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Evaluation of bread wheat genotypes for early drought resistance via germination under osmotic stress, cell membrane damage, and paraquat tolerance

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Abstract: In order to develop genotypes with stable, higher yields in dry farming conditions, it is necessary to characterize genetic resources based on drought adaptation, determine suitable genotypes, and then use them in breeding programs. This study was carried out at the laboratories of the Field Crops Department of Atatürk University Agricultural Faculty. A total of 64 certified and local bread wheat genotypes were used to test germination characters under osmotic stress, cell membrane damage, and paraquat tolerance. There were significant differences among genotypes with respect to the selection parameters in this study. Average germination percentages in osmotic environment treatments ranged from 63.3% to 94.7%, total root lengths were 10.54–23.12 cm, and shoot lengths were 4.73–10.56 cm. Seed vigor indexes ranged from 1392.4 to 3048.6, cell membrane damage ranged from 0.16% to 47.26%, and chlorophyll content varied between 0.005 and 0.101 mg mL^{-1} g FW^{-1}. Kırmızı Yerli, Conkesme, and Türkmen were considered drought-resistant based on two out of the three parameters tested. In addition, Yakar 99, Pehlivan, İzgi 2001, İkizce 96, Mızrak, and Gerek 79 were considered drought-susceptible based on two out of the three parameters tested. Kırmızı Yerli, Conkesme, and Turkmen, which were notable in terms of both parameters, could be used as parents in breeding programs related to drought resistance.

Key words: Seed vigor index, early drought, chlorophyll, membrane stability, screening

1. Introduction

Drought is the most significant environmental stress in agriculture worldwide; thus, improved yields under water limitation are increasingly targeted in plant breeding studies (Cattivelli et al., 2008). Precipitation is insufficient and unevenly distributed over the wheat-cultivated lands of Turkey. Therefore, drought is experienced most of the time during different growth periods of wheat. Because of such drought, the differences among genotypes with regard to their drought resistance at different growth periods should be known (Lafond and Baker, 1986a). Drought resistance studies mostly focus on the high-yield potential of genotypes under dry conditions and the selection of genotypes with regard to morphological and physiological characteristics providing drought resistance (Dhanda et al., 2004). Development of drought-resistant genotypes requires designing breeding programs according to growth periods in which drought is observed and the combination of secondary plant characteristics with high-yield capacities that can serve as a buffer against yield losses under stress conditions (Ludlow and Muchow, 1990; Cooper et al., 2006). It was indicated in previous studies that drought-resistant wheat genotypes might be identified through taking secondary plant characteristics with high degrees of heredity and genetic relation to grain yield under dry conditions as the selection criteria (Blum, 1989; Lafitte et al., 2003).

Drought-resistant genotypes are able to maintain metabolic activities in their tissues with low water potential (Sairam et al., 1990). Drought resistance in genotypes recently developed through breeding programs is mostly related to the plant's ability to protect itself from water loss under dry conditions, rather than plant tolerance against water loss. Protection from water loss is a result from different structural characteristics (root length, seedling power, plant height, leaf area, flowering duration, etc.) related to plant development phenology and physiology (Blum, 2006). In environments where drought is experienced during the early growth periods, plant characteristics able to ensure germination–emergence and survival of seedlings should be taken into consideration (Monneveux and Ribaut, 2006). Singh et al. (1992) and Dhanda et al. (2004) evaluated wheat genotypes with regard to their drought resistance during early growth periods and reported significant differences in membrane damage of wheat genotypes and defined low membrane damage

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(membrane stability) as an effective selection criterion with high heredity for identifying drought tolerance. Drought stress reduces protein synthesis, slows down cell division, and ultimately decreases the germination power of seeds (Bray, 1997). Polyethylene glycol, able to form low water potential in testing environments, is commonly used in identifying drought resistance during germination and early seedling periods (Winter et al., 1988; Premchandra et al., 1990). Germination parameters obtained in a low water potential environment are regarded as an effective method for determining drought-resistant genotypes (Liley and Ludlow, 1996; Kumar and Singh, 1998). Dhanda et al. (2004) defined wheat genotypes with high seed vigor indexes and root lengths and the ability to germinate and form seedlings within –10 bar PEG 6000 solution as drought-tolerant genotypes. Drought stress also results in oxidative stress in plants (Foyer et al., 1994; Moran et al., 1994). Active oxygen ratios in chloroplasts may increase or antioxidant defense activity may be inhibited during the stress periods (Smirnoff and Colombe, 1988). Since such impacts of drought stress resemble the stress exerted on plants by the herbicide paraquat (Dodge, 1971), there is a close relationship between plant drought tolerance and paraquat tolerance. Altinkut et al. (2001) and Ekmekçi and Terzioğlu (2005) successfully employed paraquat tolerance to determine drought-resistant wheat and barley genotypes. Altinkut et al. (2003) reported higher leaf chlorophyll content in drought-resistant barley genotypes after paraquat treatment.

In breeding programs for drought resistance during the early growth stages, germination characteristics under low water potentials, cell membrane damage ratios, and paraquat tolerance selection criteria have been successfully employed to present the differences among genotypes and to find proper parents. It is necessary to define the gene sources with regard to their characteristics related to drought resistance and to determine the available parents to be used in breeding programs. In the present study, 64 registered and local bread wheat genotypes were assessed for their resistance to drought during germination and early seedling growth stages by using germination in low water potential, cell membrane damage ratio, and paraquat tolerance as the selection criteria. The primary objective was to determine the available genotypes to be used as parents in relevant breeding programs and to recommend genotypes for environments where drought is experienced during the early growth stages of wheat.

2. Materials and methods

2.1. Materials

The present research was conducted at the laboratories of the Field Crops Department of Atatürk University Agricultural Faculty between 1 January 2010 and 1 January 2011. A total of 64 bread wheat genotypes were used as the plant material. Genotype characteristics are briefly provided in Table 1. Of these genotypes, 44 were selected from a national cultivar list of nationally recommended genotypes for dry farming lands from 2007, while the remaining 20 were selected from previously and currently grown registered and local cultivars. For control cultivars, Bezostaja 1 and Karasu 90 (recommended for irrigated farming lands) were used. In paraquat tolerance experiments, T.T. Makro, Turf-Seedling Growth Soil with 0.98% N, 0.02% P, 0.09% K, 0.84% Ca, 0.28% Mg, 2820 ppm Fe, 41 ppm Mn, 9 ppm Zn, 36.6% organic matter, 49% moisture content, and a pH of 6.7 was used.

2.2. Methods

2.2.1. Procurement of seed source

Seed size and age significantly alter water absorption ratio and amount; duration of germination and emergence; leaf area, length, and width; leaf and seedling dry weight; and the number of leaves and tiller per plant. Thus, size and age significantly affect relevant research outcomes (Lafond and Baker, 1986b; Naylor et al., 1990; Richards and Lukacs, 2002). Seeds of equal age and relatively equal size were used to minimize variations due to these factors. Therefore, entire genotypes of the research were grown in the number 4 experimental field of Agricultural Research and Extension Center of Atatürk University Agricultural Faculty during the cropping year of 2008–2009. Standard growing techniques under rainfed conditions were applied. Resultant kernels were cleaned and sieved. The ones that passed through a 3.6 mm sieve but remained over a 3.2 mm sieve were separated from the others (Lafond and Fowler, 1989). Then the seeds were visually inspected to further separate the damaged and unhealthy ones. The resultant selected seeds were used in all of the following tests.

2.2.2. Germination in low water potential

Experiments were conducted using a completely randomized factorial design (4 osmotic environments × 64 genotypes) with 3 replications. Genotype seeds were washed in tap water, stirred with 70% ethyl alcohol for 5 min, washed 3 times with distilled water in a sterile cabin, stirred with 1% sodium hypochlorite including a couple drops of Tween 20 (Sigma-Aldrich Co., USA) for 10 min, and then rewashed 3 times with sterile distilled water (Dhanda et al., 2004). The PEG 6000 solutions prepared for –5, –10, and –15 bar osmotic environments were calculated in accordance with Michel and Kaufmann (1973). A total of 50 seeds were placed over two layers of Whatman (#2) filter papers in the petri dishes (9 cm diameter) with 0 (control), –5, –10, and –15 bar osmotic environments prepared by using PEG 6000 solution. For the control treatment, 5 mL of distilled water was added to each petri dish; for osmotic environment treatments, 5 mL of relevant PEG 6000 solution was added to each petri dish.

Table 1. Bread wheat genotypes used in the study.

No.	Genotypes	Origin/Institute	Growth habit
Listed in the 2007 national cultivar list			
1	Aksel 2000	Central Research Institute of Field Crops, Ankara	Facultative
2	Alparslan	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
3	Altay 2000	Anatolia Agricultural Research Institute, Eskişehir	Winter
4	Atlı 2002	Central Research Institute of Field Crops, Ankara	Facultative
5	Aytın 98	Anatolia Agricultural Research Institute, Eskişehir	Winter
6	Bağcı 2002	Bahri Dağdaş International Agricultural Research Institute, Konya	Facultative
7	Bayraktar 2000	Central Research Institute of Field Crops, Ankara	Facultative
8	Bolal 2973	Anatolia Agricultural Research Institute, Eskişehir	Facultative
9	Çetinel 2000	Anatolia Agricultural Research Institute, Eskişehir	Winter
10	Dağdaş 94	Bahri Dağdaş International Agricultural Research Institute, Konya	Facultative
11	Demir 2000	Central Research Institute of Field Crops, Ankara	Facultative
12	Doğankent 1	Çukurova Agricultural Research Institute, Adana	Spring
13	Doğu 88	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
14	Gerek 79	Anatolia Agricultural Research Institute, Eskişehir	Winter
15	Gün 91	Central Research Institute of Field Crops, Ankara	Winter
16	Harmankaya 99	Anatolian Agricultural Research Institute, Eskişehir	Winter
17	İkizce 96	Central Research Institute of Field Crops, Ankara	Facultative
18	İzgi 2001	Anatolia Agricultural Research Institute, Eskişehir	Winter
19	Karahan 99	Bahri Dağdaş International Agricultural Research Institute, Konya	Winter
20	Kate A-1	Trakya Agricultural Research Institute, Edirne	Winter
21	Kıraç 66	Anatolia Agricultural Research Institute, Eskişehir	Winter
22	Kırgız 95	Anatolia Agricultural Research Institute, Eskişehir	Winter
23	Kırkpınar 79	Trakya Agricultural Research Institute, Edirne	Facultative
24	Kutluk 94	Anatolia Agricultural Research Institute, Eskişehir	Winter
25	Lancer	Eastern Anatolia Agricultural Research Institute, Erzurum (Introduction cultivar, A.B.D.)	Winter
26	Mızrak	Central Research Institute of Field Crops, Ankara	Facultative
27	Müfitbey	Anatolia Agricultural Research Institute, Eskişehir	Winter
28	Nenehatun	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
29	Palandöken 97	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter
30	Pamukova 97	Sakarya Agricultural Research Institute, Sakarya	Spring
31	Pehlivan	Trakya Agricultural Research Institute, Edirne	Winter
32	Prostor	Trakya Agricultural Research Institute, Edirne	Winter
33	Seri 82	Çukurova Agricultural Research Institute, Adana	Winter
34	Soyer02	Anatolia Agricultural Research Institute, Eskişehir	Winter
35	Sönmez 2001	Anatolia Agricultural Research Institute, Eskişehir	Winter
36	Sultan 95	Anatolia Agricultural Research Institute, Eskişehir	Winter
37	Süzen 97	Anatolia Agricultural Research Institute, Eskişehir	Winter
38	Tosunbey	Central Research Institute of Field Crops, Ankara	Winter
39	Türkmen	Central Research Institute of Field Crops, Ankara	Facultative
40	Uzunyayla	Central Research Institute of Field Crops, Ankara	Facultative
41	Yakar 99	Central Research Institute of Field Crops, Ankara	Facultative
42	Zencirci 2002	Central Research Institute of Field Crops, Ankara	Facultative
Local and old genotypes not listed in 2007 national cultivar list			
43	Ak-702	Anatolia Agricultural Research Institute, Eskişehir	Winter
44	Ak Buğday	Central Anatolia Region	Winter
45	Ankara 093/44	Central Research Institute of Field Crops, Ankara	Winter
46	Conkesme	Eastern Anatolia Region	Facultative
47	Haymana 79	Central Research Institute of Field Crops, Ankara	Winter
48	Hawk (Şahin)	Eastern Anatolia Agricultural Research Institute, Erzurum (Introduction cultivar, A.B.D.)	Winter
49	Kılçıksız Buğday	Central Anatolia Region	Winter
50	Kırik	Eastern Anatolia Region	Facultative
51	Kırmızı Kılçık	Eastern Anatolia Region	Facultative
52	Kırmızı Yerli	Eastern Anatolia Region	Facultative
53	Koca Buğday	Central Anatolia Region	Winter
54	Köse 220/39	Central Research Institute of Field Crops, Ankara	Facultative
55	Orso	Sakarya Agricultural Research Institute, Sakarya	Facultative
56	Özlü Buğday	Central Anatolia Region	Winter
57	Polatlı Kösesi	Central Anatolia Region	Facultative
58	Sert Buğday	Central Anatolia Region	Winter
59	Sürak 1593/51	Central Research Institute of Field Crops, Ankara	Winter
60	Tir	Eastern Anatolia Region	Winter
61	Yayla 305	Anatolia Agricultural Research Institute, Eskişehir	Winter
62	Zerin	Central Anatolia Region	Facultative
Control genotypes			
63	Bezostaja 1	Anatolia Agricultural Research Institute, Eskişehir (Introduction cultivar, Russia)	Winter
64	Karasu 90	Eastern Anatolia Agricultural Research Institute, Erzurum	Winter

This process was repeated in 2-day intervals to replace the evaporated water. Then all petri dishes were placed in a plant growth chamber with 22 °C constant temperatures and stayed in there for 10 days. At the end of this period, root and shoot lengths of 20 randomly selected seedlings of each genotype were precisely measured. Seeds with at least 2 mm radicle length were assumed to be germinated and % germination rates were then determined. Seed vigor index was calculated by using the following equation (Dhanda et al., 2004):

Seed vigor index = (total embryonic root length + shoot length) × % germination

None of the seeds germinated in the –10 bar and –15 bar osmotic environment treatments; hence these treatments were discarded from the experiment.

2.2.3. Cell membrane damage

Experiments were conducted in a completely randomized block design with 3 replications. Seeds were sterilized in 10% bleach for 10 min, washed 3 times with sterile distilled water, and 50 seeds of each genotype were placed in petri dishes. Seeded petri dishes were supplemented with 5 mL of distilled water and placed in a 22 °C growth chamber, where they were kept for 15 days. Watering was repeated in 2-day intervals to replace the evaporated water. At the end of this period, samples (2 cm in length) were taken from the central portions of the first leaves of 20 randomly selected seedlings and washed with distilled water. For drying treatments, leaf samples were placed into (T) test tubes including 30 mL of 30% PEG 6000 solution while control treatments (C) were placed into 30 mL of distilled water and kept at 10 °C for 24 h. At the end of the incubation period, both drying and control samples were washed with distilled water 3 times; then 30 mL of distilled water was added to each sample again. Samples were then placed into a 25 °C water bath for 1 h and stirred completely. Electrical conductivity of the solution was measured at 25 °C with an electrical conductivity meter. With these measurements, T_1 values were obtained for drying samples and C_1 values were obtained for control samples. Following the first measurement, to measure the total electrolyte concentration, all sample tubes were autoclaved at 121 °C under 1 kg/cm^2 pressure for 15 min. Then they were placed into a 25 °C water bath for 1 h and stirred completely. Electrical conductivity of the solution was again measured at 25 °C. Following these measurements after the autoclaving process, T_2 values were obtained for drying samples and C_2 values were obtained for control samples. Percent (%) membrane damage as an indicator of cell membrane permeability was then calculated by using the following equation (Premchandra et al., 1990):

$$\% \text{ damage} = \{1 - [(1 - T_1/T_2) / (1 - C_1/C_2)]\} \times 100$$

2.2.4. Paraquat tolerance

Experiments were conducted in a completely randomized block design with 3 replications. Wooden boxes (80 × 100 × 12 cm) were covered with drying papers and filled with the aforementioned soil. Then 50 seeds of each genotype were sown with 2-cm spacing over 2-cm-deep grooves and buried carefully. Row spacing was 5 cm. Sufficient water was supplied to each box after sowing and they were placed into a growth chamber with a 16/8 h light/dark photoperiod and a temperature of 23 °C. When the emerged plants had 5–6 leaves, the second leaf from the top of 10 randomly selected plants was cut and sampled. Their immediate fresh weights were determined with a sensitive scale. Leaf samples were then placed into petri dishes including 100 µM paraquat solution (Paraquat, M 2254) and stayed under 25 °C and 12,000 lux light for 24 h. Then the leaf samples were pulped in 15 mL of 80% acetone with a homogenizer and absorbance values were read at 652 nm wavelength. Total chlorophyll content of samples was calculated by using the following equation (Altinkut et al., 2001):

Amount of chlorophyll (mg mL^{-1} g FW^{-1}) = [27.8 × (A_{652})] × (V/1000 FW)

A: Absorbance value at specified wavelength

V: Volume of 80% acetone (mL)

FW: Fresh weight of sampled tissue (g)

2.2.5. Statistical data analyses

Resultant data were subjected to variance analysis according to experimental designs with SAS GLM (SAS Inst., USA) software. Duncan's multiple range test was used to compare genotype averages. Treatments were evaluated separately when the genotype × treatment interactions were significant.

3. Results and discussion

3.1. Germination characters in osmotic ambient conditions

3.1.1. Germination percentage

The changes in germination percentages with drought stress are regarded as an indicator of drought resistance for wheat genotypes. With regard to germination percentages, the differences between genotypes and between osmotic potentials were found to be significant; genotype × treatment interaction was also found to be significant (Table 2). In control treatments, germination percentages of genotypes varied between 85.3% and 99.3%. The highest germination percentages were observed in Orso, Karasu 90, and Bezostaja 1, while the lowest germination percentages were observed in Karahan 99, İzgi 2001, and Kate A-1. Germination percentage of genotypes under –5 bar osmotic potential varied between 38.7% and 90.7%, with the highest values in Kılçıksız Buğday, Kırmızı Kılçık,

Table 2. The effect of osmotic stress on germination percentage and root length of wheat genotypes[1].

		Germination percentage (%)			Total root length (cm)		
No.	Genotypes	Control	–5 bar	Mean	Control	–5 bar	Mean
1	Aksel 2000	92.0 f–i	65.3 p–t	78.7 p–u	27.41 f–i	4.20 z	15.81 p–v
2	Alparslan	92.7 d–h	66.0 o–s	79.3 o–s	18.93 yz	5.91 w	12.42 xy
3	Altay 2000	93.3 c–g	68.0 m–s	80.7 m–q	27.43 f–i	6.48 u–z	16.95 i–o
4	Atlı 2002	94.7 b–f	63.3 r–u	79.0 q–t	20.03 yz	5.88 w	12.96 xy
5	Aytın 98	92.7 d–h	70.0 k–q	81.3 l–q	24.79 m–p	10.67 efg	17.73 g–j
6	Bağcı 2002	91.3 f–i	64.0 r–t	77.7 q–v	25.05 k–p	5.40 z	15.23 t–w
7	Bayraktar 2000	97.3 a–d	68.7 m–s	83.0 j–o	31.85 d	6.76 s–y	19.30 de
8	Bolal 2973	94.7 b–f	80.0 d–g	87.3 e–ı	20.38 yz	7.69 n–t	14.04 wx
9	Çetinel 2000	94.0 b–g	58.0 uvw	76.0 s–w	23.31 r–v	6.91 r–x	15.11 vw
10	Dağdaş 94	92.0 f–i	44.0 z	68.0 xyz	31.55 d	8.48 j–q	20.02 cd
11	Demir 2000	96.0 a–e	64.0 r–t	80.0 n–r	22.40 v–x	10.04 ghi	16.22 n–s
12	Doğankent 1	93.3 c–g	55.3 vwx	74.3 v–y	25.66 j–o	7.07 r–v	16.37 m–s
13	Doğu 88	95.3 a–f	48.7 yz	72.0 wxy	20.91 yz	7.03 r–w	13.97 x
14	Gerek 79	90.0 g–i	52.7 wxy	71.3 wxy	27.90 fgh	8.44 j–q	18.17 fg
15	Gün 91	88.7 hij	53.3 wxy	71.0 xy	23.91 p–u	7.37 r–v	15.64 r–w
16	Harmankaya 99	91.3 f–i	50.0 xy	70.7 xy	17.53 z	7.60 p–u	12.57 xy
17	İkizce 96	94.0 b–g	42.7 z	68.3 xy	20.87 yz	7.40 r–v	14.14 wx
18	İzgi 2001	88.0 ij	38.7 z	63.3 z	25.18 k–p	8.71 j–p	16.94 i–o
19	Karahan 99	85.3 j	42.0 z	63.7 z	24.46 o–s	7.07 r–v	15.76 p–w
20	Kate A-1	88.0 ij	44.0 z	66.0 yz	25.97 j–n	9.13 ijk	17.55 g–l
21	Kıraç 66	91.3 f–i	42.7 z	67.0 xyz	23.37 q–v	8.71 j–p	16.04 o–u
22	Kırgız 95	92.7 d–h	68.0 m–s	80.3 m–r	20.65 yz	10.79 d–g	15.72 q–w
23	Kırkpınar 79	97.3 a–d	60.0 tuv	78.7p–u	26.40 ijk	6.68 t–y	16.54 m–r
24	Kutluk 94	95.3 a–f	79.3 d–h	87.3 e–i	24.28 o–t	6.67 t–y	15.47 s–w
25	Lancer	95.3 a–f	72.7 i–n	84.0 i–m	21.19 x–z	5.83 x	13.51 x
26	Mızrak	93.3 c–g	79.3 d–h	86.3 g–j	27.54 f–i	10.08 ghi	18.81 ef
27	Müfitbey	96.7 a–d	54.0 wxy	75.3 u–x	24.66 n–r	5.11 z	14.89 wx
28	Nenehatun	96.7 a–d	69.3 l–r	83.0 j–o	24.81 m–p	7.92 l–s	16.37 m–s
29	Palandöken 97	95.3 a–f	71.3 j–p	83.3 j–n	25.34 j–p	7.34 r–v	16.34 m–s
30	Pamukova 97	88.7 h–j	62.7 s–u	75.7 t–w	22.35 v–x	9.20 ijk	15.78 p–w
31	Pehlivan	94.7 b–f	54.0 wxy	74.3 v–y	23.15 s–w	4.19 z	13.67 x
32	Prostor	95.3 a–f	63.3 r–u	79.3 o–s	26.19 i–m	8.76 j–p	17.48 g–l
33	Seri 82	94.0 b–g	74.0 g–m	84.0 i–m	20.28 yz	6.76 s–y	13.52 x
34	Soyer02	98.7 ab	86.0 abc	92.3 ab	29.58 e	8.26 k–q	18.92 ef
35	Sönmez 2001	94.7 b–f	80.0 d–g	87.3 e–i	14.84 z	7.87 m–s	11.35 yz
36	Sultan 95	97.3 a–d	66.7 n–s	82.0 k–p	22.61 u–w	8.87 j–m	15.74 q–w
37	Süzen 97	96.0 a–e	88.0 ab	92.0 abc	34.91 b	11.34 c–f	23.12 a
38	Tosunbey	94.0 b–g	68.7 m–s	81.3 l–q	25.53 j–o	7.61 o–u	16.57 m–q
39	Türkmen	98.0 abc	68.0 m–s	83.0 j–o	28.12 fg	12.69 b	20.40 c
40	Uzunyayla	95.3 a–f	58.0 uvw	76.7 r–w	29.66 e	5.88 w	17.77 ghi
41	Yakar 99	94.7 b–f	65.3 p–t	80.0 n–r	20.66 yz	2.91 z	11.79 yz
42	Zencirci 2002	94.0 b–g	66.0 o–s	80.0 n–r	38.13 a	5.71 yz	21.92 b
43	Ak-702	96.7 a–d	50.7 xy	73.7 wxy	28.34 f	10.44 fgh	19.39 de
44	Ak Buğday	96.7 a–d	74.0 g–m	85.3 g–k	18.24 z	5.90 w	12.07 y
45	Ankara 093/44	97.3 a–d	79.3 d–h	88.3 d–h	26.28 i–l	6.26 v–z	16.27 m–s
46	Conkesme	96.7 a–d	80.0 d–g	88.3 d–h	24.75 m–p	10.45 fgh	17.60 g–k
47	Haymana 79	96.0 a–e	80.7 c–f	88.3 d–h	23.05 t–w	9.09 i–l	16.07 o–t
48	Hawk (Şahin)	97.3 a–d	83.3 bcd	90.3 b–f	25.94 j–n	11.92 bc	18.93 ef
49	Kılçıksız Buğday	98.7 ab	90.7 a	94.7 a	33.60 c	10.93 c–g	22.27 b
50	Kırik	98.0 abc	68.0 m–s	83.0 j–o	24.87 l–p	8.73 j–p	16.80 k–o
51	Kırmızı Kılçık	97.3 a–d	89.3 a	93.3 ab	21.88 w–z	13.92 a	17.90 gh
52	Kırmızı Yerli	92.7 d–h	79.3 d–h	86.0 g–j	20.82 yz	11.84 bcd	16.33 m–s
53	Koca Buğday	95.3 a–f	72.0 j–o	83.7 i–n	26.20 i–m	11.75 b–e	18.97 ef
54	Köse 220/39	96.7 a–d	76.7 e–j	86.7 f–j	25.71 j–o	7.96 l–r	16.83 j–o
55	Orso	99.3 a	82.7 b–e	91.0 bcd	31.06 d	7.01 r–w	19.04 ef
56	Özlü Buğday	97.3 a–d	73.3 h–m	85.3 g–k	24.70 n–q	8.78 j–o	16.74 k–o
57	Polatlı Kösesi	95.3 a–f	80.7 c–f	88.0 d–h	26.71 hij	8.46 j–q	17.59 g–l
58	Sert Buğday	98.7 ab	78.7 d–h	88.7 c–g	16.96 z	4.12 z	10.54 z
59	Sürak 1593/51	97.3 a–d	75.3 f–l	86.3 g–j	23.11 s–w	9.48 hij	16.29 m–s
60	Tir	98.0 abc	83.3 bcd	90.7 b–e	26.79 ghi	10.75 d–g	18.77 ef
61	Yayla 305	97.3 a–d	76.0 f–k	86.7 f–j	25.45 j–o	8.58 j–p	17.01 h–n
62	Zerin	98.0 abc	71.3 j–p	84.7 h–l	22.09 v–y	8.23 k–q	15.16 uvw
63	Bezostaja 1	98.7 ab	78.0 d–i	88.3 d–h	26.34 ijk	7.02 r–w	16.68 l–p
64	Karasu 90	98.7 ab	74.0 g–m	86.3 g–j	25.55 j–o	8.85 j–n	17.20 h–m
Mean		94.9 A	67.7 B	81.3	24.82 A	8.09 B	16.45
F value (Genotype, G)		9.10**	85.43**	76.68**	160.82**	68.95**	142.31**
F value (Treatment, T)		-	-	15817.80**	-	-	99253.30**
F value (G × T)		-	-	42.34**	-	-	107.36**
$LSD_{(0.01)}$ (G)		3.7	5.2	3.2	1.20	0.98	0.78
$LSD_{(0.01)}$ (T)		-	-	0.6	-	-	0.13
$LSD_{(0.01)}$ (G × T)		-	-	4.5	-	-	1.10
CV (%)		1.8	3.6	2.6	2.3	5.7	3.2
		0.24	0.94	0.85	0.30	0.16	0.46

[1] Means in a column not sharing a common letter are significantly different. ** Significant at $P < 0.01$.

Süzen 97, Soyer 02, Tir, and Hawk and the lowest values in İzgi 2001, Karahan 99, İkizce 96, Kıraç 66, Dağdaş 94, and Kate A-1. Average germination percentages of genotypes in the osmotic treatments varied between 63.3% and 94.7%, with the highest values in Kılçıksız Buğday, Kırmızı Kılçık, Soyer 02, and Süzen 97 and the lowest values in İzgi 2001, Karahan 99, and Kate A-1. Sapra et al. (1991), Kumar and Singh (1998), and Dhanda et al. (2004) also observed significant differences in the germination percentages of wheat genotypes under low water potential conditions. While the average germination percentage was 94.9% in the control treatment, the value significantly decreased under –5 bar osmotic potential and the value was as low as 67.7% (Table 2). Lafond and Fowler (1989) indicated retarded germination and decreased germination percentage under low water potential and reported that germination percentage of above 80% under low stress levels decreased to 56% under –1.5 MPa treatment. Almansouri et al. (2001) reported significant decreases in germination percentages of durum wheat genotypes with increasing osmotic stress levels and also indicated that the negative impacts of PEG treatment on germination resulted from the inhibition of seed water uptake instead of inhibition's impact on reserve transport. Dhanda et al. (2004) reported that germination rates of 30 wheat genotypes under –10 bar osmotic stress treatments varied between 14.3% and 64.6%, representing a 63.3% decrease from the control treatment. Razzaq et al. (2013) reported the average germination rates of 9 bread wheat genotypes under 0, –2, –4, and –8 bar osmotic stress levels as 89.7%, 55.6%, 41.7%, and 24.1%, respectively. Germination was not observed in osmotic treatments under –10 and –15 bar; the seeds were hard and they did not absorb water at the end of the study. Considering the other outcomes of the present study, it can be stated that genetic source of bread wheat genotypes of Turkey is relatively limited with regard to germination under low water potential.

3.1.2. Total root length

Total root lengths reveal significant information about drought resistances of wheat genotypes under osmotic stress conditions. The differences between root lengths of the genotypes, effects of osmotic stress treatments on root lengths, and genotype × treatment interaction were significant (Table 2). Total root lengths of genotypes of the control treatment varied between 14.84 and 38.13 cm, with the longest roots in Zencirci 2002, Süzen 97, Kılçıksız Buğday, and Bayraktar 2000 and the shortest roots in Sönmez 2001 and Sert Buğday. Total root lengths of genotypes under –5 bar osmotic potential varied between 2.91 and 13.92 cm, with the longest roots in Kırmızı Kılçık, Türkmen, Hawk, and Kırmızı Yerli and the shortest roots in Yakar 99, Sert Buğday, Pehlivan, and Aksel 2000. Average total root lengths of the genotypes in osmotic environment treatments varied between 10.54 and 23.12 cm. Süzen 97 had the highest total root length and it was followed by Kılçıksız Buğday, Zencirci 2000, Türkmen, and Dağdaş 94. The shortest root lengths were observed in Sert Buğday, Sönmez 2001, Yakar 99, and Akbuğday. While the average total root length was 24.82 cm in the control treatment, the value significantly decreased and dropped to 8.09 cm in the –5 bar osmotic environment treatment (Table 2). Similar to the current findings, Dhanda et al. (2004), Rauf et al. (2007), and Baloch et al. (2012) observed significant differences between root lengths of wheat genotypes under low water potential and stated that root lengths decreased with increasing stress levels. Rauf et al. (2007) observed significant decreases in root lengths and fresh and dry root weights as stress levels increased. Ahmadizadeh et al. (2011) observed significant differences in root lengths of genotypes under stress conditions. They reported the average root lengths of the genotypes as 12.71, 6.92, and 4.46 cm, respectively; compared to control treatment, they reported 45.55% and 64.91% decreases in root lengths under –0.6 and –0.8 MPa treatments, respectively. Again compared to the control treatment, Baloch et al. (2012) observed a 74.4% decrease in root lengths of 16 wheat genotypes under stress conditions (15% PEG). Dhanda et al. (2004) reported root lengths of 30 bread wheat genotypes under –10 bar stress conditions as between 3.5 and 7.5 cm and reported a 53.8% decrease in root length compared to the control treatment. Since drought-resistant genotypes can meet water demands from deeper sections of the soil profile, root system development of drought-tolerant genotypes during early growth stages is highly significant in selecting genotypes for water deficit conditions. Considering the root lengths under stress conditions, the genotypes used in the present study seem to be more sensitive to drought than the genotypes in the aforementioned literature. Additionally, significant differences observed between root lengths of genotypes under stress conditions revealed the possibility of selecting relatively drought-tolerant genotypes.

3.1.3. Shoot length

Differences between wheat genotypes, effects of osmotic environments on shoot lengths, and genotype × treatment interaction were significant with respect to shoot length (Table 3). Shoot lengths of genotypes in control treatments varied between 7.99 and 19.55 cm, with the longest shoots in Ak Buğday, Doğu 88, and Özlü Buğday and the shortest shoots in Harmankaya 99, Demir 2000, Seri 82, Orso, Prostor, İzgi, and Karahan 99. The shoot lengths of genotypes under –5 bar osmotic potential varied between 0.07 and 4.73 cm, with the longest shoots in Kırmızı Kılçık and Hawk, and the shortest shoots in Bezostaja 1, Yakar 99, Tosunbey, Aksel 2000, Bayraktar, Müfitbey, Palandöken 97, Uzunyayla, and Zencirci 2002.

Table 3. The effect of osmotic stress on shoot length and seed vigor index of wheat genotypes[1].

		Shoot length (cm)			Seed vigor index		
No.	Genotypes	Control	–5 bar	Mean	Control	–5 bar	Mean
1	Aksel 2000	12.29 yz	0.32 z	6.30 w–z	3652.0 o–s	294.9 yz	1973.5 t–x
2	Alparslan	12.65 yz	0.73 x	6.69 t–x	2927.2 z	437.9 w	1682.5 y
3	Altay 2000	14.75 k–q	0.72 x	7.74 ı–q	3936.7 h–l	489.0 t–x	2212.8 m–r
4	Atlı 2002	14.93 j–p	0.75 x	7.84 h–p	3310.2 vw	420.2 w	1865.2 wxy
5	Aytın 98	13.98 o–y	2.20 de	8.09 g–m	3593.9 p–t	901.2 fgh	2247.5 l–q
6	Bağcı 2002	13.59 q–z	0.52 y	7.05 r–v	3529.7 r–v	380.0 y	1954.8 t–z
7	Bayraktar 2000	12.93 x	0.47 z	6.7 t–x	4358.6 cd	496.2 t–x	2427.4 f–i
8	Bolal 2973	14.29 l–v	1.04 s–x	7.67 k–r	3282.4 x	699.0 m–q	1990.7 r–w
9	Çetinel 2000	11.26 z	1.18 o–u	6.22 w–z	3249.2 x	468.8 u–y	1859.0 wxy
10	Dağdaş 94	16.99 b–e	1.50 i–p	9.24 bcd	4465.7 bc	438.2 w	2451.9 e–h
11	Demir 2000	10.73 z	1.83 f–j	6.28 w–z	3180.2 y	759.4 j–n	1969.8 t–x
12	Doğankent 1	13.31 u	2.02 efg	7.67 k–r	3637.1 p–s	503.0 t–w	2069.8 p–t
13	Doğu 88	19.08 a	1.86 e–h	10.47 a	3812.1 j–p	433.0 w	2122.5 o–s
14	Gerek 79	16.38 b–g	1.97 efg	9.18 bcd	3985.3 g–l	549.0 r–v	2266.9 k–p
15	Gün 91	11.22 z	1.34 m–s	6.28 w–z	3114.6 z	465.5 u–y	1790.0 xyz
16	Harmankaya 99	7.99 z	1.47 j–q	4.73 z	2331.1 z	454.0 v–z	1392.4 z
17	İkizce 96	14.07 n–x	1.97 efg	8.02 h–n	3283.6 w	400.4 x	1842.0 w–z
18	İzgi 2001	11.56 z	1.16 p–v	6.36 wxy	3232.5 x	381.6 y	1807.1 w–z
19	Karahan 99	11.76 z	1.27 m–t	6.51 vwx	3090.6 z	349.3 yz	1720.0 yz
20	Kate A-1	15.42 g–l	1.15 p–v	8.29 f–k	3643.5 o–s	452.3 v–z	2047.9 p–u
21	Kıraç 66	16.37 b–h	1.45 k–r	8.91 cde	3629.3 p–s	433.1 w	2031.2 rtu
22	Kırgız 95	12.79 y	1.71 g–l	7.25 p–t	3098.6 z	850.0 g–j	1974.3 r–x
23	Kırkpınar 79	13.76 p–z	0.58 y	7.17 q–u	3907.9 i–m	434.5 w	2171.2 o–s
24	Kutluk 94	15.19 h–o	1.22 n–u	8.21 f–l	3762.2 l–r	625.5 p–s	2193.8 n–s
25	Lancer	17.22 bcd	0.85 v–y	9.03 cd	3662.4 n–s	484.8 u–x	2073.6 p–t
26	Mızrak	15.20 g–n	1.60 h–m	8.4 e–h	3989.8 g–l	926.4 fg	2458.1 e–h
27	Müfitbey	14.53 k–t	0.33 z	7.43 n–r	3788.7 k–q	294.3 yz	2041.5 p–u
28	Nenehatun	14.26 m–v	0.99 t–x	7.63 l–r	3777.4 k–r	618.0 p–s	2197.7 n–s
29	Palandöken 97	13.23 v	0.40 z	6.81 s–w	3676.2 m–s	551.6 r–u	2113.9 o–s
30	Pamukova 97	12.15 yz	1.05 s–x	6.60 u–x	3060.9 z	642.1 o–r	1851.5 w–z
31	Pehlivan	13.86 p–y	0.76 w–z	7.31o–s	3503.7 s–w	266.2 z	1884.9 u–y
32	Prostor	11.47 z	0.87 u–y	6.17 xyz	3591.5 p–t	609.6 qrs	2100.6 o–t
33	Seri 82	10.80 z	0.75 x	5.78 yz	2919.9 z	555.4 r–u	1737.7 yz
34	Soyer02	13.49 s	1.87 e–h	7.68 k–q	4249.1 c–f	870.9 ghi	2560.0 de
35	Sönmez 2001	13.43 t	2.00 efg	7.72 j–q	2677.2 z	789.2 i–m	1733.2 yz
36	Sultan 95	11.77 yz	1.47 j–q	6.62 u–x	3346.3 u	691.1 n–q	2018.7 r–v
37	Süzen 97	13.50 r	1.17 p–v	7.33 o–s	4648.2 b	1100.0 cd	2874.1 b
38	Tosunbey	12.36 yz	0.30 z	6.33 wxy	3561.9 p–u	543.4 s–v	2052.7 p–u
39	Türkmen	14.02 n–x	1.84 f–i	7.93 h–o	4129.7 d–i	988.3 ef	2559.0 de
40	Uzunyayla	14.71 k–r	0.34 z	7.52 m–r	4229.1 d–g	360.3 yz	2294.7 j–o
41	Yakar 99	14.51 k–u	0.27 z	7.39 o–s	3329.8 uv	210.1 z	1770.0 xyz
42	Zencirci 2002	15.36 g–m	0.45 z	7.91 h–o	5028.2 a	407.4 w	2717.8 c
43	Ak-702	15.08 i–o	1.10 r–w	8.09 g–m	4197.0 d–g	584.4 rst	2390.7 g–k
44	Ak Buğday	19.55 a	1.57 h–n	10.56 a	3653.0 o–s	552.4 r–u	2102.7 o–t
45	Ankara 093/44	14.19 m–w	1.12 r–v	7.65 l–r	3938.3 h–l	584.9 rst	2261.6 l–p
46	Conkesme	16.97 b–e	2.43 cd	9.7 b	4032.0 f–j	1031.0 de	2531.5 def
47	Haymana 79	13.98 o–y	1.75 g–l	7.86 h–p	3555.4 r–u	874.4 ghi	2214.9 m–r
48	Hawk (Şahin)	15.34 g–m	3.55 b	9.44 bc	4017.6 f–k	1288.0 b	2652.7 cd
49	Kılçıksız Buğday	16.17 c–i	2.16 def	9.17 bcd	4910.2 a	1187.0 c	3048.6 a
50	Kırik	14.90 j–p	1.76 g–k	8.33 e–j	3896.6 i–n	713.3 l–p	2305.0 i–n
51	Kırmızı Kılçık	13.52 r	4.73 a	9.13 bcd	3446.0 s–x	1666.8 a	2556.4 de
52	Kırmızı Yerli	15.55 f–k	2.67 c	9.11 bcd	3370.4 t	1150.8 c	2260.6 l–p
53	Koca Buğday	15.96 e–j	2.39 cd	9.17 bcd	4019.0 f–k	1017.7 de	2518.3 efg
54	Köse 220/39	16.88 b–e	1.45 k–r	9.17 bcd	4117.3 d–i	721.7 k–o	2419.5 f–j
55	Orso	10.88 z	0.58 y	5.73 z	4165.3 d–h	627.5 o–s	2396.4 g–j
56	Özlü Buğday	17.36 b	1.48 j–q	9.42 bc	4094.1 e–i	751.8 k–n	2422.9 f–j
57	Polatlı Kösesi	16.07 d–j	1.40 l–s	8.73 def	4077.6 f–i	795.0 i–l	2436.3 e–h
58	Sert Buğday	16.59 b–f	0.72 x	8.66 d–g	3308.0 vw	380.7 y	1844.3 w–z
59	Sürak 1593/51	17.01 b–e	1.31 m–t	9.16 bcd	3905.4 i–m	812.0 h–k	2358.7 h–l
60	Tir	17.34 bc	1.70 g–l	9.52 bc	4327.8 cde	1037.7 de	2682.7 c
61	Yayla 305	14.68 k–s	1.53 h–o	8.11 g–m	3907.0 i–m	768.0 j–n	2337.2 h–m
62	Zerin	14.59 k–t	1.54 h–o	8.07 g–m	3594.0 p–t	695.4 m–q	2144.5 o–s
63	Bezostaja 1	13.05 w	0.07 z	6.56 vwx	3887.0 i–o	551.8 r–u	2219.4 m–r
64	Karasu 90	16.19 b–h	0.52 y	8.35 e–i	4117.9 d–i	692.7 n–q	2405.3 f–j
Mean		14.30 A	1.33 B	7.81	3714.4 A	648.6 B	2181.5
F value (Genotype, G)		61.42**	95.84**	72.12**	76.83**	149.55**	105.02**
F value (Treatment, T)		-	-	130921.00**	-	-	159454.00**
F value (GxT)		-	-	56.34**	-	-	68.41**
LSD $_{(0.01)}$ (G)		1.02	0.30	0.53	211.1	83.7	112.7
LSD $_{(0.01)}$ (T)		-	-	0.09	-	-	19.9
LSD $_{(0.01)}$ (GxT)		-	-	0.74	-	-	159.4
CV (%)		3.3	10.7	4.5	2.7	6.0	3.4
		0.16	0.06	0.34	36.40	20.01	81.03

[1] Means in a column not sharing a common letter are significantly different. ** Significant at $P < 0.01$.

In osmotic environment treatments, average shoot lengths of genotypes varied between 4.73 and 10.56 cm, with the longest shoots in Akbuğday, Doğu 88, and Conkesme, and the shortest shoots in Harmankaya 99, Orso, Seri 82, and Prostor. While the average shoot length was 14.30 cm, the value decreased to 1.33 cm under –5 bar osmotic potential. Similar to the current findings, Naylor and Gurmu (1990), Dhanda et al. (2004), and Rauf et al. (2007) observed significant differences in shoot lengths of genotypes under stress conditions and reported decreased shoot lengths with increasing stress levels. Baloch et al. (2012) stated that shoot length was highly susceptible to stress conditions (15% PEG); compared to the control treatment, they reported a 57.5%–68.4% decrease in shoot lengths in the stress treatments. Jajarmi (2009) regarded shoot length as the plant characteristic most susceptible to drought and reported significant decreases in shoot lengths, particularly after –6 bar stress levels. Dhanda et al. (2004) reported a 63.9% decrease in shoot lengths of genotypes under stress conditions. Rauf et al. (2007) reported significant decreases in shoot lengths with increasing stress levels and indicated positive and significant relationships between shoot lengths and germination rate, root length, and coleoptile length. Naylor and Gurmu (1990) indicated that coleoptile emergence was more susceptible to low water potential than radicle emergence and pointed out the significantly low coleoptile lengths of aged seeds under low water potential. Ahmadizadeh et al. (2011) reported shoot lengths of 37 wheat genotypes under 0 MPa, –0.6 MPa, and –0.8 MPa stress levels, respectively, as 9.44 cm, 2.83 cm, and 1.38 cm. Researchers observed different responses in genotypes and 70.02% and 85.34% decreases, respectively, in shoot lengths compared to the control treatment. Since a longer coleoptile supports the emergence of the seedling under insufficient moisture conditions, they may play a significant role in seedling establishment (Baloch et al., 2012). Average shoot length of the present study was 1.33 cm under –5 bar treatment and this value indicates a 90.7% decrease compared to the control treatment. Considering the shoot lengths under stress conditions, current findings revealed that modern wheat cultivars are more susceptible to drought stress and such a case may result in significant decreases in germination and seedling emergence under low field water potentials.

3.1.4. Seed vigor index

With regard to seed vigor index, the differences between the genotypes, between the osmotic ambient treatments, and genotype × treatment interaction were significant (Table 3). Seed vigor indexes of genotypes in control treatments varied between 2331.1 and 5028.2, with the highest values in Zencirci 2002, followed by Kılçıksız Buğday and Süzen 97, and the lowest values in Harmankaya 99, Sönmez 2001, Seri 82, Alparslan, Karahan 99, Kırgız 95, and Pamukova 97. Seed vigor index of genotypes under –5 bar osmotic potential varied between 210.1 and 1666.8, with the highest values in Kırmızı Kılçık, Hawk, Kılçıksız Buğday, Kırmızı Yerli, and Süzen 97 and the lowest values in Yakar 99, Pehlivan, Müfitbey, Aksel 2000, and Karahan 99. Average seed vigor indexes of genotypes varied between 1392.4 and 3048.6, with the highest value in Kılçıksız Buğday, followed by Süzen 97, Zencirci 2002, Tir, and Hawk and the lowest values in Harmankaya 99, Alparslan, Karahan 99, Sönmez 2001, and Seri 82. While the average seed vigor index was 3714.4 in the control treatment, the value significantly decreased under –5 bar osmotic potential to 648.6 (Table 3). Since germination rate and shoot and root length decreased with increasing stress level, seed vigor of genotypes also decreased. Average germination rate, total embryonic root length, shoot length, and seed vigor index of genotypes under –5 bar osmotic potential decreased by 28.7%, 67.4%, 90.7%, and 82.5%, respectively, compared to the control treatments. The greatest decrease rate was observed in shoot length, followed by seed vigor index. Such a finding is in accordance with the outcomes of the previous studies, indicating greater susceptibility of shoot length to drought stress than root length (Naylor and Gurmu, 1990; Dhanda et al., 2004). Under drought stress, limited water and nutrient supply to shoots and root-originated hormonal messages may result in increased root/shoot length ratios (Sharp and Davis, 1989). Dhanda et al. (2004) gave the germination rates of 30 bread wheat genotypes under –10 bar stress level as between 14.3% and 64.6%, root lengths as between 3.5 and 7.5 cm, shoot lengths as between 2.0 and 7.5 cm, and seed vigor indexes as between 146.2 and 585.6. Compared to control treatments, researchers also reported the greatest decrease in seed vigor indexes (85.8%). Baloch et al. (2012) also reported that seed vigor indexes of genotypes under stress conditions (15% PEG) decreased by 60.1%–76.6% compared to the control treatment.

Since none of the genotypes exhibited germination at –10 bar stress level, it can be stated that genetic source of Turkey is limited in terms of drought-tolerant wheat genotypes. Moreover, with regard to germination rates, significant differences were observed between the genotypes and genotype × treatment interactions were found to be significant. The decrease rates in these characteristics were significantly high in some genotypes and at medium–low levels in some others. Such outcomes resulted from differences in susceptibility of genotypes to water stress. Current findings indicate that genotypic variation might provide opportunities in breeding studies aiming to develop germination characteristics under stress conditions. Seed vigor index, calculated as a common function of responses to water stress, may be more beneficial than the other germination characteristics when

comparing genotype responses to water stress. Lower index values represent drought sensitivity and higher index values represent drought tolerance. Considering their values at the –5 bar stress level, Kırmızı Kılçık, Hawk, Kılçıksız Buğday, and Kırmızı Yerli (the highest seed vigor indexes) and Sönmez 2001, Kırgız 95, Conkesme, and Koca Buğday (the smallest decreases in seed vigor index compared to the control treatment) may be defined as drought-tolerant during germination period. These genotypes may yield better germination and seedling establishment and may be used as parent material in breeding programs. On the other hand, Yakar 99, Pehlivan, Müfitbey, and Aksel 2000 (the lowest seed vigor index) and Zencirci 2002, Uzunyayla, Dağdaş 94, and Bağcı 2002 (the greatest decreases in seed vigor index compared to the control treatment) may be defined as drought-sensitive genotypes.

3.2. Cell membrane damage

Osmotic stress-induced cell membrane damage is regarded as an indicator for drought resistance of wheat genotypes. The differences between cell membrane damage in genotypes were significant (Table 4). Cell membrane damage ratios of genotypes varied between 0.16% and 47.26%; the average across genotypes was 13.69%. The highest leaf osmotic membrane stability was observed in Ankara 093/44, which had the lowest membrane damage ratio. With increasing damage ratios, it was followed by Sürak 1593/51 (0.28%), Köse 220/39 (0.67%), Kutluk 94 (0.73%), and Polatlı Kösesi (1.11%). The highest cell membrane damage ratios were observed in Dağdaş-94 (47.26%), Mızrak (35.12%), Tosunbey (35.01%), Zencirci (28.84%), and Doğankent 1 (28.48%). Similar to current findings, Singh et al. (1992), Assad and Paulsen (2002), Dhanda et al. (2004), Gerevandi et al. (2011), Gavuzzi et al. (1997), Premachandra and Shimada (1987), and Bajji et al. (2002) reported significant differences between cell membrane damage ratios of wheat genotypes. Under stress conditions, damage is primarily observed in cell membranes; consequent destruction of membrane integrity increases cell permeability and electrolytes leak out from the cell (Collado et al., 2010). Such a case is mainly observed in drought-sensitive genotypes and the primary reason for metabolic damage in plants exposed to stress is the loss of the semipermeable nature of the cell membrane (Habibpor et al., 2011). Therefore, cell membrane stability and integrity under stress conditions are considered indicators of stress resistance. Cell membrane damage ratio may vary based on plant growth conditions, growth periods, leaf waxiness, leaf position, and the method used in damage measurement (Premachandra and Shimada, 1987; Gavuzzi et al., 1997). Gavuzzi et al. (1997) investigated cell membrane damage ratio over flag leaves sampled during the heading stage of 6 bread wheat (58%–98%), 6 durum wheat (36%–56%), and 6 barley (48%–58%) genotypes and observed higher damage ratios than the present study. Kocheva and Georgiev (2003) investigated the effects of osmotic stress on barley genotypes. They indicated the relationship between cold and drought tolerance and observed higher proline accumulation, relative humidity level, and lower cell membrane damage ratio in the leaves of the cold-tolerant genotype Odeskii. Kocheva et al. (2009) indicated that sustainability of high leaf relative water content following osmotic stress during wheat's seedling period results from high membrane stability. Bandurska et al. (1997) investigated membrane damages of barley species under osmotic stress conditions and reported lower membrane damage ratios in Aramir. Researchers indicated that ascorbic acid peroxidase activity under stress conditions removed lipid-peroxiding hydrogen peroxidase from the tissues and that lower cell membrane damage ratios were related to higher ascorbic acid contents of leaves. Tas and Tas (2007) investigated the drought responses of Atay 85 and Bezostaja 1 bread wheat and Gerek 75 and Çakmak 79 durum wheat genotypes and reported decreased membrane stability in all genotypes on days 60, 70, and 80 after sowing based on leaf aging; Çakmak 79 and Bezostaja 1, with the highest membrane stability, were considered drought-tolerant genotypes. Bezostaja 1 had a membrane damage ratio of 5.86% and was placed among the genotypes relatively resistant to drought. Bajji et al. (2002) reported that drought-sensitive durum wheat genotype Kabir 1, with low yield stability, had a higher membrane damage ratio than Omrabi 5 and Haurani, which have high yield stability and have been adapted to dry farming conditions. Researchers indicated that the mechanisms by which membrane characteristics support drought tolerance of genotypes were not clear. Lower membrane damage ratios were related to sucrose and trehalose-like sugar accumulation capacities in leaves during stress periods; accumulation of these sugars decreased the water loss damages in drought-resistant genotypes and supported plant growth during stress and poststress periods. Dhanda et al. (2004) reported higher cell membrane damage ratios for bread wheat genotypes (20.4%–65.3%) than for the current genotypes (0.16%–47.26%) and indicated close relationships of membrane damage with root length ($r = -0.37$) and root/shoot ratio ($r = -0.42$). Premachandra and Shimada (1987) investigated cell membrane damages in 11 spring and one winter wheat genotypes. They reported significantly lower membrane damages for the Lancer winter wheat genotype than the spring wheat genotypes and indicated relationships between drought and cold tolerance in genotypes. In another study, the same researchers used 14 winter wheat genotypes and reported cell membrane damages as between 10% and 31%. In both studies, the response

Table 4. Cell membrane damage after PEG stress and chlorophyll content after PQ treatment of wheat genotypes[1].

No.	Genotypes	Cell membrane damage (%)	Chlorophyll content (mg mL^{-1} g FW^{-1})
1	Aksel 2000	17.54 ij	0.076 c
2	Alparslan	12.27 n–r	0.014 l–p
3	Altay 2000	23.41 fgh	0.013 l–p
4	Atlı 2002	19.19 i	0.094 ab
5	Aytın 98	10.42 r–v	0.078 bc
6	Bağcı 2002	8.59 t–y	0.018 i–p
7	Bayraktar 2000	12.26 n–r	0.027 f–n
8	Bolal 2973	12.84 n–q	0.033 d–l
9	Çetinel 2000	18.28 ij	0.090 abc
10	Dağdaş 94	47.26 a	0.013 l–p
11	Demir 2000	14.34 l–o	0.050 d
12	Doğankent 1	28.48 cd	0.039 d–h
13	Doğu 88	25.63 ef	0.049 d
14	Gerek 79	26.40 cde	0.009 m–p
15	Gün 91	11.70 o–s	0.012 m–p
16	Harmankaya 99	23.84 e–h	0.014 l–p
17	İkizce 96	4.63 xyz	0.005 p
18	İzgi 2001	6.28 x	0.008 nop
19	Karahan 99	8.44 u–y	0.039 d–g
20	Kate A-1	26.12 def	0.019 i–p
21	Kıraç 66	7.84 w–z	0.014 l–p
22	Kırgız 95	3.12 xyz	0.012 m–p
23	Kırkpınar 79	13.67 m–p	0.006 op
24	Kutluk 94	0.73 yz	0.021 g–p
25	Lancer	21.94 h	0.016 j–p
26	Mızrak	35.12 b	0.009 m–p
27	Müfitbey	14.42 l–o	0.024 f–p
28	Nenehatun	8.33 v–y	0.012 m–p
29	Palandöken 97	11.41 p–t	0.009 m–p
30	Pamukova 97	17.80 ij	0.040 def
31	Pehlivan	14.70 k–n	0.007 nop
32	Prostor	22.54 gh	0.021 g–p
33	Seri 82	10.69 r–v	0.009 m–p
34	Soyer02	12.50 n–r	0.013 l–p
35	Sönmez 2001	9.84 r–w	0.026 f–o
36	Sultan 95	12.26 n–r	0.013 l–p
37	Süzen 97	9.81 r–w	0.026 f–o
38	Tosunbey	35.01 b	0.015 k–p
39	Türkmen	2.10 xyz	0.018 i–p
40	Uzunyayla	8.61 t–y	0.017 j–p
41	Yakar 99	24.93 efg	0.036 d–i
42	Zencirci 2002	28.84 c	0.015 k–p
43	Ak-702	16.24 i–m	0.018 i–p
44	Ak Buğday	17.23 ijk	0.014 l–p
45	Ankara 093/44	0.16 z	0.014 l–p
46	Conkesme	17.00 i–l	0.046 de
47	Haymana 79	11.39 p–t	0.012 m–p
48	Hawk (Şahin)	7.43 w–z	0.010 m–p
49	Kılçıksız Buğday	11.30 r–u	0.020 h–p
50	Kırik	10.71 r–u	0.014 l–p
51	Kırmızı Kılçık	7.15 w	0.013 l–p
52	Kırmızı Yerli	3.94 xyz	0.034 d–k
53	Koca Buğday	13.71 m–p	0.012 m–p
54	Köse 220/39	0.67 yz	0.024 f–p
55	Orso	12.87 n–q	0.101 a
56	Özlü Buğday	8.95 s–x	0.035 d–j
57	Polatlı Kösesi	1.11 xyz	0.017 j–p
58	Sert Buğday	2.16 xyz	0.019 i–p
59	Sürak 1593/51	0.28 z	0.027 f–n
60	Tir	5.10 xyz	0.028 e–m
61	Yayla 305	9.85 r–w	0.024 f–p
62	Zerin	4.20 xyz	0.010 m–p
63	Bezostaja 1	5.86 xyz	0.028 e–m
64	Karasu 90	24.42 e–h	0.020 h–p
Mean		13.69	0.025
F value		197.95**	24.24**
LSD $_{(0.01)}$		2.50	0.016
CV (%)		8.6	9.9
		0.685	0.002

[1] Means in a column not sharing a common letter are significantly different. ** Significant at $P < 0.01$.

of entire genotypes to drought stress was similar and membrane damage ratios were lower in drought-adapted plants. Habibpor et al. (2011) carried out experiments with 30 bread wheat genotypes under osmotic stress conditions created with 20% and 30% PEG 6000 solutions and reported cell membrane damage ratios of genotypes as between 12.65% and 36.80% and between 19.55% and 44.90%, respectively.

Significant differences among cell membrane damages of bread wheat genotypes under osmotic stress conditions revealed the existence of genetic differences among the genotypes and the possibility of selecting drought-tolerant genotypes. Considering the membrane damage ratio as a criterion, 17 genotypes (Ankara 093/44, Sürak 1593/51, Köse 220/39, Kutluk 94, Polatlı Kösesi, Türkmen, Sert Buğday, Kırgız 95, Kırmızı Yerli, Zerin, İkizce 96, Tir, Bezostaja 1, İzgi 2001, Kırmızı Kılçık, Hawk, Kıraç 66) with the lowest membrane damage ratios and not significantly different from each other may be defined as drought-tolerant at early growth stages. On the other hand, the genotypes Dağdaş-94, Mızrak, Tosunbey, Zencirci, Doğankent 1, Gerek 79, Kate A-1, Doğu 88, Yakar 99, and Karasu 99, with the highest cell membrane damage ratios, may be defined as drought-sensitive during early growth stages. Current findings revealed that local genotypes had lower cell membrane damage ratios than the breeding genotypes. Thus, local genotypes used in this study had higher membrane stability under osmotic stress conditions.

3.3. Chlorophyll content after paraquat treatment

Drought-induced chlorophyll loss in green tissues of plants is related to oxidative stress-induced photooxidation (Fu and Huang, 2001). The decrease in antioxidative activity and lipid peroxidation of plants under stress conditions may result in chlorophyll losses (Sairam and Saxena, 2000). Paraquat is an herbicide and paraquat-induced stress on plants is similar to stress exerted on a plant by drought. During photosynthesis, oxygen molecules of chloroplasts react with paraquat radicals and highly toxic free radicals are formed. Thus, there is a close relationship between plant tolerance to water stress and plant tolerance to paraquat (Dodge, 1971). Therefore, total chlorophyll contents of wheat genotypes after paraquat treatment is regarded as an indicator for drought resistance. Present results revealed significant differences in leaf total chlorophyll contents of wheat genotypes after paraquat treatment (Table 4). Chlorophyll contents of genotypes varied between 0.005 and 0.101 mg mL^{-1} g FW^{-1} and average of genotypes was 0.025 mg mL^{-1} g FW^{-1}. The highest total chlorophyll content was observed in Orso, Atlı 2002, and Çetinel 2000 genotypes, respectively, with 0.101, 0.094, and 0.090 mg mL^{-1} g FW^{-1}. The lowest chlorophyll contents were observed in İkizce 96, Kırkpınar 79, Pehlivan, and İzgi 2001 genotypes, respectively, with 0.005, 0.006, 0.007, and 0.008 mg ml^{-1} g FW^{-1}. Fotovat et al. (2007) reported decreased chlorophyll contents in all genotypes under stress conditions and indicated total chlorophyll content measurements as a cheap and reliable method to determine a genotype's resistance to drought at early stages. Similar to the current findings, Anderson and Nielsen (1991), Altinkut et al. (2001), Lascano et al. (2003), and Ekmekçi and Terzioğlu (2005) reported significant differences in chlorophyll contents of paraquat-treated wheat genotypes and indicated chlorophyll content as an efficient criterion in the selection of drought-resistant genotypes. Aydın et al. (1999) carried out a study with 19 wheat genotypes, 12 of which were included in the current study, and reported the chlorophyll contents of genotypes as between 0.87 and 3.71 mg/g. Researchers defined Partizanka, Gün 91, Zitarka, ES SBVD2-8, Gerek 79, Kırgız 95, Bolal 2973, and Dağdaş 94 as drought-resistant and Sertak 52, ES 14, Atay 85, Ak 702, Kutluk 94, and Kıraç 66 as drought-sensitive. While Kıraç 66, Ak 702, and Kutluk 94 were similarly included among the drought-sensitive genotypes of the present study, in contrast Gerek 79, Gün 91, Kırgız 95, Kırkpınar 79, and Dağdaş 95 were placed among the drought-sensitive genotypes of the present study. Altinkut et al. (2001) reported significantly lower chlorophyll contents for drought-sensitive Sultan after paraquat treatment than for drought-resistant Kıraç 66. Altinkut et al. (2003) also treated seedling leaves of 80 barley genotypes with paraquat to determine drought-resistant genotypes and reported chlorophyll contents of tolerant genotypes as between 1.28 and 1.53 mg chlorophyll/fresh weight and chlorophyll contents of sensitive genotypes as between 0.03 and 0.15 mg chlorophyll/fresh weight. Ekmekçi and Terzioğlu (2005) classified Harran 95 as tolerant to paraquat, Kızıltan 91 and Bezostaja 1 as medium tolerant, and the other genotypes as sensitive genotypes. Lascano et al. (2003) applied different paraquat concentrations (0, 0.5, 1.0, 1.5 μM) to Oasis and Elite bread wheat genotypes and reported different paraquat responses of the genotypes based on antioxidant system activity levels of the genotypes. Researchers indicated increasing enzyme activities and decreasing chlorophyll contents with increasing paraquat concentrations.

Preservation of chlorophyll in plant tissues under drought stress is essential for photosynthesis and tolerant genotypes have higher chlorophyll contents in stress conditions (Sairam et al., 1990). Significant differences among chlorophyll contents after paraquat treatment of bread wheat genotypes also indicated significant differences in paraquat and hence in drought tolerance of the genotypes. Orso, Atlı 2002, and Çetinel 2000 had the highest chlorophyll contents after paraquat treatment and may be identified as drought-tolerant at early growth stages.

Moreover, Aksel 2000, Aytın 98, Demir 2000, and Doğu 88 had relatively high chlorophyll contents after paraquat treatment and may be defined as moderately tolerant to early drought. On the other hand, İkizce 96, Kırkpınar 79, Pehlivan, İzgi 2001, Gerek 79, Mızrak, Palandöken 97, and Seri 82, which had the lowest chlorophyll contents, may be defined as sensitive to drought at early growth stages.

In light of our results, it was determined that Mızrak had a high seed vigor index, high cell membrane damage, and low paraquat tolerance; Zerin had low cell membrane damage and low paraquat tolerance; Aksel 2000 had high paraquat tolerance and a low seed vigor index; Doğu 88 had high paraquat tolerance and high cell membrane damage; and Karahan 99 had a high paraquat tolerance and a low seed vigor index. The substantially different selection criteria analyzed in this study revealed significant genetic differences that would enable us to select drought-tolerant genotypes. However, a genotype defined as tolerant based on one criterion could be susceptible with respect to another criterion. It could be that the selection parameters used in this study are controlled by different genetic or physiological factors, making it difficult to assess and recommend suitable genotypes for places where early drought is experienced. Kırmızı Yerli, Conkesme, and Türkmen were considered drought-resistant based on two out of the three parameters tested. These genotypes may have a greater adaptive ability in a drought environment in the early developmental stage. Kırmızı Yerli, Conkesme, and Turkmen, which were notable in terms of both parameters, could be used as parents in breeding programs related to drought resistance. On the other hand, Yakar 99, Pehlivan, İzgi 2001, İkizce 96, Mızrak, and Gerek 79 were determined to be drought-susceptible regarding two out of three parameters tested.

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