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Trait-Based Characterization of Barley Genotypes under Simulated Early Drought Stress Conditions

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ABSTRACT

This study was carried out to determine the barley varieties that can be used as parents in drought resistance breeding and can be grown in regions where drought is experienced during the early growth and development periods. Seedling survival after drought, coleoptile length, seedling vigor, cell membrane damage and germination parameters at low water potential were measured. The seedling survival after drought rates of the varieties ranged from 8.0% to 76.0%, the coleoptile lengths ranged from 45.47 mm to 94.60 mm, the specific leaf area ranged from 100.1 $cm^2\ g^{-1}$ to 255.8 $cm^2\ g^{-1}$, the first leaf width ranged from 3.11 mm to 8.93 mm, and the cell membrane damage rates ranged from 2.34% to 37.79%. In our study, the germination rate, root length, shoot length and seed vigor index decreased as the osmotic potential increased. The 74 barley varieties used in the study were divided into four groups, resistant, medium resistant, medium sensitive and sensitive, according to the rank total values calculated over 6 selection criteria. Accordingly, the Konevi, İnce-04 and Fahrettinbey varieties were determined to be resistant to early drought. Twenty-six varieties of medium hardness with a rank total ranging from 29.1 to 40.3 were identified. Thirty-two varieties with a rank total between 40.4 and 51.6 were determined to be moderately sensitive, and 13 varieties with a rank total between 51.7 and 62.8 were determined to be sensitive.

1. INTRODUCTION

Stress in plant production can be defined as abiotic and biotic factors that negatively affect plant growth and development and consequently decrease yield (Kusvuran, 2010). Some environmental factors can become very stressful in a short period of time, while others can become very stressful days later. Some parts of the plant may be resistant to a stressor, while others may be sensitive (Boyer, 1982). Drought is a major abiotic stress that limits agricultural production and significantly threatens the world's food supply. Drought ranks first among abiotic stresses, with a share of 26% (Blum & Ebercon, 1981). It is a global problem that restricts agricultural production in arid and semiarid areas, which make up approximately 35% of the world's land. Drought is defined as the occurrence of a significant water deficit in the soil or atmosphere that depletes soil moisture and stresses plants. In plants, growth occurs through cell division, cell growth and differentiation and depends on genetic, physiological, biochemical, ecological and morphological events and their complex interactions. The quality and quantity of plant growth depend on these events, which are affected by water deficit (Ahmed et al., 2016). Barley production is generally carried out in dry agricultural areas in Türkiye, and irregular or insufficient rainfall throughout vegetation causes serious problems in these areas. Drought first reduces the water potential of the soil and then the plant. In subsequent periods, low turgor pressure, stomatal closure, a decrease in leaf growth and a decrease in the photosynthesis rate occur. Drought is a complex abiotic stress that varies according to the degree of severity and can be effective in any period of plant growth. Van Oosterom et al. (1993) reported that drought is the most important abiotic stress factor that reduces the grain yield of barley, but this decrease depends not only on the duration and severity of the drought but also on the period of development during which the plant is exposed to drought. Drought can be effective in three periods in cereals: the vegetative period (germination, emergence, seedling and tillering), anthesis period (stem elongation, booting and heading) and after anthesis period (anthesis and grain filling) (Shavrukov et al., 2017). In plants where drought stress is observed, there are conditions such as limited growth, decreased dry matter production, increased susceptibility to diseases and pests, and decreased product quantity and quality (Monti, 1987). Drought in autumn and winter causes the plant to enter the winter without a good seedling plant or tillering. Drought that occurs for a long time in the winter months and spring causes a decrease in the number of tillers and a decrease in the number of spikelets and flowers due to the reduction in plant size, spikelets and flowers, as it will include the tillering, jointing and heading periods, even if timely and adequate emergence occurs. In this case, since drought lasts in winter and spring, earliness is no longer a mechanism for escaping drought and is the reason for being more affected by drought. Barley is more affected by this situation due to its early age (Kutlu, 2010).

Drought tolerance occurs as a function of morphological (coleoptile length, first leaf emergence, root characteristics, tillering, flowering, awn formation, stomatal density, and cell membrane stability), physiological (low transpiration rate, relative water content, stomatal density, high water use efficiency, osmotic pressure, and leaf turgor) and biochemical (increased nitrate reductase activity and proline deposition) characteristics (Mitra, 2001). Tolerance to drought stress is a quantitative trait controlled by many different genes (Ahmed et al., 2016). The drought resistance of plants can vary depending on the genetic background of the cultivar, the duration and severity of drought, and the stage of development (Beltrano & Ronco 2008; Hu et al., 2007). In plants exposed to drought in early development periods, earlier flowering, plant height, leaf area, and the number of fertile tillers are reduced (Robertson & Giunta 1994). Drought-tolerant varieties are defined as those that can produce relatively high yields under drought conditions (Hall, 1993). Drought tolerance can be divided into three categories: drought escape, drought avoidance and drought tolerance (Blum, 2011).

This study was carried out to investigate the effectiveness of early drought resistance selection criteria based on seedling survival, coleoptile length, seedling vigor, cell membrane damage and germination in barley (*Hordeum vulgare* L.) at different osmotic potentials after drought and to determine suitable varieties that can be used as parents in drought-related breeding programs and can be grown in drought-prone regions in the early stages of plant development.

2. MATERIALS AND METHODS

In this study, 74 barley varieties included in the 2015 National Variety List of Türkiye were used as plant material (Table 1). Among the 74 barley varieties included in the experiment, 34 were alternative, 26 were winter, and 14 were spring varieties.

Table 1. Season character and spike type of the barley genotypes used in the study

Cultivar	Institution	Release Date	Spike Type	Season Character
Akar	FCCRI	2012	Two-Rowed	Alternative
Akdane	AEBMI	2011	Two-Rowed	Alternative
Akhisar 98	AARI	1998	Six-Rowed	Spring
Altıkat	GAPIAREC	2011	Six-Rowed	Spring
Arcanda	PSI	2014	Two-Rowed	Alternative
Atılır	AEBMI	2005	Two-Rowed	Alternative
Avcı-2002	FCCRI	2002	Six-Rowed	Winter
Aydanhanım	FCCRI	2002	Two-Rowed	Winter
Balkan 96 (Igri)	TARI	1996	Two-Rowed	Winter
Barış	GAPIAREC	2015	Two-Rowed	Spring
Başgül	AEBMI	2003	Two-Rowed	Alternative
Bayrak	AARI	2014	Six-Rowed	Spring
Bilgi-91	TZARI	1991	Two-Rowed	Spring
Bolayır	TARI	2007	Two-Rowed	Winter
Burakbey	FCCRI	2013	Two-Rowed	Alternative
Bülbül 89	FCCRI	1989	Two-Rowed	Alternative
Cervoise	ASI	2011	Six-Rowed	Alternative
Clarica	ASI	2013	Two-Rowed	Winter
Cumhuriyet 50	TZARI	1973	Two-Rowed	Alternative
Çatalhüyük 2001	AEBMI	2001	Two-Rowed	Spring
Çetin 2000	FCCRI	2000	Six-Rowed	Winter
Çıldır 02	TZARI	2002	Two-Rowed	Alternative
Çumra 2001	AEBMI	2001	Two-Rowed	Alternative
Durusu	AEBMI	2007	Two-Rowed	Winter
Efes 98	AEBMI	1998	Two-Rowed	Alternative
Emon	TFFI	2014	Two-Rowed	Winter
Erciyes	AEBMI	2006	Two-Rowed	Alternative
Erginel 90	TZARI	1990	Six-Rowed	Alternative
Escadre	ASI	2013	Six-Rowed	Winter
Fahrettinbey	KARI	2004	Two-Rowed	Spring
Fırat	AEBMI	2005	Two-Rowed	Spring
Gazda	TAPI	2013	Two-Rowed	Winter
Harman	TARI	2011	Two-Rowed	Winter
Hasat	TARI	2014	Two-Rowed	Winter
Hilal	AARI	2010	Two-Rowed	Spring
İnce-04	TZARI	2004	Two-Rowed	Alternative
Kalaycı-97	TZARI	1997	Two-Rowed	Alternative
Karatay 94	BDIARI	1996	Two-Rowed	Alternative
Kendal	GAPIARE	2013	Six-Rowed	Spring
Keser	TZARI	2007	Six-Rowed	Alternative
Kıral-97	BDIARI	1997	Six-Rowed	Alternative
Konevi	BDIARI	1998	Two-Rowed	Alternative
Larende	BDIARI	2006	Two-Rowed	Alternative
Lord	TAPI	2011	Six-Rowed	Winter
Manava	ASAFI	2014	Two-Rowed	Winter
Martı	TARI	2009	Six-Rowed	Alternative
Meriç	AEBMI	2005	Six-Rowed	Winter
Olgun	EAARI	2011	Six-Rowed	Winter
Oliver	TAPI	2013	Six-Rowed	Winter
Orza 96	FCCRI	1996	Two-Rowed	Alternative
Özdemir-05	TZARI	2005	Two-Rowed	Alternative
Özen	FCCRI	2012	Two-Rowed	Spring
Premium	ASI	2013	Two-Rowed	Winter
Ramata	ASAFI	2015	Six-Rowed	Winter
Samyeli	GAPIAREC	2011	Two-Rowed	Spring
Sancak	AARI	2014	Two-Rowed	Spring
Scarpia	MSDI	2015	Six-Rowed	Winter
Seymen	SSI	2015	Two-Rowed	Winter

Table 1. (continued)

Sladoran	TARI	1998	Two-Rowed	Winter
Sultan	TSFI	2015	Six-Rowed	Winter
Sur-93	GAPIAREC	2002	Two-Rowed	Alternative
Şahin-91	GAPIAREC	1991	Two-Rowed	Alternative
Tarm-92	FCCRI	1992	Two-Rowed	Alternative
Tokak 157/37	FCCRI	1963	Six-Rowed	Winter
Toprak	AEBMI	2011	Two-Rowed	Alternative
Ünver	TZARI	2013	Two-Rowed	Alternative
Vamıkhoca 98	AARI	1998	Six-Rowed	Spring
Yalın	FCCRI	2014	Two-Rowed	Alternative
Yerçil-147	TZARI	1976	Two-Rowed	Alternative
Yesevi 93	FCCRI	1993	Two-Rowed	Alternative
Yıldız	AEBMI	2007	Two-Rowed	Winter
Zeus	PSI	2014	Six-Rowed	Winter
Zeynel Ağa	FCCRI	2003	Two-Rowed	Alternative

AARI: Aegean Agricultural Research Institute; BDIARI: Bahri Dağdaş International Agricultural Research Institute; Eaari: East Anatolian Agricultural Research Institute; FCCRI: Field Crops Central Research Institute; TARI: Trakya Agricultural Research Institute; TZARI: Transition Zone Agricultural Research Institute; GAPIAREC: GAP International Agricultural Research and Education Center; KARI; Karadeniz Agricultural Research Institute, EAARI; Eastern Anatolia Agricultural Research Institute, AEBMI: Anadolu Efes Beer and Malt Industry, ASI; Ata Seed Industry, TFFI; Tarar Flour and Food Industry, PSI; Progen Seed Industry, TAPI; Tareks Agricultural Pruduction Industry, ASAFI; Alfa Seed, Agricultural and Food Industry, MSDI; Marmara Seed Development Industry, SSI; Sarı Seed Industry, TSFI; Tekcan Seed and Food Industry

Seedling survival after drought

The experiment was conducted according to a completely randomized block design with 4 repetitions. Fifty seeds of each genotype were planted in wooden crates with dimensions of 80x100x12 cm, width 5 cm, 2 cm row and intrarow spacing at depths of 3 cm, respectively. After planting, the plants were sufficiently irrigated until they reached 3 leaves. After this period, the plants were not watered until most of the plants died from drought. When most of the seedlings died from drought, the moisture content of the soil was determined with the help of a soil moisture meter (HH2 Soil Moisture Meter) on the basis of volume at a depth of 10 cm; the plants were given enough water again, and their regrowth was ensured. Seedlings that remained viable approximately 10 days after redevelopment were counted in the crates, and the percentage of seedlings remaining viable after drought was calculated as a percentage for each genotype (Winter et al., 1988).

Coleoptile length

The experiment was conducted according to a completely randomized design with 4 replications. Fifty seeds of each genotype were planted in wooden crates with dimensions of 80×100×12 cm at depths of 3 cm and 5 cm and with 2 cm row and intrarow spacing. The crates, which were given sufficient water after planting, were placed in a growth cabinet set to 15°C and kept for 10 days in darkness. Then, 10 plants of each genotype were carefully removed from the soil, and the distance between the seed and the tip of the coleoptile, from which the first leaf emerged, was measured with a millimeter ruler (Rebetzke et al., 1999).

Seedling vigor

The experiment was carried out in research fields of the Atatürk University Plant Production and Application Center Directorate according to the randomized complete block design with 4 replications. When the number of leaves per plant averaged 4-5, 10 plants were randomly selected. The maximum width of the first leaf of each plant was measured using an electronic caliper. Then, the first 3 leaves of the plants were separated, and their total area was measured with a leaf area meter (LI-COR LI-3000C). The leaves were kept in a drying oven set to 70°C for 72 hours and then weighed on a 0.001 g sensitive balance, and their total dry weight was determined. Using the obtained values, the specific leaf area (cm^2 g^{-1}) was calculated with the following formula (Rebetzke et al., 2004):

Specific leaf area (cm^2 g^{-1}) = (Total leaf area) / (Total leaf dry weight)

Cell membrane damage

The experiment was conducted in triplicate according to a randomized completely block design. After the seeds were sterilized, 50 seeds of each genotype were placed in Petri dishes. Distilled water (5 ml) was added to the Petri dish and subsequently incubated at 22°C for 15 days. At the end of this period, samples approximately 2 cm in length were taken from the middle parts of the first leaves of 20 plants and were subsequently washed with distilled water. Leaf samples were kept at 10°C for 24 hours in 30 ml of 30% polyethylene glycol (PEG, average molecular weight 6000) solution in test tubes for drying application (T) and in 30 ml of distilled water for control application (C). At the end of this period, both the drying and control samples were washed three times with distilled water, 30 ml of distilled water was added again, and the samples were kept in a water bath with a thermostat set to 25°C for 1 hour. Afterwards, the samples were mixed thoroughly, and the electrical conductivity of the solution was measured at 25°C with an EC meter. At the end of this measurement, T1 values were obtained from the dried samples, and C1 values were obtained from the control samples. After the first measurement, all sample tubes were autoclaved at 121°C for 15 minutes under 1 kg cm^{-2} pressure to measure the total electrolyte concentration. Then, the sample tubes were kept in a water bath with a thermostat set to 25°C for 1 hour and mixed thoroughly, and their electrical conductivity was measured again at 25°C with an EC meter. At the end of this measurement, after autoclaving, T2 values were obtained from the dried samples, and C2 values were obtained from the control samples.

Damage % =1 - [((T1:T2)) / (1 - (C1:C2))] × 100

Germination in Different Osmotic Potentials

The experiment was conducted in 3 replications according to a complete randomized block design. After the seeds were sterilized, 50 seeds were placed in petri dishes with osmotic potential conditions of 0 (control), -4 and -6 bar prepared using PEG 6000 solution. Five milliliters of distilled water were added to each Petri dish for control application, and 5 ml of the corresponding PEG solution was added to each Petri dish to osmotic stress application. All Petri dishes were placed in a plant growth cabinet at a temperature of 22°C and kept at that temperature for 10 days. At the end of this period, the root, shoot and coleoptile lengths of 10 plants of each genotype were measured under a stereomicroscope. Seeds with a rootlet length of at least 2 mm were considered germinated and counted, and the germination percentage was calculated. The seed vigor index was calculated by multiplying the embryonic root and shoot lengths sum by the germination percentage (Dhanda et al., 2004).

Seed Vigor Index = (Root length + Shoot length) × germination%

Statistical analysis

In the early drought resistance study, the data obtained under field, laboratory and greenhouse conditions were analyzed using the SAS GLM (SAS Ins., Cary, NC) computer program, and the LSD multiple comparison test was used to compare the means of the varieties. The parameters of seedling survival, coleoptile length, seedling vigor and cell membrane damage after drought were compared among the varieties. For the germination parameters at low water potentials, the varieties and applications were compared, and the applications were evaluated separately in cases where variety × application interactions were important. The relationships between the selection criteria used in the study were examined by correlation analysis. Selection criteria and varieties were grouped principal component analysis. In addition, according to the Rank method, the varieties were grouped in terms of early drought resistance.

3. RESULTS AND DISCUSSION

Seedling survival after drought

In the present study, there were significant differences between barley varieties in terms of seedling survival after drought ($P<0.05$) (Table 2). After drought treatment, the seedling survival rates of the varieties varied between 8.0% and 76.0%, and the average seedling survival rate was 51.4%. While the Scarpia variety had the highest seedling survival rate after drought, the Tarm-92 variety had the lowest seedling survival rate (Table 2). Ozturk et al. (2014) reported that the seedling survival rate after drought was between 18.5% and 51.1% in their study of 64 bread wheat genotypes. Volaire (2003) reported that the seedling survival rate was 100% in orchardgrass variety, as a result of his study investigating the responses of a drought-tolerant orchardgrass and a drought-tolerant and sensitive barley genotype to drought during the seedling period. He also reported that the seedling retention rates of the Tadmor and Plaisant barley varieties were 66% and 69%, respectively, when there was no irrigation for 44 days, and the seedling retention rate of both barley varieties was 4% when there was no irrigation for 53 days; moreover, there was no difference between the barley varieties in terms of the seedling survival rate. On the other hand, Tomar & Kumar (2004) reported that post drought seedling survival, which is a dominant character controlled by a single gene, can be used as a selection criterion to improve drought tolerance in early development. Accordingly, it can be demonstrated that the Scarpia, Hilal, Meriç, Kalaycı-97, Hasat and Erciyes varieties, which are in the first place in terms of seedling survival after drought, can better adapt to places where drought occurs in early development stages.

Coleoptile Length

There were significant differences between barley varieties in terms of coleoptile length ($P<0.05$) (Table 2). The coleoptile length of the varieties ranged from 45.47 mm to 94.60 mm, and the average coleoptile length was 63.76 mm. The Hilal variety had the longest coleoptile, while the Premium variety had the shortest coleoptile length (Table 2). In this experiment, one variety had a coleoptile length greater than 90.1 mm, five varieties had a coleoptile length between 75.01 and 90.00 mm, 39 varieties had a coleoptile length between 60.01 and 75.00 mm, and 29 varieties had a coleoptile length between 45.00 and 60.00 mm (Table 2). In the research conducted by Paynter & Clarke (2010) on 44 summer barley varieties, significant differences were detected between the varieties in terms of coleoptile length. Radford (1987) reported that the results for the coleoptile are in agreement with the results we obtained from our study. Under dry farming conditions, varieties with long coleoptiles can increase yield by showing better emergence. Therefore, it can be demonstrated that the Hilal, Balkan 96 (Igri), Çatalhüyük 2001, Akdane and Başgül varieties, which have long coleoptiles, can better adapt to dry farming areas, with lengths ranging from 60-80 mm in most varieties, while Paynter & Clarke (2010) reported lengths ranging from 39 to 93 mm. Ozturk et al. (2014), on the other hand, reported that the length of the coleoptile varied between 39 and 74 mm in their study of 64 bread wheat genotypes.

Seedling vigor

Differences between barley varieties in terms of specific leaf area and first leaf width, which are elements of seedling vigor, were significant ($P<0.05$) (Table 2). The specific leaf area of the cultivars ranged from 100.1 cm^2 g^{-1} to 255.8 cm^2 g^{-1}, with an average of 151.7 cm^2 g^{-1}. The Olgun variety had the greatest specific leaf area, while the Çetin 2000 variety had the lowest specific leaf area (Table 2). Ozturk et al. (2014) reported that the specific leaf area ranged from 164.4-204.2 cm^2 g^{-1}. Amanullah (2015) reported that the particular leaf areas measured 30, 60 and 90 days after emergence in barley were 710.0 cm^2 g^{-1}, 558.3 cm^2 $g^{-1}$and 699.6 cm^2 g^{-1}, respectively. In our study, lower values were found. This difference may have occurred because the leaf shapes of the varieties used in our study differed. The first leaf width varied between 3.11 and 8.93 mm, with an average of 4.97 mm. The Bolayır variety had the greatest first leaf width, while the Kendal variety had the shortest first leaf width (Table 1). Ozturk et al. (2014) reported that the 1st leaf width ranged between 3.27 and 4.71 mm in their study of 64 bread wheat genotypes. Seedling vigor is defined as the rapid development of leaf area in the early development period (Richards & Lukacs, 2002). Seedling vigor increases the plant growth rate and grain yield by reducing evaporation (López-Castañeda & Richards 1994), increasing the plant's ability to compete with weeds (Coleman et al., 2001) and increasing the efficiency of water and light use under dry farming conditions (Rebetzke et al., 2004). Accordingly, in terms of the elements of seedling vigor; Olgun, Gazda, Atılır, Yercil-147, Ramata and Tokak 157/37 varieties were in first place for specific leaf area, thus Bolayır, Burakbey, Keser, Toprak and Çıldır 02 varieties, were in the first place in terms of first leaf width, and it can better adapt to places where drought occurs in early development periods.

Table 2. Seedling survival after drought, coleoptile length, specific leaf area, first leaf width, and cell membrane damage of barley varieties and variance analysis results of these characteristics

Cultivars	Seedling survival after drought (%)	Coleoptile length (mm)	Specific leaf area (cm^2 g^{-1})	First leaf width (mm)	Cell membrane damage (%)
Akar	60.0	57.62	197.0	4.19	9.18
Akdane	56.0	77.87	150.4	5.21	2.34
Akhisar 98	34.0	66.73	129.9	5.17	3.11
Altıkat	40.0	64.60	119.4	5.85	7.60
Arcanda	52.0	58.27	131.1	3.85	4.14
Atılır	62.0	57.47	223.0	6.06	5.45
Avcı-2002	24.0	61.13	118.7	5.27	5.44
Aydanhanım	54.0	68.07	207.2	4.85	3.26
Balkan 96 (Igri)	64.0	81.00	110.0	5.21	6.23
Barış	62.0	47.13	155.4	5.13	5.92
Başgül	30.0	77.60	201.3	3.81	7.10
Bayrak	64.0	56.27	154.8	4.49	8.72
Beyşehir	64.0	74.00	102.7	5.16	5.14
Bilgi-91	46.0	57.33	123.6	4.67	4.44
Bolayır	70.0	55.47	163.2	8.93	6.32
Burakbey	64.0	68.20	127.0	7.79	9.40
Bülbül 89	58.0	61.00	129.4	5.21	12.70
Cervoise	50.0	57.00	113.4	6.28	7.59
Clarica	40.0	64.20	103.1	4.30	8.82
Cumhuriyet 50	52.0	71.67	104.1	5.83	4.95
Çatalhüyük 2001	60.0	79.00	105.2	6.09	5.13

Table 2. (continued)

Çetin 2000	40.0	64.67	100.1	4.12	3.69
Çıldır 02	54.0	76.87	132.3	6.48	8.62
Çumra 2001	54.0	68.47	101.6	4.90	3.39
Durusu	60.0	69.13	127.8	4.59	4.28
Efes 98	66.0	73.00	118.6	6.10	18.82
Emon	64.0	62.40	114.2	5.66	9.79
Erciyes	70.0	73.47	168.4	4.10	7.62
Erginel 90	64.0	70.00	152.6	4.13	10.62
Escadre	50.0	69.00	136.8	5.30	10.33
Fahrettinbey	54.0	68.87	206.0	4.83	18.98
Fırat	64.0	63.33	166.4	5.06	10.25
Gazda	48.0	57.27	241.5	5.32	20.62
Harman	44.0	62.80	107.0	5.21	8.31
Hasat	70.0	69.80	107.1	4.53	12.57
Hilal	74.0	94.60	123.9	3.95	17.36
İnce-04	52.0	69.07	198.5	4.83	14.86
Kalaycı-97	70.0	72.53	116.8	4.28	10.52
Karatay 94	42.0	72.40	170.6	3.22	9.12
Kendal	34.0	69.00	174.0	3.11	10.84
Keser	52.0	68.07	153.4	7.09	12.15
Kıral-97	58.0	52.73	181.9	5.41	12.11
Konevi	68.0	73.53	200.5	5.79	23.94
Larende	42.0	68.80	158.4	4.24	13.42
Lord	62.0	63.53	118.5	3.86	7.76
Manava	58.0	59.00	104.9	4.29	14.27
Martı	56.0	65.20	126.0	4.82	14.20
Meriç	74.0	63.53	131.1	4.69	14.42
Olgun	54.0	58.93	255.8	4.36	37.79
Oliver	58.0	57.93	205.2	5.20	17.33
Orza 96	64.0	57.67	158.1	5.50	16.59
Özdemir-05	38.0	55.73	166.3	4.94	16.38
Özen	44.0	59.73	162.4	4.65	12.63
Premium	54.0	45.47	123.7	5.50	15.74
Ramata	58.0	67.47	215.2	4.08	7.35
Samyeli	56.0	47.47	153.3	4.08	11.97
Sancak	50.0	62.47	132.0	3.88	19.53
Scarpia	76.0	56.27	123.0	4.12	13.54
Seymen	54.0	61.33	104.6	4.14	12.43
Sladoran	42.0	54.07	192.5	3.28	11.61
Sultan	28.0	63.73	157.0	4.98	17.46
Sur-93	14.0	55.47	174.1	3.86	11.00
Şahin-91	16.0	68.27	205.3	4.51	13.01
Tarm-92	8.0	68.53	112.7	6.22	23.99
Tokak 157/37	10.0	59.26	214.9	5.31	15.17
Toprak	24.0	67.93	175.2	6.63	14.87
Ünver	34.0	63.80	148.4	5.54	15.59
Vamıkhoca 98	38.0	55.40	158.8	5.68	10.50
Yalın	30.0	58.00	155.4	4.51	17.06
Yerçil-147	54.0	50.53	216.8	4.49	18.00
Yesevi 93	66.0	50.40	122.2	4.69	21.32
Yıldız	68.0	54.53	142.0	4.73	21.48
Zeus	58.0	57.60	176.0	4.66	22.44
Zeynel Ağa	60.0	57.40	162.0	4.58	17.17
Mean	51.4	63.76	151.7	4.97	12.00
F value (Variety)	90.23**	9.07**	5993.6**	115.71**	29.67**
LSD (0.05)	6.00	8.02	1.4	0.26	3.21
CV (%)	6.35	9.03	0.7	3.72	19.18

F values marked with ** are significant at the probability level of 0.01.

Cell membrane damage

The cell membrane is one of the first targets of many stresses, including drought, and therefore, the stability of the cell membrane is crucial. Cell membrane stability is considered one of the best physiological indicators of drought stress tolerance (Bandurska, 2004). The difference between barley varieties in terms of cell membrane damage was significant (P<0.05) (Table 2). The cell membrane damage rates of the varieties ranged from 2.34%

to 37.79%, and the mean rate was 12.00%. The Olgun variety had the highest cell membrane damage rate, while the lowest rate of cell membrane damage was found in the Akdane variety (Table 2). Kocheva & Georgiev (2003) reported that the cell membrane damage rate of both varieties was 20% in their study of two barley varieties. Ozturk et al. (2016) reported that cell membrane damage ranged from 0.16-47.26% in their study of 64 bread wheat genotypes. Wang & Huang (2004) reported that barley genotypes with high cell membrane stability (71-80%) performed better under drought conditions. Therefore, the Akdane, Akhisar 98, Aydanhanım, Çumra 2001 and Çetin 2000 varieties, which have a low rate of cell membrane damage, may perform better in drought-prone regions.

Germination at Different Osmotic Potentials

Germination rate

The difference between the varieties and their osmotic potential treatments was significant in terms of the germination rate, and the "variety x treatment" interaction was important due to the different reactions of the varieties to their osmotic potential treatment (Table 3). In the control treatment, the germination rates of the varieties ranged from 89.0% to 100.0%. The highest germination rates were obtained for the Arcanda, Bilgi-91, Burakbey, Çıldır 02, Erciyes and Sultan varieties. The lowest germination rate was observed for Vamıkhoca 98.

In this study, the germination rates of varieties with an osmotic potential of -4 bar ranged from 18.0-100.0%. The Arcanda, Bolayır and Fahrettinbey varieties had the highest germination rates, while the Akhisar 98 variety had the low germination rate (Table 3). In this study, the germination rates of varieties with an osmotic potential of -6 bar ranged between 2.0-100.0%. The Çetin 2000 variety had the highest germination rate, while the Sladoran variety had the lowest. (Table 3). In our study, the germination rate decreased as the osmotic potential increased. The average germination rate, which was 95.96% in the control treatment, decreased to 78.10% at -4 bar osmotic potential and 56.88% at -6 bar osmotic potential. Balkan & Genctan (2013) reported that the germination rate of bread wheat decreased with the treatment of osmotic stress, and the germination rate, which was 96.72% on average in the control treatment, was 86.25% at -0.5 MPa and 27.50% at -1.0 MPa. Oukarroum et al. (2005) reported that the germination rate of barley varieties relative to the average decreases as osmotic stress increases to 100% at 0.0 MPa, 87.8% at -0.5 MPa, 78.5% at -1.0 MPa, 59.7% at -1.5 MPa, and 51.4% at -2.0 MPa. Karami & Sepehri (2017) reported that the germination rate was 82.0% in the control treatment, 68.7% of an osmotic potential of -0.3 bars, and 60.6% in an osmotic potential of -0.6 bar and that the drought created by PEG 6000 caused a decrease in the germination rate of barley. Ozturk et al. (2016), who measured the germination rate of bread wheat genotypes under osmotic stress, reported that the germination percentage of genotypes ranged between 85.3-99.3% in the control treatment and 38.7-90.7% at -5 bar osmotic potential.

Root length

The difference between the varieties and their osmotic potential treatment was significant in terms of root length, and the "variety x treatment" interaction was important due to the different reactions of the varieties to osmotic potential treatments (Table 3). In the control treatment, the lengths of the roots of the varieties ranged from 5.57-17.31 cm. The Kıral-97 variety had the greatest root length, while the Şahin-91 variety had the shortest. In this study, the lengths of the roots of the cultivars with an osmotic potential of -4 bar ranged from 3.00-9.09 cm. The Bolayır variety had the longest root length, while the Hilal variety had the shortest. In this study, the lengths of the embryonal roots of the varieties with an osmotic potential of -6 bar ranged from 0.63-8.13 cm. The Cervoise variety had the longest length of the roots, while the Sladoran variety had the shortest (Table 3). In our study, it was determined that root length decreased as osmotic potential increased. The average shoot length, which was 10.21 cm in the control treatment, decreased to 6.16 cm at -4 bar osmotic potential and 5.27 cm at -6 bar osmotic potential. Balkan & Genctan (2013) reported that the root length, which was 137.71 mm on average in the control treatment, decreased to 83.64 mm at -0.5 MPa and 9.47 mm at -1.0 MPa. Karami & Sepehri (2017) reported that the root length was 9.20 cm in the control treatment, 8.00 cm at an osmotic potential of -0.3 bar, and 6.00 cm at an osmotic potential of -0.6 bar and that the drought created by PEG 6000 caused a decrease in root length in barley. Ozturk et al. (2016), who measured the embryonal root length of bread wheat genotypes under osmotic stress, reported that the embryonal root length of the genotypes ranged between 14.84 and 38.13 cm in the control treatment and between 2.91 and 13.92 cm at an osmotic potential of -5 bar.

Table 3. Germination Rates and Embryonal Root Lengths and Variance Analysis Results of Barley Varieties According to Different Opposing Potential Treatments

Cultivars	Germination Rate				Root Length			
	Control	-4 Bar	-6 Bar	Mean	Control	-4 Bar	-6 Bar	Mean
Akar	98.67	99.00	93.00	96.89	12.57	6.43	6.37	8.46
Akdane	93.33	96.00	92.00	93.78	12.04	7.80	7.03	8.96
Akhisar 98	94.67	18.00	7.00	39.89	11.81	3.86	7.84	7.84
Altıkat	96.00	87.00	96.00	93.00	9.29	5.57	5.93	6.93
Arcanda	100.00	100.00	96.00	98.67	11.44	6.27	7.47	8.39
Atılır	93.33	55.00	77.00	75.11	10.51	3.87	5.27	6.55
Avcı-2002	97.33	96.00	99.00	97.44	10.31	6.19	6.57	7.69
Aydanhanım	97.33	87.00	71.00	85.11	11.59	6.17	5.83	7.86
Balkan 96 (Igri)	97.33	96.00	97.00	96.78	9.43	7.97	6.83	8.08
Barış	94.67	96.00	87.00	92.56	11.21	7.61	7.20	8.67
Başgül	96.00	94.67	60.00	83.56	10.84	7.03	6.37	8.08
Bayrak	97.33	18.67	49.00	55.00	14.12	5.73	6.93	8.93
Beyşehir	98.67	94.67	92.00	95.11	12.59	6.51	6.13	8.41
Bilgi-91	100.00	88.00	93.00	93.67	13.19	5.75	7.03	8.66
Bolayır	98.67	100.00	97.00	98.56	9.12	9.03	7.33	8.50
Burakbey	100.00	93.33	84.00	92.44	10.24	5.56	4.93	6.91
Bülbül 89	94.67	96.00	91.00	93.89	11.18	5.27	5.20	7.22
Cervoise	94.67	91.00	73.00	86.22	8.71	7.57	8.13	8.14
Clarica	97.33	95.00	82.67	91.67	12.50	7.43	7.60	9.18
Cumhuriyet 50	96.00	99.00	80.00	91.67	11.57	6.77	7.20	8.51
Çatalhüyük 2001	97.33	97.00	99.00	97.78	11.95	7.13	7.40	8.83
Çetin 2000	93.33	96.00	100.00	96.44	12.08	7.67	6.47	8.74
Çıldır 02	100.00	98.00	88.00	95.33	12.57	7.03	7.10	8.90
Çumra 2001	93.33	92.00	87.00	90.78	9.21	5.17	6.73	7.04
Durusu	93.33	97.00	97.00	95.78	11.31	7.40	7.60	8.77
Efes 98	96.00	72.00	77.00	81.67	12.67	5.33	4.73	7.58
Emon	98.67	55.00	61.00	71.56	12.11	5.00	5.40	7.50
Erciyes	100.00	34.00	14.00	49.33	12.59	6.33	4.72	7.88
Erginel 90	98.67	82.00	91.00	90.56	8.69	5.17	6.43	6.76
Escadre	98.67	84.00	57.00	79.89	14.97	6.33	5.57	8.96
Fahrettinbey	98.67	100.00	88.00	95.56	5.87	5.33	5.10	5.44
Fırat	98.67	60.00	80.00	79.56	11.23	3.83	5.17	6.74
Gazda	93.00	60.00	68.00	73.67	9.72	5.50	3.83	6.35
Harman	97.00	60.00	90.00	82.33	12.09	6.83	5.57	8.16
Hasat	92.00	56.00	68.00	72.00	11.54	5.83	6.54	7.97
Hilal	94.00	49.00	6.00	49.67	9.01	3.00	1.58	4.53
İnce-04	95.00	45.00	81.33	73.78	11.50	7.00	6.27	8.26
Kalaycı-97	93.00	68.00	24.00	61.67	12.52	6.50	2.53	7.18
Karatay 94	98.00	51.00	64.00	71.00	13.97	5.17	5.13	8.09
Kendal	97.00	61.00	51.00	69.67	13.95	5.50	4.90	8.12
Keser	96.00	59.00	65.00	73.33	14.09	7.33	5.40	8.94
Kıral-97	92.00	84.00	63.00	79.67	17.31	6.67	5.37	9.78
Konevi	98.00	60.00	81.00	79.67	11.21	7.33	6.77	8.44
Larende	96.00	93.00	51.00	80.00	11.93	6.33	4.90	7.72
Lord	97.00	82.00	88.00	89.00	12.83	8.17	6.23	9.08
Manava	94.00	78.00	27.00	66.33	12.35	6.17	3.54	7.35
Martı	97.00	82.00	85.00	88.00	11.03	7.67	6.57	8.42
Meriç	96.00	87.00	82.67	88.56	10.19	6.17	5.40	7.25
Olgun	96.00	67.00	57.00	73.33	9.20	6.83	7.20	7.74
Oliver	92.00	74.00	88.00	84.67	8.19	6.00	6.27	6.82
Orza 96	96.00	82.67	26.67	68.44	7.22	5.83	3.92	5.66
Özdemir-05	95.00	76.00	49.33	73.44	7.77	6.60	4.87	6.41
Özen	92.00	87.33	53.33	77.56	9.01	5.87	3.63	6.17
Premium	94.00	94.67	4.00	64.22	8.51	5.87	2.17	5.52
Ramata	95.00	96.00	21.33	70.78	8.28	7.33	3.41	6.34
Samyeli	96.00	85.33	6.67	62.67	7.64	5.47	3.06	5.39

Table 3. (continued)

Sancak	94.00	61.33	32.00	62.44	7.97	6.40	4.73	6.37
Scarpia	94.00	80.00	10.67	61.56	6.57	6.40	4.71	5.89
Seymen	89.33	77.33	6.67	57.78	9.37	6.00	3.25	6.21
Sladoran	94.00	81.33	2.00	59.11	6.97	5.57	0.63	4.39
Sultan	100.00	93.33	33.33	75.56	6.53	5.17	4.40	5.37
Sur-93	94.67	88.00	25.33	69.33	7.07	7.70	4.97	6.58
Şahin-91	92.00	82.67	28.00	67.56	5.57	4.90	3.30	4.59
Tarm-92	94.67	88.00	32.00	71.56	6.70	6.07	4.50	5.76
Tokak 157/37	92.00	98.00	12.00	67.33	10.37	6.87	4.47	7.24
Toprak	94.67	88.00	21.00	67.89	6.37	5.97	4.47	5.60
Ünver	96.00	60.00	8.00	54.67	5.63	4.43	3.00	4.36
Vamıkhoca 98	89.00	31.00	16.00	45.33	8.77	6.60	3.52	6.30
Yalın	98.00	85.00	44.00	75.67	7.80	3.63	2.03	4.49
Yerçil-147	94.67	32.00	10.00	45.56	6.13	5.87	4.25	5.42
Yesevi 93	93.33	64.00	10.00	55.78	8.20	5.20	6.39	6.60
Yıldız	97.00	88.00	29.00	71.33	8.90	6.43	3.90	6.41
Zeus	94.67	93.00	16.00	67.89	6.10	5.60	3.01	4.90
Zeynel Ağa	93.33	83.00	16.00	64.11	9.87	6.27	3.94	6.69
Mean	95.66	78.10	56.88	76.88	10.21	6.16	5.27	7.22
F value (Variety)	2.99**	17.14**	41.82**	39.30**	10.3**	5.87**	14.69**	16.36**
F value (Treatment)	-	-	-	1611.12**	-	-	-	1449.43**
F value (V x T)	-	-	-	23.43**	-	-	-	6.83**
LSD (0.05)	4.10	13.71	14.11	6.67	2.21	1.29	1.19	0.94
CV (%)	3.07	12.60	17.80	10.83	15.56	15.01	16.25	16.23

F values marked with ** are significant at the probability level of 0.01.

Shoot length

The difference between the varieties and their osmotic potential treatment was significant in terms of shoot length, and the "variety × treatment" interaction was important due to the different reactions of the varieties to osmotic potential treatment (Table 4). In the control treatment, the shoot lengths of the varieties varied between 8.92 and 17.31 cm. The Kıral-97 variety had the longest shoot, while the Özen variety had the shortest. In this study, the shoot lengths of the varieties with an osmotic potential of -4 bar ranged between 2.88 and 10.20 cm. The Bolayır variety had the longest shoot, while the Yalın variety had the shortest. The shoot lengths of the varieties with an osmotic potential of -6 bar ranged between 0.50 and 9.17 cm. The Durusu variety had the longest shoot length, while the Sladoran variety had the shortest shoot length (Table 4). In our study, the shoot length decreased as the osmotic potential increased. The average shoot length, which was 12.64 cm in the control treatment, decreased to 6.04 cm at -4 bar osmotic potential and to 4.31 cm at -6 bar osmotic potential. Szira et al. (2008) reported that osmotic stress caused a decrease in shoot length and that the average shoot length was 28.89 cm in the control treatment and 18.16 cm in the stress treatment. Balkan & Genctan (2013) reported that the average shoot length, which was 136.76 mm in the control treatment, decreased to 114.92 mm at -0.5 MPa and reached -1.0 MPa, but there was no seedling development. Karami & Sepehri (2017) reported that the shoot length was 10.22 cm, 8.0 cm at -0.3 bar osmotic potential and 6.39 cm at -0.6 bar osmotic potential in the control treatment and that the drought created by PEG 6000 caused a decrease in shoot length in barley. Ozturk et al. (2016) who measured the shoot length of bread wheat genotypes under osmotic stress, reported that the shoot length ranged between 7.99-19.55 cm in the control treatment and 0.07-4.73 cm at -5 bar osmotic potential according to the genotype.

Seed vigor index

The difference between the varieties and their osmotic potential treatments was significant in terms of the seed vigor index, and the "variety × treatment" interaction was important due to the different reactions of the varieties to the osmotic potential treatments (Table 4). In the control treatment, the seed vigor indices of the varieties ranged from 1520.6 to 3198.0. The Kıral-97 variety had the highest seed vigor index, while the Şahin-91 variety had the lowest seed vigor index. The seed vigor indices of the varieties with an osmotic potential of -4 bar ranged from 202.5 to 1923.3. The Bolayır variety had the highest seed vigor index, while the Akhisar 98 variety had the lowest seed vigor index. In this study, the seed vigor indices of the varieties with an osmotic potential of -6 bar ranged from 9.0 to 1623.9. The Durusu variety had the highest seed vigor index, while the Sladoran variety had the lowest seed vigor index (Table 4). In our study, the seed vigor index decreased as the osmotic potential increased. The average seed vigor index, which was 2186.5 in the control treatment, decreased to 984.0 at -4 bar osmotic potential and to 648.7 at -6 bar osmotic potential. Dhanda et al. (2004) reported that the seed vigor index varies between 1313.1-3400.3 under normal conditions and between 146.2-585.6 under arid conditions to determine the differences in various characteristics of wheat under osmotic stress conditions and the interactions between them. Karami & Sepehri (2017) reported that the seed vigor index was 1558.10 in the control treatment, 1154.21 at an osmotic potential of -0.3 bar, and 802.59 at an osmotic potential of -0.6 bar and that the drought created by PEG 6000 caused a decrease in the seed vigor index in barley. Ozturk et al. (2016), who measured the seed vigor index of bread wheat genotypes under osmotic stress, reported that the seed vigor index of the genotypes ranged between 2331.1-5028.2 in the control treatment and 210.1-1666.8 at an osmotic potential of -5 bar.

Table 4. Shoot Lengths and Seed Vigor Indices and Variance Analysis Results of Barley Varieties According to Different Osmotic Potential Treatments

Cultivars	Shoot Length				Seed Vigor Index			
	Control	-4 Bar	-6 Bar	Mean	Control	-4 Bar	-6 Bar	Mean
Akar	11.44	6.73	6.13	8.10	2368.4	1303.4	1162.7	1611.5
Akdane	14.22	7.05	6.33	9.20	2448.8	1425.9	1228.7	1701.2
Akhisar 98	15.47	4.45	6.65	8.86	2584.3	202.5	108.9	965.2
Altıkat	12.67	5.95	6.10	8.24	2108.1	998.7	1155.2	1420.7
Arcanda	13.11	7.60	7.70	9.47	2454.7	1386.7	1455.0	1765.4
Atılır	12.57	3.68	4.37	6.87	2150.4	569.3	747.2	1155.6
Avcı-2002	12.70	8.83	9.03	10.19	2236.8	1442.6	1543.4	1740.9
Aydanhanım	13.51	5.36	4.73	7.87	2441.5	1001.5	789.3	1410.8
Balkan 96 (Igri)	11.87	9.87	8.05	9.93	2073.3	1712.7	1448.6	1744.9
Barış	14.15	8.09	6.30	9.51	2400.7	1506.6	1172.2	1693.2
Başgül	13.35	5.65	4.21	7.74	2322.6	1203.1	671.4	1399.0
Bayrak	13.73	5.25	5.47	8.15	2715.5	209.0	609.7	1178.0
Beyşehir	11.35	8.07	6.17	8.53	2366.3	1381.2	1134.6	1627.4
Bilgi-91	10.47	6.03	7.40	7.96	2366.0	1035.3	1343.7	1581.6
Bolayır	9.60	10.20	7.97	9.26	1848.9	1923.3	1485.1	1752.4
Burakbey	11.51	6.25	6.37	8.04	2174.7	1102.5	949.2	1408.8
Bülbül 89	12.61	7.01	6.20	8.61	2253.0	1178.5	1036.1	1489.2
Cervoise	14.41	7.49	8.27	10.06	2185.6	1368.8	1208.6	1587.7
Clarica	14.84	5.72	6.77	9.11	2667.7	1249.2	1185.6	1700.8
Cumhuriyet 50	12.89	7.68	7.47	9.34	2348.9	1429.0	1206.3	1661.4
Çatalhüyük 2001	14.09	7.91	8.90	10.30	2532.1	1456.2	1615.2	1867.8
Çetin 2000	12.99	8.42	7.50	9.64	2340.4	1544.9	1396.7	1760.7
Çıldır 02	12.65	8.53	7.03	9.40	2522.0	1525.0	1243.7	1763.6
Çumra 2001	12.85	7.68	8.47	9.66	2058.2	1182.0	1321.8	1520.7
Durusu	13.07	9.40	9.17	10.54	2276.0	1628.8	1623.9	1842.9
Efes 98	13.53	6.25	3.60	7.80	2515.2	927.6	642.6	1361.8
Emon	13.46	3.74	3.91	7.04	2523.7	513.6	635.9	1224.4
Erciyes	13.99	6.99	1.90	7.63	2658.7	455.4	93.0	1069.0
Erginel 90	10.93	6.62	5.63	7.73	1937.4	971.4	1095.7	1334.8
Escadre	12.20	5.75	3.95	7.30	2681.1	1032.0	558.8	1424.0
Fahrettinbey	11.01	7.31	4.07	7.46	1668.8	1264.7	807.2	1246.9
Fırat	11.68	4.83	4.23	6.91	2260.9	525.5	753.7	1180.0
Gazda	9.72	5.22	2.97	5.97	1811.4	654.5	461.0	975.7
Harman	12.09	4.40	4.90	7.13	2347.7	702.3	948.4	1332.8
Hasat	11.54	6.33	5.93	7.94	2120.0	666.4	874.2	1220.2
Hilal	9.01	3.63	2.17	4.94	1695.2	326.1	30.0	683.8
İnce-04	11.50	3.31	4.67	6.49	2185.0	498.4	889.4	1190.9
Kalaycı-97	12.52	5.23	2.30	6.68	2328.0	812.8	116.3	1085.7
Karatay 94	13.97	3.73	2.60	6.77	2736.6	474.0	526.0	1245.5
Kendal	13.95	4.23	2.33	6.84	2709.2	609.9	380.6	1233.2
Keser	14.09	4.87	4.13	7.70	2705.9	722.9	619.1	1349.3
Kıral-97	17.31	7.57	3.93	9.61	3198.0	1202.6	584.5	1661.7
Konevi	11.21	5.20	5.53	7.32	2198.1	764.7	1003.0	1321.9
Larende	11.93	5.79	2.33	6.69	2290.3	1127.2	380.6	1266.1
Lord	12.83	4.66	4.77	7.42	2489.5	1046.6	967.5	1501.2
Manava	12.35	4.29	2.23	6.29	2319.5	815.8	160.0	1098.4

Table 4. (continued)

Martı	14.47	6.83	3.93	8.41	2471.3	1190.8	895.6	1519.2
Meriç	10.19	5.74	3.90	6.61	1957.1	1036.3	771.4	1254.9
Olgun	11.54	5.52	4.80	7.29	1991.0	828.4	713.7	1177.7
Oliver	10.81	5.59	4.75	7.05	1747.3	857.1	970.9	1191.7
Orza 96	10.75	5.20	2.03	6.00	1722.7	917.8	172.2	937.6
Özdemir-05	9.53	5.50	2.53	5.86	1643.9	923.1	383.5	983.5
Özen	8.92	5.73	2.40	5.68	1648.8	1013.2	322.2	994.7
Premium	11.55	6.57	1.50	6.54	1886.7	1176.8	21.7	1028.4
Ramata	12.77	7.10	2.22	7.36	2000.3	1389.6	129.8	1173.2
Samyeli	12.52	4.77	1.00	6.10	1932.1	876.7	37.3	948.7
Sancak	13.92	6.63	2.40	7.65	2056.4	805.2	232.1	1031.2
Scarpia	12.93	6.03	2.33	7.10	1831.2	997.9	72.8	967.3
Seymen	14.17	5.53	1.58	7.09	2102.4	891.5	42.1	1012.0
Sladoran	15.60	5.75	0.50	7.28	2122.0	924.1	9.0	1018.4
Sultan	13.20	6.93	3.63	7.92	1973.3	1133.5	268.9	1125.3
Sur-93	12.37	5.57	2.62	6.85	1832.7	1167.1	186.1	1062.0
Şahin-91	10.93	6.57	2.53	6.68	1520.6	958.6	164.9	881.4
Tarm-92	14.57	5.20	2.13	7.30	2011.9	995.9	212.3	1073.3
Tokak 157/37	15.79	6.63	2.07	8.16	2408.2	1323.2	80.1	1270.5
Toprak	14.17	5.90	2.30	7.46	1947.7	1044.3	142.6	1044.9
Ünver	13.03	3.17	1.75	5.98	1792.0	458.6	38.0	762.9
Vamıkhoca 98	13.43	7.82	1.90	7.72	1969.0	449.8	86.2	835.0
Yalın	12.70	2.88	1.83	5.80	2008.6	403.2	170.6	860.8
Yerçil-147	12.83	4.73	2.50	6.69	1796.9	353.9	66.3	739.0
Yesevi 93	12.63	3.70	3.44	6.59	1942.3	570.0	99.5	870.6
Yıldız	11.70	5.10	1.75	6.18	1995.6	1019.5	163.8	1059.6
Zeus	12.17	4.73	1.84	6.25	1729.6	962.1	77.4	923.0
Zeynel Ağa	13.01	6.60	2.23	7.28	2137.6	1068.7	100.2	1102.2
Mean	12.64	6.04	4.31	7.66	2186.5	984.0	648.7	1273.1
F value (Variety)	5.55**	9.00**	27.51**	15.84**	6.62**	16.45	39.13**	26.59**
F value (Treatment)	-	-	-	4636.18**	-	-	-	4669.70**
F value (V x T)	-	-	-	8.68**	-	-	-	10.59**
LSD (0.05)	1.89	1.47	1.21	0.89	356.1	255.7	222.1	163.2
CV (%)	10.72	17.41	20.14	14.48	11.69	18.64	24.57	15.99

F values marked with ** are significant at the probability level of 0.01.

Correlations between early drought selection criteria

The correlation coefficients between the early selection criteria are given in Table 5. According to the correlation table, there was a positive and significant correlation between coleoptile length and germination rate (r=0.261*), shoot length (r=0.246*) and seed vigor index (r=0.252*); a positive and highly significant correlation between specific leaf area and cell membrane damage (r=0.367**); a negative and highly significant correlation between specific leaf area and shoot length (r=-0.345**); a negative and significant correlation between specific leaf area and seed vigor index (r=-0.278*); a positive and significant correlation between first leaf width and germination rate (r=0.263*), root length (r=0.228*) and seed vigor index (r=0.278*); a positive and highly significant correlation between first leaf width and shoot length (r=0.325**); a negative and highly significant correlation between cell membrane damage and germination rate (r=-0.410**), root length (r=-0.387**), shoot length (r=-0.547**) and the seed vigor index (r=-0.507**); a positive and highly significant correlation between germination rate and root length (r=0.717**), shoot length (r=0.807**) and the seed vigor index (r=0.943**); a positive and highly significant correlation between root length and shoot length (r=0.849**) and the seed vigor index (r=0.797**); a positive and highly significant correlation between shoot length and the seed vigor index (r=0.932**).

Table 5. Simple Correlation Coefficients between Early Drought Selection Criteria

	SSAD	CL	SLA	LW	CMD	GR	RL	SL
CL	0.071							
SLA	-0.167	-0.197						
LW	0.054	0.017	-0.108					
CMD	-0.027	-0.201	**0.367****	-0.049				
GR	0.197	**0.261***	-0.174	**0.263***	**-0.410****			
RL	0.123	0,157	-0.189	**0.228***	**-0.387****	**0.717****		
SL	0.162	**0.246***	**-0.345****	**0.325****	**-0.547****	**0.807****	**0.849****	
SVI	0.200	**0.252***	**-0.278***	**0.278***	**-0.507****	**0.943****	**0.797****	**0.932****

SSAD Seedling survival after drought, CL Coleoptile length, SLA specific leaf area, LW first leaf width, CMD cell membrane damage, GR germination rate at -6 bar, RL root length at -6 bar, SL -6 bar shoot length, SVI: Seed vigor index at -6 bar

Grouping of Selection Criteria and Barley Varieties by Principal Component Analysis

The seed vigor index, shoot length, root length and germination rate selection criteria under early drought conditions were explained by principal component analysis; 46.4% of the total variance was explained by the first basic component, 59.1% of the first two basic components, and 70.2% of the first three basic components (Table 6). The highest loads for the first basic component are determined in the SVI, SL, GR and RL criteria respectively. The SVI, SL, GR and RL criteria were far from the origin of the first basic component, in the positive region and have a high correlation. They were negatively related to the SLA and CMD criteria (Figure 1). Cervoise, Avcı-2002, Bilgi-91 and Bolayır varieties, which are located in the far and positive region of origin in terms of the SVI, GR, SL and RL criteria, can be considered resistant in terms of these criteria (Figure 1). The highest loads in terms of the second component are determined in the criteria of SLA, LW, CMD, RL, GR, SVI and SL (Table 6).

Table 6. Eigenvalues of Principal Components Obtained from Early Drought Conditions Analysis Results and Selection Criteria

Selection Criteria	Principal Components					
	1	2	3	4	5	6
SSAD	0.116	-0.194	0.863	0.342	-0.140	-0.239
CL	0.164	-0.488	-0.107	0.209	0.815	-0.041
SLA	-0.197	0.599	-0.159	0.512	0.207	-0.500
LW	0.169	0.390	0.330	-0.691	0.400	-0.254
CMD	-0.299	0.343	0.316	0.163	0.313	0.739
GR	0.436	0.171	-0.008	0.203	0.057	0.050
RL	0.415	0.215	-0.082	0.130	-0.090	0.259
SL	0.468	0.082	-0.051	-0.012	-0.054	0.085
SVI	0.471	0.117	-0.028	0.118	-0.028	0.066
Eigen value	4.1778	1.1348	1.0029	0.8981	0.8452	0.5173
Variance (%)	46.4	12.6	11.1	10.0	9.4	5.8
Total variance (%)	46.4	59.1	70.2	80.2	89.5	95.3

SSAD Seedling survival after drought, CL Coleoptile length, SLA specific leaf area, LW first leaf width, CMD cell membrane damage, GR germination rate at -6 bar, RL root length at -6 bar, SL -6 bar shoot length, SVI: Seed vigor index at -6 bar

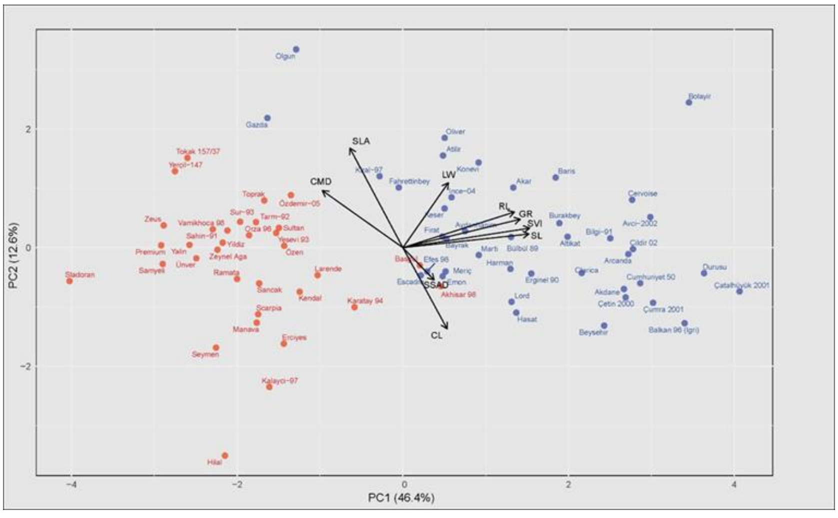

Figure 1. Biplot analysis of selection criteria (A) and cultivars (B) based on early drought conditions averages

The mean rank and standard deviation of the mean rank and rank sum values of the 74 barley varieties used in this study, calculated over the six selection criteria listed in Table 7. The rank sum values of the varieties varied between 17.8 and 62.8. These values were divided into four groups according to the scale in Table 6: resistant, medium resistant, medium sensitive and sensitive. Accordingly, the Konevi, İnce-04 and Fahretinbey varieties were included in the resistant group of 26 varieties of medium resistant, with a rank total ranging from 30.1-41.0. Thirty-two variety with rank totals ranging from 41.1 to 52.1 were determined to be moderately sensitive, and 13 varieties with rank totals ranging from 52.2 to 62.8 were determined to be sensitive.

Table 7. Mean Rank, Standard Deviation of the Average Rank and Rank Sum Values of Barley Varieties and Drought Resistance Groups According to Rank Totals

Cultivars	Rank means	Standard deviation	Rank Sum	Resistant (17,8-29,0)	Medium resistant (29,1-40,3)	Medium sensitive (40,4-51,6)	Sensitive (51,7-62,8)
Akar	21.2	15.0	36.2	Konevi	Oliver	Altıkat	Ünver
Akdane	19.1	19.7	38.8	İnce-04	Erginel 90	Şahin-91	Kalaycı-97
Akhisar 98	32.4	22.1	54.6	Fahrettinbey	Çıldır 02	Çatalhüyük 2001	Manava
Altıkat	23.9	17.2	41.1		Olgun	Özdemir-05	Vamıkhoca 98
Arcanda	23.3	21.4	44.8		Fırat	Kıral-97	Yerçil-147
Atılır	24.3	18.7	43.0		Keser	Toprak	Akhisar 98
Avcı-2002	22.9	21.7	44.6		Martı	Sancak	Yesevi 93
Aydanhanım	23.8	16.2	40.0		Meriç	Atılır	Scarpia
Balkan 96 (Igri)	18.2	22.7	40.9		Bülbül 89	Lord	Hilal
Barış	24.4	21.1	45.5		Larende	Avcı-2002	Samyeli
Başgül	24.1	13.7	37.8		Akar	Bayrak	Seymen
Bayrak	28.8	15.9	44.7		Burakbey	Arcanda	Sladoran
Beyşehir	23.6	23.2	46.7		Kendal	Emon	Premium
Bilgi-91	25.3	21.8	47.1		Escadre	Cumhuriyet 50	
Bolayır	17.4	21.9	39.4		Başgül	Clarica	
Burakbey	21.7	15.1	36.8		Karatay 94	Barış	
Bülbül 89	22.7	13.1	35.8		Sultan	Orza 96	
Cervoise	24.1	23.1	47.2		Efes 98	Harman	
Clarica	25.2	20.3	45.5		Durusu	Yalın	
Cumhuriyet 50	22.4	23.0	45.5		Akdane	Sur-93	
Çatalhüyük 2001	16.8	25.0	41.8		Bolayır	Beyşehir	
Çetin 2000	26.2	24.6	50.8		Özen	Bilgi-91	
Çıldır 02	16.3	15.6	31.9		Aydanhanım	Cervoise	
Çumra 2001	24.1	24.6	48.7		Hasat	Tarm-92	
Durusu	17.4	21.2	38.7		Gazda	Çumra 2001	
Efes 98	21.8	16.9	38.6		Balkan 96 (Igri)	Ramata	
Emon	29.1	16.3	45.4			Tokak 157/37	
Erciyes	31.1	19.1	50.3			Zeynel Ağa	
Erginel 90	19.7	11.1	30.8			Erciyes	
Escadre	26.3	11.3	37.7			Çetin 2000	
Fahrettinbey	17.0	8.2	25.2			Yıldız	
Fırat	23.9	10.3	34.2			Zeus	
Gazda	24.0	16.8	40.8				
Harman	28.0	17.8	45.8				
Hasat	23.4	16.8	40.2				
Hilal	32.6	24.1	56.6				
İnce-04	17.8	5.1	22.8				
Kalaycı-97	33.9	19.0	52.9				
Karatay 94	27.0	10.8	37.8				
Kendal	28.6	9.1	37.6				
Keser	23.3	10.9	34.2				
Kıral-97	26.8	15.6	42.4				
Konevi	11.4	6.3	17.8				
Larende	27.6	8.4	36.0				
Lord	27.1	16.7	43.9				
Manava	36.3	17.1	53.5				
Martı	22.8	11.7	34.5				
Meriç	23.7	11.9	35.5				
Olgun	18.8	14.9	33.7				
Oliver	18.2	12.0	30.2				
Orza 96	30.0	15.7	45.7				
Özdemir-05	29.3	12.9	42.2				

Table 7. (continued)

Özen	30.3	9.6	39.9
Premium	40.4	22.4	62.8
Ramata	31.6	17.3	48.8
Samyeli	40.9	18.4	59.3
Sancak	29.9	12.8	42.7
Scarpia	36.9	19.6	56.5
Seymen	40.9	18.6	59.5
Sladoran	41.0	19.2	60.2
Sultan	27.9	10.1	38.0
Sur-93	34.1	12.1	46.2
Şahin-91	29.0	12.5	41.5
Tarm-92	29.1	18.9	48.0
Tokak 157/37	31.3	17.7	49.0
Toprak	27.8	14.8	42.6
Ünver	35.1	17.5	52.6
Vamıkhoca 98	36.8	16.7	53.5
Yalın	33.6	12.6	46.2
Yerçil-147	31.8	22.5	54.3
Yesevi 93	33.1	23.0	56.1
Yıldız	31.7	19.2	50.8
Zeus	31.8	20.3	52.1
Zeynel Ağa	32.3	17.0	49.4

4. CONCLUSION

Drought is the most important abiotic stress that limits agricultural production and significantly threatens the food supply worldwide. Drought resistance is a complex trait that is a common function of numerous morphological, physiological and biochemical characteristics. Drought-tolerant varieties are defined as those that can produce relatively high yields under drought conditions. The 74 barley varieties used in this study were divided into four groups, resistant, medium resistant, medium sensitive and sensitive, according to the rank total values calculated over 6 selection criteria. Accordingly, the Konevi, İnce-04 and Fahrettinbey varieties were determined to be resistant to early drought, 26 variety of medium hardiness with a rank total ranging from 29.1 to 40.3 were detected, 32 varieties with a rank total between 40.4 and 51.6 were determined to be moderately sensitive, and 13 variety with a rank total between 51.7 and 62.8 were determined to be sensitive. The Konevi, İnce-04 and Fahrettinbey varieties can be used as parents in drought resistance breeding and may also provide advantages in areas where early drought occurs.

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DISCLOSURE STATEMENT

The authors declare that they have no known competing personal relationships that could have appeared to influence the work reported in this paper.

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