are in parallel with those given in the study by Chachar *et al.*(2014), who reported that the increasing concentrations of PEG - 6000 significantly and negatively affected several traits in wheat genotypes such as RL, CL, and SL compared to the control application.

The results of the current study showed that drought stress directly affected GR in both einkorn populations and bread wheat cultivars. GR was reduced to 24.48% in bread wheat and 15.93% in einkorn populations with a mean of 72.95 % and 86.10 %, respectively (Table 3). The lowest GR for bread wheat cultivars was recorded in Kıraç - 66 (71.90 %) and the highest was obtained from Gün - 91 (83.30 %). Among the einkorn populations, the lowest and highest GRs were recorded in Population 9 (78.10 %) and Population 3 (92.90 %), respectively. Similar results were obtained for GP with an average of 81 % in bread wheat and 91.3 % in einkorn populations. The results showed that bread wheat cultivars were more affected by drought stress compared to einkorn populations. Drought stress reduced GP by 19.21 % in bread wheat genotypes and by 9.6 % in einkorn populations. In bread wheat genotypes, the lowest and highest GPs were observed in Pehlivan (71.90 %) and Gün - 91 (89.00 %), respectively. Among the einkorn populations, Population- 8 had the lowest GP (85.70 %) and Population- 5 had the highest GP (95.70 %). These results indicated that with their better GR and GP values, einkorn populations presented as potential genetic sources in wheat breeding programs for vigorous germination under drought stress conditions. Similarly, Mujtaba *et al.* (2016) reported that PEG-6000-induced drought stress reduced the GR of modern wheat cultivars by 55% and suggested that wheat breeders should benefit from the variation in primitive and wild wheat genetic resources.

Table 1. F values in analysis of variance for the GR, GP, CL, SL, RL, SRLR, FW, RDW, and RFDWR under the drought effect of PEG- 600: (0 (Control), 0.09M, 0.17 M, 0.25M, 0.34M, 0.43M and 0.51M).

Sources of variation	DF	GR†	GP	CL	SL	RL	SRLR	RFW	RDW	RFDWR
Blocks	2	10.67**	3.78**	0.07**	8.64 *	3.34 *	0.27**	9.02**	2.97ns	0.67 *
Treatments	153	27.92**	17.87**	1.13**	56.25**	44.18**	5.88**	56.16**	39.53**	13.31**
Genotype	21	6.18**	3.90ns	0.07**	1.98 *	5.91**	0.62ns	7.68ns	7.11**	1.26**
Levels	6	189.83**	113.06**	8.83**	456.42*	339.71**	37.81**	434.21**	295.62**	100.25**
Genotype *Levels	126	1.23**	1.20ns	0.03ns	0.71ns	0.72**	0.48ns	0.78ns	0.74**	0.40ns
Error	306									

* and ** are respectively significant at P ≤ 0.05 and P ≤ 0.01, ns: not significant

Table 2. Differences between for GR, GP, CL, SL, RL, SRLR, FW, RDW, and RFDWR under the drought effect of PEG 600: (0 (Control), 0.09M, 0.17 M, 0.25M, 0.34M, 0.43M and 0.51M).

Levels	GR†	GP	CL	SL	RL	SRLR	RFW	RDW	RFDWR
Control	98.50 ^{a}	100.00 ^{a}	4.08 ^{a}	14.08 ^{a}	8.64^{ab}	1.89^{ab}	87.26 ^{a}	7.60 ^{a}-^{c}	11.46 ^{a}
0,09 M	98.00^{ab}	100.00^{ab}	4.57 ^{ab}	12.29 ^{b}	9.01 ^{a}	3.96 ^{a}	86.41^{ab}	9.90 ^{ab}	8.71^{ab}
0,17M	94.40^{a}-^{c}	97.60^{a}-^{c}	4.11 ^{a}-^{c}	7.37^{bc}	7.48^{a}-^{c}	0.97 ^{b}	68.04^{a}-^{c}	9.96 ^{a}	6.83^{a}-^{c}
0,25M	90.90^{a}-^{d}	95.20^{a}-^{d}	1.95 ^{a}-^{c}	0.74 ^{d}	4.49^{a}-^{c}	0.12 ^{b}	36.87^{a}-^{c}	6.73 ^{a}-^{c}	5.49^{b}-^{d}
0,34M	83.90^{a}-^{e}	87.30^{a}-^{e}	0.33 ^{d}	0.00^{de}	1.85 ^{c}	0.00 ^{b}	13.78 ^{c}	2.94 ^{a}-^{c}	4.93^{b}-^{e}
0,43M	63.20^{a}-^{f}	75.50^{a}-^{f}	0.16 ^{d}	0.00^{de}	0.38 ^{c}	0.00 ^{b}	3.53 ^{c}	0.90 ^{c}	4.45^{b}-^{e}
0,51M	26.70 ^{f}	44.10^{f}g	0.06 ^{d}	0.00^{de}	0.08 ^{c}	0.00 ^{b}	0.99 ^{c}	0.24 ^{c}	4.11^{b}-^{e}
% Decrease	72.89	55.90	98.69	100.00	99.07	100.00	98.87	97.60	64.13

Differences between the averages shown with same letters are insignificant at a level of P<0.05.

In this study, CL, an important criterion demonstrating drought resistance of wheat, had statistically significant variations with a mean of 2.31 cm in bread wheat cultivars and 2.02 cm in einkorn populations (Table 3). Among the bread wheat genotypes, Bayraktar - 2000 attained the maximum CL (2.73 cm) while other genotypes, Kenanbey (2.68 cm), Gün - 91 (2.63 cm), Gerek - 79 (2.57 cm), Demir - 2000 (2.53 cm), and Momtchill (2.46 cm) were included in the same statistical group in terms of their maximum CL.

Among the einkorn populations, the longest CL was found in Population- 1 (2.37 cm) and Population- 4 (2.24 cm) and the remaining genotypes had a lower CL. When wheat genotypes with a longer CL are deeply sown, they can germinate and emerge easily above the soil surface. Therefore, the genotypes with longer CL in the present study can be used to develop drought - resistant wheat genotypes. Following the drought stress, CL decreased by 30.97% in bread wheat genotypes and by 29.95 % in einkorn populations. Despite the higher mean of CL in bread wheat, the einkorn populations underwent a lower decrease in CL due to drought. When genotypes that have a longer CL are deeply sown, the seeds germinated under the soil are not much affected by the water-limited conditions. With the roots extending deeper into the ground, the plant not only becomes more resistant to drought but is also healthier due to its long coleoptile to emerge to the surface from deeper soil. Longer CL through deep sowing increases the number and yield of plants (Matsui *et al.,* 2002; Rebetzke *et al.,* 2007). It has been reported that CL significantly varies among winter wheat genotypes and is positively correlated with yield components (Kaydan and Yağmur, 2005; Matsui *et al.,* 2002). Our study clearly confirmed that einkorn wheat populations were more tolerant to drought, and therefore, can be used to improve the CL of wheat cultivars in breeding programs.

Table 3. Means and LSD mean separation of traits of wheat genotypes under drought stress induced by PEG-6000.

	GR	GP	CL	SL	RL	SRLR	RFW	RDW	RFDWR
Gerek– 79	70.38^{f-q}	80.50^{g-q}	2.57^{a-d}	5.74^{a-c}	5.79^{ab}	0.68^{k-s}	47.12^{a-h}	5.79^{c-h}	7.41^{a-c}
İkizce– 96	76.70^{d-m}	83.30^{d-m}	2.39^{a-g}	5.56^{a-d}	5.26^{a-I}	0.69^{k-r}	48.97^{a-g}	6.99^{a-c}	6.05^{h-s}
Kıraç – 66	62.90^{o-v}	76.20^{l-t}	2.01^{f-n}	3.58^{a-u}	3.77^{j-q}	0.68^{k-r}	40.24^{d-k}	5.57^{c-k}	6.98^{a-f}
Kenanbey	78.60^{c-j}	86.70^{a-k}	2.68 ^{ab}	5.76^{ab}	5.65^{a-c}	0.73^{k-p}	58.46 ^{a}	7.73 ^{a}	6.52^{d-k}
Flamura - 85	72.90^{g-s}	82.90^{e-o}	1.80^{i-s}	4.08^{a-s}	5.26^{a-h}	0.64^{l-t}	50.00^{a-f}	6.25 $^{a-f}$	6.97^{a-g}
Momtchil	75.20^{e-o}	82.90^{e-p}	2.46^{a-f}	4.94^{a-m}	5.55^{a-e}	0.76^{i-n}	55.02^{a-c}	6.36 $^{a-e}$	7.60 ^{a}
Bayraktar–2000	78.10^{c-l}	83.30^{d-n}	2.73 ^{a}	5.47^{a-f}	5.97 ^{a}	0.76^{i-n}	55.87 ^{ab}	7.60 ^{ab}	6.36^{d-n}
Tosunbey	73.80^{f-p}	80.00^{g-r}	1.81^{i-r}	3.60^{a-u}	5.50^{a-f}	0.69^{k-r}	51.46^{a-e}	5.87^{b-g}	7.52 ^{ab}
Pandas	73.30^{g-r}	79.00^{g-s}	1.86^{h-q}	5.30^{a-h}	5.64^{a-d}	0.83^{i-m}	46.14^{a-I}	5.76^{c-j}	6.42^{d-l}
Pehlivan	66.20^{j-u}	71.90^{q-v}	2.23^{a-j}	4.74^{a-o}	4.34^{c-k}	0.91^{e-l}	37.44^{f-p}	4.58^{f-q}	6.61^{c-I}
Demir– 2000	70.00^{j-t}	75.70^{l-u}	2.53^{a-e}	6.34 ^{a}	4.63^{a-j}	1.04^{c-j}	44.32^{b-j}	5.76 $^{c-I}$	6.52^{d-j}
Gün– 91	83.30^{a-h}	89.00^{a-g}	2.63^{a-c}	4.79^{a-n}	5.33^{a-g}	0.95^{d-k}	51.55^{a-d}	6.61^{a-d}	7.02^{a-e}
Mean	72.95	81,00	2,31	4,99	5,22	0.78	48,9	6,24	6,83
Population – 1	88.60^{a-d}	93.30^{a-d}	2.37^{a-I}	5.46^{a-f}	3.82^{h-p}	1.09^{b-I}	38.65^{d-m}	5.21^{d-l}	6.05^{h-t}
Population – 2	88.10^{a-e}	91.90^{a-f}	2.04^{e-m}	5.15^{a-j}	3.69^{j-r}	1.14^{b-f}	32.62^{i-t}	4.19^{g-t}	6.65^{c-h}
Population – 3	92.90 ^{a}	94.30^{a-c}	2.09^{d-k}	5.12^{a-k}	3.96^{f-n}	1.12^{b-h}	34.13^{h-r}	4.66^{e-p}	6.09^{h-q}
Population – 4	90.00^{a-c}	94.80^{ab}	2.24^{a-I}	5.25^{a-I}	3.91^{h-o}	1.76 ^{a}	37.68^{f-o}	5.13^{d-m}	6.05^{h-r}
Population – 5	92.90 ^{ab}	95.70 ^{a}	2.15^{c-k}	5.02^{a-l}	4.19^{e-m}	1.14^{b-g}	38.61^{d-e}	4.88^{d-n}	5.95^{h-u}
Population – 6	86.70 $^{a-f}$	92.40^{a-e}	2.07^{d-l}	5.39^{a-g}	4.24^{e-l}	1.23^{b-d}	39.62^{d-l}	4.86^{e-o}	7.18^{a-d}
Population – 7	76.20^{d-n}	88.10^{a-I}	1.66^{k-u}	3.95^{a-t}	3.20^{k-u}	1.17^{b-e}	27.22^{k-v}	3.76^{l-v}	6.10^{h-p}
Population – 8	82.40^{a-I}	85.70^{a-l}	1.72^{k-t}	4.18^{a-r}	3.46^{j-t}	1.24 ^{b}	29.44^{j-u}	4.07^{h-u}	5.85^{h-v}
Population – 9	78.10^{c-k}	88.10^{a-j}	1.89^{g-p}	4.41^{a-q}	3.67^{j-s}	1.24^{bc}	34.68^{h-q}	4.41^{g-r}	6.23^{e-o}
Population – 10	84.80^{a-g}	88.60^{a-h}	1.99^{f-o}	4.55^{a-p}	3.54^{j-t}	1.35 ^{b}	33.80^{h-s}	0.64 ^{y}	6.40^{d-m}
Mean	86.10	91.3	2.02	4..85	3.77	1.25	34.65	4.2	6.26
Decrease % Wheat	24.48	19.21	30.97	37.84	36.85	32.63	35.95	39.73	19.34
Decrease % Populations	15.93	9.65	29.95	1.28	24.52	31.81	31.29	87.71	18.52
Decrease % Overall	32.29	24.87	39.19	43.53	46.39	63.63	53.44	51.36	23.02

Differences between the averages shown with same letters are insignificant at a level of $P<0.05$.

Concerning SL, the mean value was found to be 4.99 cm for bread wheat genotypes, ranging from 3.58 cm (Kıraç – 66) to 6.34 cm (Demir – 2000). In einkorn populations, the mean SL was 4.85 cm with the lowest 3.95 cm being obtained from Population- 7 and the highest from Population- 1 (5.46 cm). The longest SL was recorded in Demir - 200, Pehlivan, Kenanbey, Gerek - 79, İkizce - 96, Bayraktar - 2000, and Tosunbey as well as einkorn populations of 1, 2, and 5. Furthermore, according to the results, these genotypes did not statistically differ from each other (Table 3).

RL is an important trait affecting wheat's resistance to drought during the seedling and advanced stages (Mahmoodabad *et al.,* 2001). In this study, the mean RL was found to be 5.22 cm and 3.77 cm in bread wheat cultivars and einkorn populations respectively. This shows that drought stress had more effect on the RL of bread wheat cultivars than einkorn populations decreasing RL by 36.85% in the former and by 24.52% in the latter genotypes. Some researchers reported that after the drought application, the shortening of roots was only limited in drought-tolerant genotypes. (Miller *et al.,* 2006; Rauf *et al.,* 2007). In the present study, the longest RL was observed in Bayraktar - 2000, Gerek – 79, and Kenanbey bread wheat cultivars and einkorn Population-5 and 6 (Table 3). Most of these bread wheat cultivars have been released recently but Gerek – 79 is a very old bread wheat cultivar released in 1979 but it is still the most preferred and cultivated in the Central Anatolia of Turkey where precipitation is very low. Longer RL allows the plant to reach deeper into the ground and thus provides higher yields even under water-limited conditions (Miller *et al.,* 2006). Cultivars with a longer root structure formed deeper in the soil exhibit higher tolerance to drought during the seedling stage (Matsui *et al.,* 2002). Therefore, RL and SL are drought tolerance traits that can be used in the screening of wheat genotypes (Noorka and Khaliq, 2007).

Among einkorn genotypes, the highest SRLR was obtained from Population- 4 (1.76 mg) followed by Population- 10 (1.35 mg) and Population-8 (1.24 mg). Demir - 2000 and Gün – 91 were bread wheat genotypes presenting with the highest SRLR (1.04 mg and 0.95 mg, respectively). For SRLR, the einkorn populations performed much better than the bread wheat cultivars with the mean value being 1.25 mg for the former and 0.78 mg for the latter. Furthermore, the decrease in SRLR due to drought stress was recorded as 32.63% for bread wheat genotypes and 31.81% for einkorn populations (Table 3).

Among the bread wheat cultivars, the highest RFW value (Table 3) was observed in Kenanbey (58.46 mg), followed by Bayraktar - 2000 (55.87 mg), Momtchil (55.02 mg), and Gün - 91 (51.55 mg). The RFW performance of einkorn populations was lower than that of bread wheat cultivars with a mean value of 34.65 mg and 48.9 mg, respectively. However, the decrease in RFW following drought stress was lower for einkorn populations (31.29%) than in bread wheat cultivars (35.95%). These results show that bread wheat genotypes were more affected by drought despite their higher productive capacity. This is consistent with the results reported by Karakaş (2016), who investigated the effect of salt and drought on germination traits of bread wheat and einkorn genotypes under in vitro conditions. In the current study, similar results were obtained for RDW with the highest value being observed in Kenanbey (7.73 mg), followed by Bayraktar - 2000 (7.60 mg), İkizce - 96 (6.99 mg) and Gün - 91 (6.61 mg) bread wheat cultivars. The mean RDW was 6.24 mg in bread wheat genotypes and 4.2 mg in einkorn populations. This indicated that bread wheat had a better RDW performance compared to einkorn populations.

Concerning the mean RFDWR following PEG-6000-induced drought, all the genotypes had reduced values compared to the baseline. The decrease in RFDWR was 19.24 % and 18.52 % in bread wheat and einkorn genotypes, respectively. In addition, the mean RFDWR was 6.83 mg in the former and 6.26 mg in the latter. The highest values were found in Momtchil (7.60 mg), followed by Tosunbey (7.52 mg), Gerek - 79 (7.41 mg), Population 9 (7.18 mg), and Gün - 91 (7.02 mg).

Evaluation of the Results Using Genotype, Traits and GGE Biplot Analysis under Drought: The GGE biplot method is commonly used by plant breeders to visualize and practically present the relationships between a genotype and its certain traits as well as the relationship between the traits (Adjabi *et al.,* 2014). In the current study, a GGE biplot analysis was performed to present a visual demonstration of the results obtained. These results indicated that the total variation between the genotypes and the investigated traits was 75.97 %, of which 51.51 % was represented by PC1 and 24.47 % by PC2 (Figures 5 and 6). Figure 5 shows that the bread wheat cultivars are located on the right and einkorn populations are located on the left of the central line. This indicates that these two different groups of genotypes have different behaviors for the traits investigated.

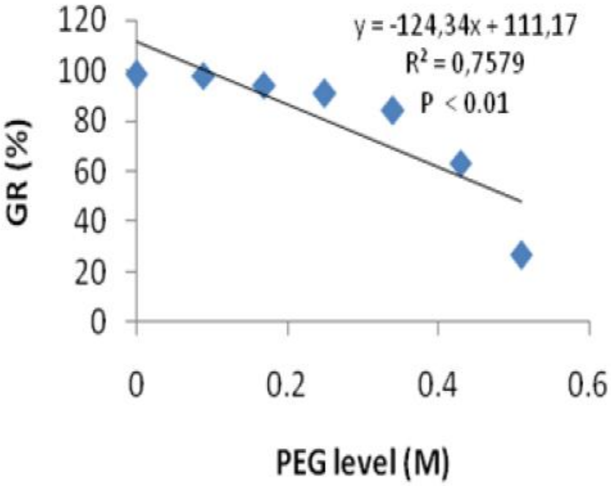

Figure 1. Regression graph showing relationship between PEG level and germination rate (GR).

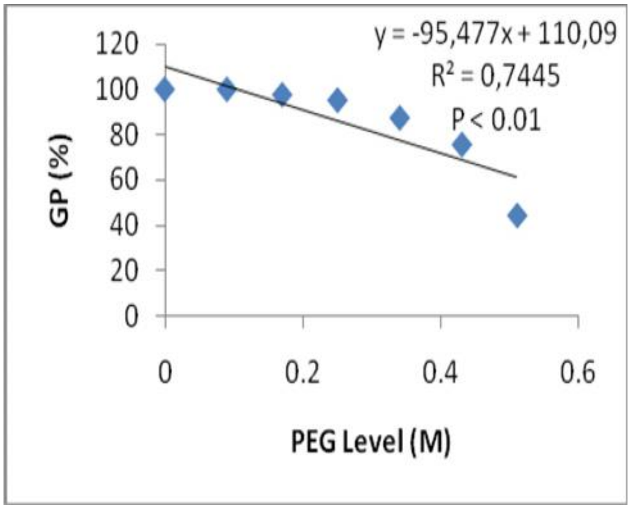

Figure2. Regression graph showing relationship between PEG level and germination power (GP)

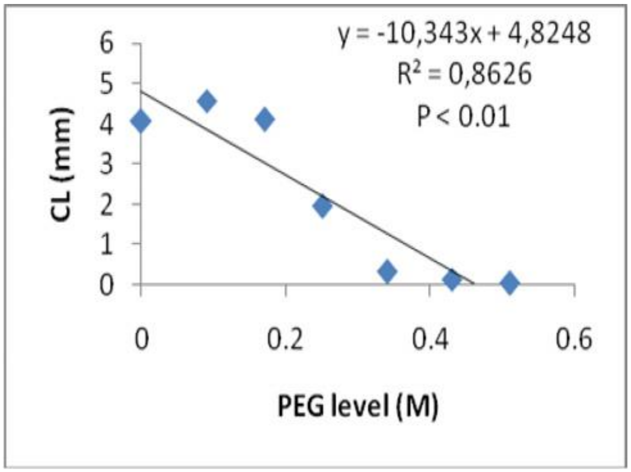

Figure3. Regression graph showing relationship between PEG level and coleoptile length (CL)

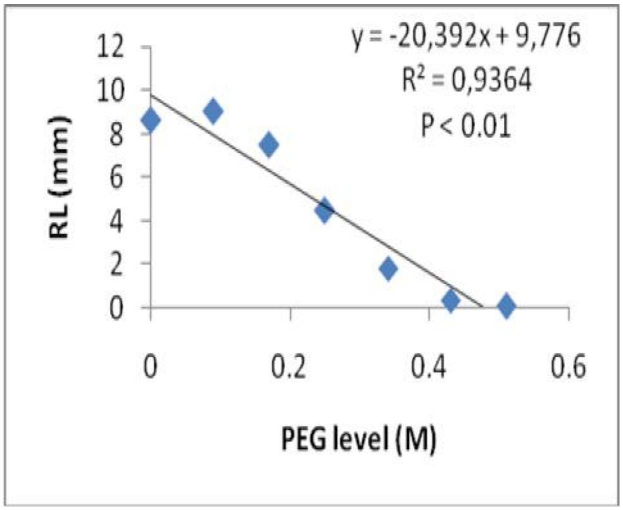

Figure4. Regression graph showing relationship between PEG level and root length (RL)

In a GGE biplot, genotypes located at the corners of the polygon in a sector of an investigated trait is considered to have the highest or lowest performance for that trait (Abate *et al.,* 2015). In this respect, a GGE biplot indicates “which is best for what”. In the current study, the polygon view of the GGE biplot (Figure 5) shows that Population- 4 (P4) and Population- 5 (P5) genotypes are located at the left corner of the polygon indicating that they had the highest performance for the GR, GP and SRLR traits. Similarly, Kenanbey (G4), Bayraktar – 2000 (G7), Gerek – 79 (G1), and Momtchill (G6) are seen in the sector of the SL, CL, RDW, RL, RFW, RDW, and RFDWR traits, which demonstrates their better performance for these traits. However, in Figure 5, Populations- 7 to 10 (P7 to P10) and G3 Kıraç – 66 (G3) and Tosunbey (G8) genotypes are located at the corners outside the two sectors further from the origin, indicating that they had weak or undesirable traits. Figure 6., presents the interrelationships between the examined traits. The angle between the vectors of the traits represents the correlation between them (Kendal and Sayar, 2016). Angles in a GGE biplot are used to determine the level of relationships between the traits under investigation. According to GGE biplot methodology, if the angle between the vectors representing two traits is 90^0 or lower, there is a strong relationship or correlation between these traits (Yan and Kang, 2003). In this study (Figure 6), this angle was lower than 90^0 between SL, CL, RDW, RFW, RL, and RFDWR for most bread wheat cultivars, indicating a strong relationship between these traits. In addition, a strong relationship was observed between GR, GP, and SRLR that were better represented by einkorn populations. Having a higher tolerance to drought stress at early developmental stages including germination is important for healthy germination and vigorous wheat production particularly under rainfall conditions. Therefore, determination of wheat genotypes, landrace, and wild relatives with a high GR and GP under drought conditions is vital for successful outcomes in breeding programs. Sayar *et al.* (2008) and Alian *et al.* (2000) reported similar results following their in vitro evaluation of wheat and tomato genotypes against drought and salinity. Sayar and Han (2015) reported that the GGE biplot was useful to visualize interaction between traits and genotypes, and provided clustering genotypes or traits based on the mean values. The different clusters visualized in GGE biplots provide an understanding of the relation or correlation between genotypes or traits, also genotype by traits (Yan, 2001). Maqbool *et al.* (2015) reported that the GGE biplot offered useful information for the selection of superior chickpea genotypes under variable water conditions and Basha *et* *al.* (2015) reported similar results to our study demonstrating a positive correlation between the RL, SL and CL at different PEG levels during the seedling stage of tomato. Dörffling *et al.* (1997) reported that wild and primitive wheat genotypes under in vitro conditions had increased frost tolerance and higher proline levels. Similarly, a higher variation was determined between modern and wild species of potato in terms of their seedling traits under in vitro conditions (Arvin and Donnely, 2008).

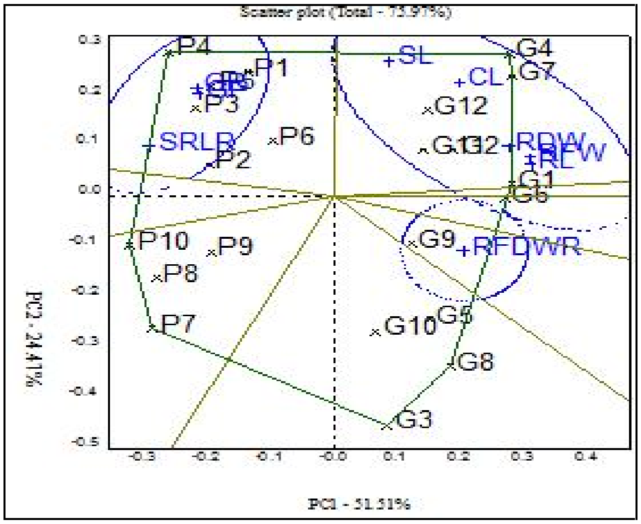

Figure 5. GGE biplot of the relationships between genotype and traits under drought stress

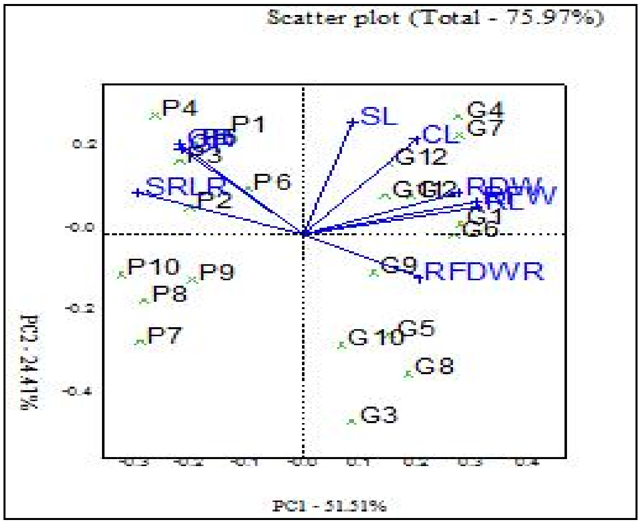

Figure 6. GGE biplot of the relationships between traits under drought stress

+ : Examined traits, x: Genotypes (1 - Gerek-79; 2 - İkizce-96; 3 - Kıraç-66; 4 - Kenanbey; 5 – Flamura - 85; 6 - Momtchill; 7 – Bayraktar - 2000; 8 - Tosunbey; 9 – Pandas; 10 - Pehlivan; 11 – Demir – 2000; 12 – Gün - 91; P1 – Population - 1; P2 - Population - 2; P3 - Population - 3; P4 -: Population - 4; P5 - Population - 5; P6 - Population - 6; P7 - Population - 7; P8 - Population 8; P9 - Population - 9; P10 - Population-10

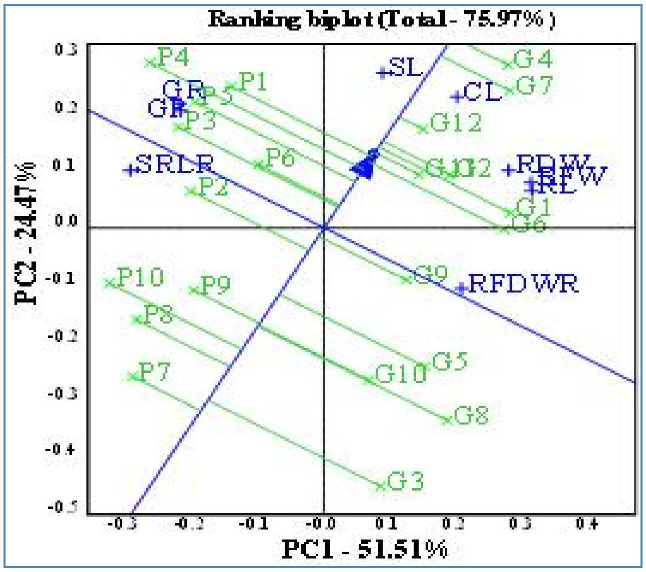

Figure 7. Ranking of genotypes on means of examined traits.

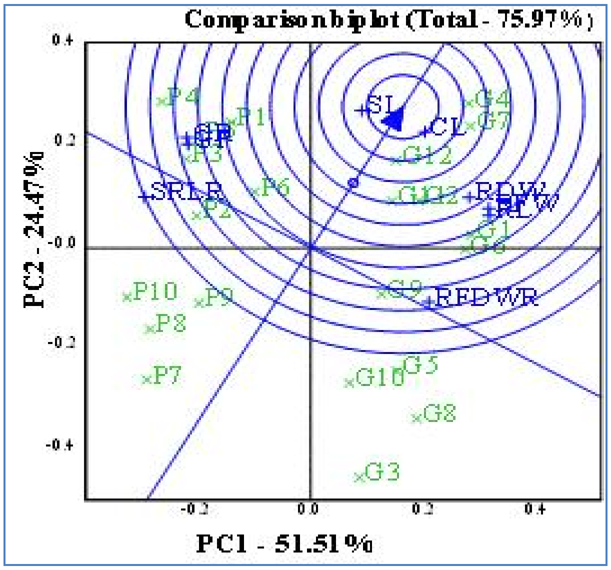

Figure 8. Comparison of genotypes on means of examined traits

The mean examined traits of genotypes were evaluated using average environment axes (AEA) as shown in Figures 7 and 8. The genotypes with both high mean and stability regarding all traits is considered as an ideal genotype. A line drawn through the biplot origin is called the average environment axis and serves as absisca of AEA. Genotypes are separated by the AEA ordinate (axis) and genotypes having a shorter absolute length of projection in either direction of the AEA ordinate (genotypes located closer to AEA abscissa) indicate that these genotypes have a higher mean and are stable for the examined traits (Yan and Kang, 2003). According to the ranking and comparison of genotypes based on their traits (Figures 7 and 8), Gün-91 (G12) was an ideal genotype. Bread wheat genotypes, Kenanbey (G4), Bayraktar-2000 (G7), Demir-2000 (G11) and İkizce-96 (G2), and einkorn Populations 1, 3, 5 and 6, had a similar performance with Gün-91. Furthermore, these genotypes can also be considered ideal since their values for all the examined traits were above the mean values. Other researchers reported similar results for wheat, triticale, and potato (Aktaş, 2016; Lule *et al.,* 2014; Hassanpanah, 2011).

According to the results of the cluster analysis, both populations were distributed into two groups (Figure 9). The bread wheat cultivars were clustered under one group (Group 1) and einkorn populations under another group (Group 2). Group 1 was further divided into four sub-groups as follows: Gerek - 79 and Momtchil cultivars in the first sub-group; Kenanbey, Bayraktar – 2000, and Gün - 91 in the second sub-group; İkizce - 96, Pandas, and Demir - 2000 in the third sub–group, and Pehlivan, Flamura – 85, and Tosunbey in the last sub-group. Each sub-group had a similar performance or behavior for the investigated traits. Group 2 was divided into two sub-groups; the first containing Populations 1 to 6 and the second consisting of Populations 7 to 10.

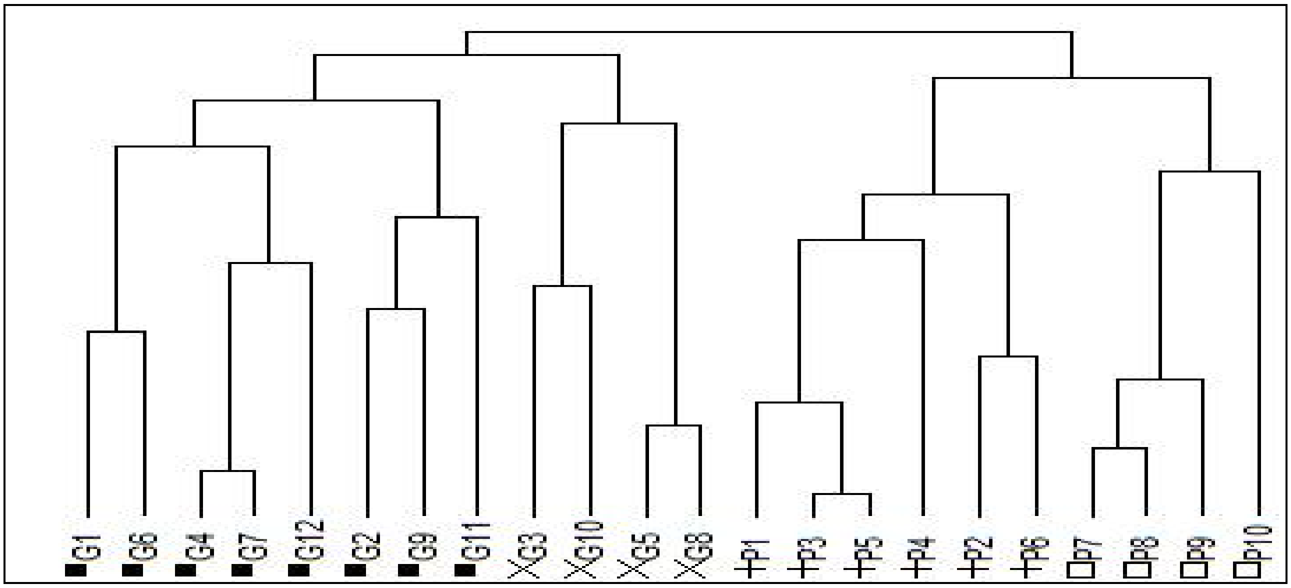

Figure 9. Results of the cluster analysis examined traits based on drought stress

Conclusion: This study showed that significant differences were present among the genotypes for the traits under investigation. However, the results of this study clearly show that the values of all traits in both bread wheat and einkorn genotypes decreased following PEG - induced drought compared to the baseline. The einkorn populations performed very well under stress conditions and had better GR and GP; therefore, we recommend that these genotypes be used as genitors for the development of genotypes with better GR and GP under drought stress conditions for healthy germination and strong vigorous growth. The bread wheat cultivars, particularly Demir – 2000, Gün - 91, Gerek – 79, and Kenanbey, produced better results for CL, RL, RFW, and RDW; thus, they are considered to be good candidates for drought resistance studies conducted under field or in vivo conditions. Although these bread wheat genotypes produced higher bio-materials for some of the traits at all PEG levels, the proportion of decrease among the einkorn wheat populations due to PEG was lower for almost all the examined traits compared to bread wheat genotypes. These results indicate that einkorn wheat has better drought tolerance traits at the seedling stage. We believe that further combined field and in vivo experiments based on the results of this study will greatly contribute to the literature.

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