

THE EFFECTS OF WATER STRESS ON GRAIN YIELD AND YIELD COMPONENTS IN BREAD WHEAT

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Abstract

The study was carried out with 24 wheat genotypes at different drought levels. The 24 genotypes used in the study were determined based on data from 45 genotypes at drought levels created with PEG. The experiment was carried out in plastic tubes 30 cm wide × 70 cm high. In the study, plant height, spike length, number of spikelets per spike, number of grains per spike, grain weight per spike, root length and root weight were investigated.

When the plants were grown in tubes with 100%, 75%, 50%, and 25% field capacity, the highest values for all properties, except plant height, were obtained in plants with 100% field capacity. According to the data obtained, Bora, NKU Ergene, Enola and Rumeli were least affected by drought, while LG 59, Adelaide and Kavlıca genotypes were most affected by drought.

Root length increased with drought and the longest roots were at 25% field capacity, which was the highest level of drought. The root weight was highest at 100% field capacity and lowest at 25% field capacity. Spike length, number of spikelets per spike, number of grains per spike, and grain weight per spike decreased significantly as the level of drought increased.

Key words: wheat, yield, non-stress, stress, grain yield

Introduction. Drought, one of the environmental stress factors, is the most important factor limiting crop production in rain-based agricultural areas in most of the world. Appropriate criteria should be developed for genotype evaluation to better understand how and in what way drought affects wheat yield in different

development stages. Drought stress can be simply defined as a shortage of water, which induces dramatic morphological, biochemical, physiological, and molecular changes. All of these changes reduce plant growth and crop production. Wheat (*Triticum aestivum* L.) is among the most important cereal crops and large portions of the human population in many parts of the world depend on wheat as a source of food. Plant breeding research is very important to produce new wheat cultivars with a high degree of drought tolerance. In addition, to improve drought tolerance, plant breeders must improve grain yield combined with high tolerance to drought.

Drought is expected to become more frequent, longer, and more severe in many parts of the world in the twenty-first century as a result of global warming and other climate-change-driving factors which will reduce wheat production in the future [1]. As a result, actions to increase wheat production must be implemented as soon as possible, because the primary crop yield could decrease by more than half owing to a lack of irrigation water [2]. The introduction of new wheat genotypes with greater yield potential and enhanced drought tolerance is the most acceptable strategy for improving wheat production [3]. The response of each genotype to drought varies depending on the stage of development. Drought in the early stages of development decreases plant height, leaf area and number of fertile tillers; drought between stem elongation and spike formation decreases the number of fertile flowers in the spikelet, fertile spikelet in the spike and fertile spike. Drought in the heading stage decreases the number of grains in the spike and drought after flowering causes weight loss in the grain.

Plants are exposed to the ever-changing nature of the environment and are often exposed to abiotic stresses contributing to plant malnutrition, such as water shortages, salt, excessive light, nutrient imbalance, and low/high temperatures [4]. Among these abiotic limitations, drought stress is thoroughly researched, owing to this being the major obstacle to crop production in many arid and semi-arid regions worldwide [5].

In the event of water shortages, a quick response by plants is needed, so water shortage alters all biological functions at the level of the whole plant. Plants need to innovate techniques that are beneficial for absorbing water with their roots and lifting cell turgor; that is, to avoid water loss [6]. Plants that can withstand drought stress for a long time and retain their strength and yield epitomize the tolerant genotypes [7]. For instance, amongst the morpho-physiological features, a healthy and active root guarantees in-depth soil exploration by the plant, thereby increasing the potential for water accessibility [8]. Relative water content is a very useful indicator for the rapid evaluation of drought tolerance in wheat breeding, especially at seedling stage [9].

The aim of this study was to determine the drought resistance levels of different genotypes by examining the changes in different characteristics in bread wheat genotypes.

Material and methods. The study was carried out in the 2021 growing season with 24 wheat genotypes at different drought levels. These 24 genotypes were identified from among 45 genotypes as a result of a drought study created with PEG. Plastic tubes with a width of 30 cm and a height of 70 cm were used in the experiment (Fig. 1). Each tube was filled with 20 kg soil samples taken from the Field Crops Experiment Area of Tekirdağ Faculty of Agriculture. In order to determine the field capacity of the soil, the tubes filled with 20 kg of soil were completely saturated with water and left until water infiltration stopped (approximately 2 days). Afterwards, the tubes were weighed again and the field capacity was determined. After the soil samples were completely saturated with water, they were weighed when infiltration was completed and dried in an oven at 105 °C for 24 h in the Field Crops Department. The water holding ability of the soil was determined by using the wet and dry weight values. In addition, the required amount of water in the tubes was calculated for 25%, 50%, 75%, and 100% field capacity.

It was determined that 25% drought level required 19.515 kg water, 50% drought level 20.450 kg, 75% drought level 21.385 kg and 100% drought level 22.320 kg. For each application, a non-planted tube was prepared and the tubes were weighed every week to add water reduction in the tubes. Necessary fertilizer calculations were made for each tube, and 0.9 g (20.20.0) fertilizer was administered per tube at the beginning of planting, while 0.85 g (25 kg/da) urea and

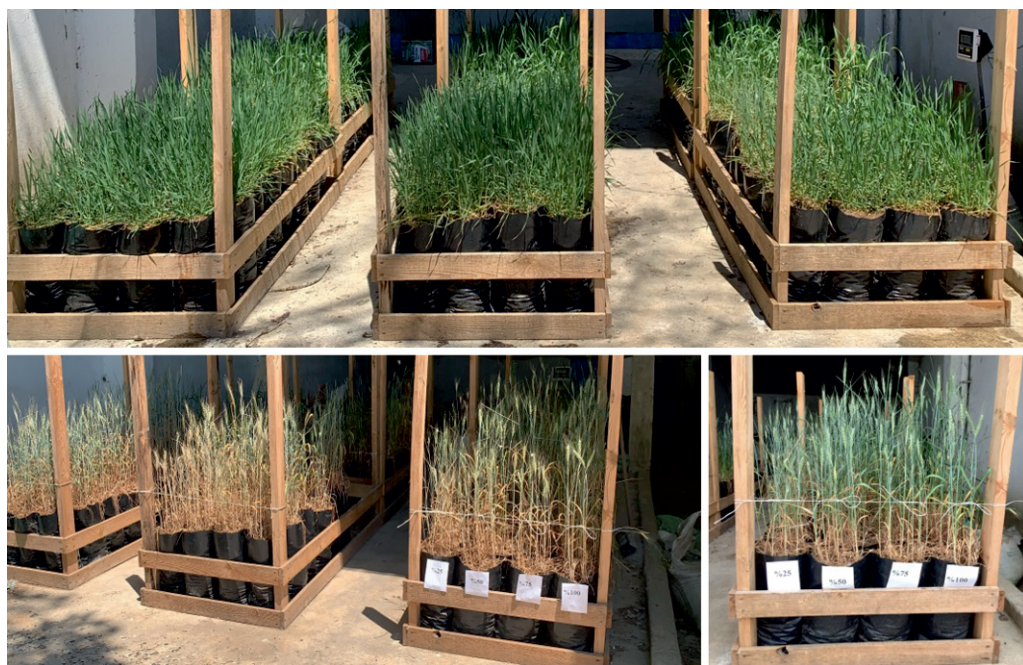


Fig. 1. Tubes used in the experiment and plant growth in tubes

0.51 g (15 kg/da) ammonium nitrate fertilizers were given at the beginning of stem lift. In the study, plant height, spike length, number of spikelets per spike, number of grains per spike, grain weight per spike, root length and root weight values were determined. The obtained data were analysed by using the JMP statistical program, and the differences between drought applications and cultivars were determined with the Tukey test.

Results. Variance analysis was performed for the values of plant height, spike length, spikelet number per spike, grain number per spike, grain weight per spike, root length and root weight of 24 bread wheat genotypes at different drought levels. The average values and significant groups are given in Table 1.

Plant height values in the genotypes included in the experiment showed high variation between 65.03–34.97 cm. The highest plant height was for Anapo variety at 65.03 cm, followed by Rumeli at 60.81 cm, Maden at 60.56 cm, Sarı Mustafa at 59.44 cm, Kaan at 58.84 cm, Selimiye at 57.03 cm, and Enola at 56.50 cm in the medium growth group. In the study, the shortest plant height was 34.96 cm

T a b l e 1

Mean values and important groups for traits examined in wheat genotypes

Genotypes	Plant height (cm)	Spike length (cm)	Number of spikelets (unit)	Number of grains per spike (unit)	Grain weight per spike (mg)	Root length (cm)	Root weight (mg)
Bora	48.59 e-j	5.72 a-d	11.00 b-e	17.38 abc	683.88 a	31.53 abc	700.63 a
NKU Ergene	50.75 c-h	5.22 b-e	11.75 a-d	17.06 abc	453.56 b	35.91 a	604.75 abc
Enola	56.50 a-e	6.69 a	13.38 ab	17.0 a-d	436.69 b	39.00	592.75 a-d
Rumeli	60.81 ab	5.13 b-e	10.75 b-e	15.75 a-e	428.38 bc	29.19 bcd	382.13 b-h
Pannonia	52.16 b-g	3.38 h	13.75 a	19.69 a	384.69 bcd	34.53 abc	502.44 a-f
Misiia Odes'ka	43.91 g-k	4.94 c-f	10.63 c-e	13.50 c-f	383.81 bcd	31.19 abc	643.50 ab
Refikbey	41.25 ijk	5.94 abc	10.25 c-f	19.00 ab	377.19 b-e	32.22 abc	522.38 a-e
NKU Asiya	49.63 d-i	5.25 b-e	10.63 c-e	14.75 a-e	376.31 b-e	31.03 abc	521.13 a-e
Esperia	50.78 c-g	5.94 abc	12.00 abc	19.50 a	356.75 b-f	28.94 b-e	380.00 b-h
Enargo	45.50 f-j	4.81 c-f	7.88 fgh	9.57 fgh	354.44 b-f	28.44 b-f	327.63 d-i
Anopa	65.03 a	5.63 a-d	9.13 d-h	16.9 a-e	312.19 c-g	21.59 d-h	224.88 ghi
Golia	53.81 b-f	5.75 a-d	9.75 c-h	19.38 a	286.69 d-h	19.34 gh	333.37 d-i
Mihelca	47.00 f-j	6.16 ab	11.88 abc	14.06 b-f	269.75 d-h	31.78 abc	664.56 a
NKU Lider	46.38 f-j	6.16 ab	9.88 c-g	12.63 c-g	259.75 e-h	32.53 abc	350.38 c-i
Selimiye	57.03 a-e	4.97 c-e	9.88 c-g	11.88 d-g	251.94 fgh	29.88 bcd	239.50 f-i
Sarı Mustafa	59.44 abc	4.69 d-g	9.38 c-h	15.19 a-e	237.19 fgh	26.69 c-g	207.25 hi
Hakan	51.53 b-g	5.31 b-e	10.75 b-e	11.81 efg	233.38 gh	34.63 ab	487.69 a-g
Kaan	58.84 a-d	5.03 b-e	10.25 c-f	12.75 c-g	220.50 gh	32.34 abc	302.31 e-i
Maden	60.56 ab	4.81 c-f	9.63 c-h	9.00 f-i	177.19 hi	30.97 abc	258.31 e-i
Rebelde	34.97 k	5.44 b-e	7.75 fgh	8.06 ghi	79.56 ij	19.53 gh	131.25 hi
Ambrosia	54.69 b-f	4.28 e-h	8.63 e-h	8.25 ghi	68.50 ij	20.00 fgh	210.63 hi
Kavlca	41.44 h-k	2.16 i	5.00 i	3.88 i	39.88 j	20.44 e-h	164.25 hi
Adelaide	51.81 b-g	3.78 fgh	7.50 ghi	4.19 i	38.06 j	15.88 h	83.69 i
LG 59	39.81 jk	3.56 gh	7.13 hi	5.25 hi	35.38 j	20.22 fgh	92.38 i

for Rebelde cultivar, which is in the late maturity group, while LG 59 in the early maturity group had height 39.8 cm, and Refikbey cultivars in the late maturity group had height 41.25 cm. When the data obtained are examined, the plant height of all varieties decreased with drought.

The average values for the properties examined at different drought levels, and the rate of change of the values obtained at different drought levels compared to 100% field capacity are given in Table 2.

T a b l e 2

Change rates of values obtained at different drought levels compared to 100% field capacity

Plant characteristic	Non-stress		Drought stress				
	100%	75%	50%		25%		
	Mean	Mean	Effect rate (%)	Mean	Effect rate (%)	Mean	Effect rate (%)
Plant height	52.45 a	54.10 a	+3.2	51.85 a	-1.1	45.29 b	-13.7
Spike length	5.48 a	5.14 b	-6.2	5.01 b	-8.6	4.48 c	-18.2
N. of spike./spike	11.35 a	9.96 b	-12.2	9.96 b	-12.2	8.48 c	-25.3
N. of grains/spike	17.24 a	12.74 b	-26.1	12.79 b	-25.8	9.96 c	-42.2
G. weight/spike	366.21 a	79.75 b	-23.6	281.33 b	-23.2	196.98 c	-46.2
Root length	27.07 b	8.98 ab	+7.1	26.54 b	-2.0	30.38 a	+12.2
Root weight	517.00 a	43.52 b	-33.6	334.40 b	-35.3	293.04 b	-43.3

When the plant height was examined in different drought levels, the tallest plants were 54.10 cm at 75% field capacity, followed by plants grown in the same statistical group at 100% and 50% field capacity. The shortest plants, on the other hand, were obtained from plants grown at 25% field capacity, the highest drought, at 45.29 cm. Compared to the plants grown at 100% field capacity, there was a 3% increase in plant height in plants grown at 75% field capacity. There was a decrease in plant height of 2% in plants grown with 50% field capacity and 13% in plants grown with 25% field capacity. Several agro-morphological traits such as plant height, peduncle length, number of fertile tillers per plant, spike length, number of grains per spike, thousand grains weight, and even awn length not only affect stress tolerance to limited soil moisture in wheat, they also reveal how adaptive genotypes cope with drought via morphological changes [10, 11].

Spike length values, one of the important selection criteria in wheat, varied between 6.69–2.16 cm in cultivars and between 5.48–4.48 cm in different drought applications. Among the genotypes, the longest spike was 6.69 cm for Enola, followed by Mihelca with 6.16 cm, Pannonia with 5.94 cm, Esperia and Rumeli with 5.94 cm, Golia with 5.75 cm, Bora with 5.72 cm and Anapo with 5.63 cm. The shortest spikes were determined in Kavlıca with 2.16 cm, Rebelde with 3.38 cm and LG 59 with 3.56 cm. When the genotypes are examined in terms of spike length, the longest spikes were obtained for genotypes in the middle maturation group. As with plant height, the spike length values also decreased significantly

with the application of drought. When the effect of drought on spike length is examined, the longest spikes were 5.84 cm in plants with 100% field capacity. In terms of spike length, this was in the same statistical group as spike length of 5.14 cm at 75% field capacity and 5.01 cm at 50% field capacity. The shortest ears, 4.48 cm, were at 25% field capacity, which was the highest drought. There was a 7% decrease in spike length of plants grown at 75% field capacity, 8% in plants with 50% field capacity, and 18% in plants with 25% field capacity. The spikelets per spike, potential florets per spike, spike length, spike dry weight, spike partitioning coefficient, and harvest index significantly decreased under water deficit.

The number of spikelets per spike in the 24 genotypes used in the study was between 13.75 and 5.00. While Pannonia cultivar had the highest number of spikelets per spike at 13.75, Enola cultivar followed this genotype with 13.38 spikelets. Among the genotypes, the lowest number of spikelets per spike was counted as 5.00 in Kavlica. The cultivars LG 59 with 7.13 spikelets and Adeleida cultivars with 7.50 spikelets were listed later. As for the other properties examined, the number of spikelets per spike decreased significantly with the application of drought. When the number of spikelets per spike was examined in different drought conditions, the highest number of spikelets per spike was 11.35 units at 100% field capacity. Plants grown at 75% and 50% field capacity had 9.96 spikelets per spike. The lowest number of spikelets per spike was determined as 4.48 in plants with 25% field capacity, which is the highest drought application. Compared to the plants grown at 100% field capacity, the number of spikelets per spike was 12% less in plants grown at 75% and 50% field capacity, and 25% less in plants grown with 25% field capacity. Drought stress significantly reduced the number of spikes per plot, number of grains per spike, grain yield, and biomass in all genotypes compared to control conditions [11].

When the genotypes were examined for the number of grains per spike, which is one of the important yield criteria, the number of grains per spike varied between 19.75 and 3.88. Drought stress results in major grain yield losses by deteriorating plant growth and disrupting various ongoing physiological mechanisms, including photosynthesis [12] and various morphological traits. While the highest number of spike grains was for Pannonia variety with 19.69 units, Esperia with 19.50 units, Golia with 19.38 units, and Refikbey varieties with 19.00 units followed this genotype. Among the 24 genotypes, Kavlica population had the lowest number of grains per spike at 3.88, while this population was followed by Adelaide at 4.19 and LG 59 at 5.25. When the change in the number of spike grains in different drought applications was examined, the number of spike grains showed a wide range of 17.24–9.95 units. While the highest number of spike grains was counted in plants with 100% field capacity with 17.23 units, it was followed by grains per spike in plants grown at 50% with 12.79 units and at 75% field capacity at 12.74 units. The lowest number of grains per spike was 9.96 units, and this was counted in plants with 25% field capacity, the highest level of drought.

Compared to the plants grown at 100% field capacity, the number of grains per spike decreased by 25% in plants grown with 75% field capacity, 26% in plants grown with 50% field capacity, and 42% in plants grown with 25% field capacity. Agronomic traits, including plant height, spike length, tillers per plant, days to heading, biological yield, grain yield, and harvest index of the genotypes decrease significantly in drought conditions [13,14].

The values obtained in terms of grain weight, which is one of the most important criteria in plant production, varied between 683.88–35.38 mg. Among the genotypes, the highest grain weight per spike was for the Bora variety with 683.88 mg, this genotype was followed by NKU Ergene with 453.56 mg, Enola with 436.69 mg and Rumeli variety with 428.38 mg. The lowest grain weight was found for LG 59 with 35.38 mg, Adelaide with 38.06 mg, and Kavlıca with 39.88 mg. In different drought applications, the grain weight per spike was obtained as 366.21 units at 100% field capacity, followed by 281.33 mg at 50% field capacity, and 279.75 mg at 75% field capacity. The lowest spike grain weight was obtained at 25% field capacity, which was the highest drought application. Compared to the plants grown at 100% field capacity, there was a decrease in grain weight of 23.61% for plants grown at 75% field capacity, 23% for plants grown at 50% field capacity, and 46% for plants grown at 25% field capacity. Grain yield is the principal selection index in water stress conditions [15], and grain yield and yield-contributing traits are widely used to evaluate the genetic variability and adaptability of wheat genotypes in response to moisture stress conditions. Given the complex polygenic nature of yield, genetic progress for highest yield could be achieved using yield-associated agronomic traits as a simpler alternative for yield prediction [16].

When the genotypes are examined in terms of root development, one of the important criteria for drought resistance of plants, root length values changed between 39.00–15.88 cm and root weight values changed between 700.63–83.69 mg. The maximum root length was 39.00 cm in Enola, followed by 35.91 cm in Ergene, 34.63 cm in Hakan and 34.53 cm in Pannonia wheat variety. The shortest root was 15.88 cm in Adelaide variety, followed by 19.34 cm in Golia and 19.33 cm in Rebelde. When root lengths are examined in different drought applications, the longest roots were 30.75 cm at 25% field capacity, while root length at 75% field capacity followed this, and was in the same statistical group at 28.98 cm. The shortest roots were 26.54 cm at 50% field capacity. In plants grown at 100% field capacity, root length increased by 7% compared to plants grown at 75% field capacity, there were two reductions at 50% field capacity, and 12% increase in root length at 25% field capacity. Results showed that drought tolerant genotypes had significantly ($p < 0.05$) more roots in the crown region with nodal and seminal roots concentrated closer to the soil surface, while susceptible genotypes had fewer roots in the crown region with most of the roots concentrated away from the soil surface [17].

Besides root length, root weight is also very important for plant development. Root weight varied between 700.63–83.69 mg. Bora variety had the highest root weight of 700.63 mg, followed by Mihelca with 664.56 mg, Misiia Odes'ka with 643.50 mg and NKU Ergene with 604.75 mg. Adelaide cultivar had the lowest root weight of 83.69 mg, followed by LG 59 cultivar with 92.38 mg. When root weight values are examined in different drought levels, the highest root weight was 517.00 mg in plants with 100% field capacity. This value was followed by 343.52 mg at 75% field capacity with and 334.04 mg at 50% field capacity. The lowest root weight was determined as 293.04 mg in plants with the highest drought at 25% field capacity. According to the root weight of the plants grown at 100% field capacity, there was a reduction of 33% at 75% field capacity, 35% at 50% field capacity, and 43% at 25% field capacity. The interaction between genotype and drought was significant for all root-related traits, except shallow root dry mass, at the level of 1% probability. The response of root-related traits to different types of drought stress is very complex. The longest root length decrease of 13.3% was during stress at the beginning of the vegetative stage in comparison to non-stress conditions, while the same trait increased by 4.9% during stress at the beginning of the reproductive stage, in comparison with non-stress conditions.

Discussion. Drought stress inhibits the cell cycle mechanism of plants, and the consequences of cellular dysfunction in cell division and differentiation eventually delay plant growth, including wheat. Although many findings on the drought tolerance of wheat have been published, further studies on drought tolerance are needed. It is very important to determine the genetic variation between genotypes and to reveal the drought resistant genotypes that can be used as a source of variation and the characteristics that can be selection criteria in drought tolerance. The development of genotypes with drought tolerance is the main goal in wheat breeding programmes. Conventional screening methods are effective ways for genotype evaluation under different water regimes to select contrasting genotypes for pre-breeding and breeding programmes.

The significant genotypic differences among the examined traits and genotypes in the study showed that the genotype and its characters could be used as a selection criterion for drought tolerance (Table 1). The data obtained in our study are in agreement with [18,19], who reported a significant genotypic variation in their studies of wheat genotypes under field-to-field conditions. In the study conducted by AKCURA et al. [20], significant genotypic differences were reported among 47 wheat genotypes under drought stress conditions.

When the plant height was examined in different drought levels, there was a 3% increase in plant height in plants grown at 75% field capacity compared to the plants grown at 100% field capacity. Plant height in plants growing at 50% and 25% field capacity decreased by 2% and 13% compared to plants with 100% field capacity. Several agro-morphological traits such as plant height, peduncle length, number of fertile tillers per plant, spike length, number of grains per spike,

thousand grains weight, and even awn length not only affect stress tolerance to limited soil moisture in wheat, they also reveal how adaptive genotypes cope with drought via morphological changes [10,11].

Spike length, number of spikelets, number of grains and weight per spike showed a significant decrease with increasing drought levels. The decreases in the spike characteristics were in a wide variation range such as 6.2–42.2%, while the reductions in 75 field capacity were low, 50% and especially 25% field capacity decreases were observed. It has been determined that there are significant reductions in ear number, grain number per ear, grain yield and biomass in all genotypes compared to control conditions in drought stress [11]. Agronomic characteristics of genotypes such as plant height, spike length, and grain yield were significantly reduced under drought conditions [13,14].

Grain yield under water stress conditions is the main selection criterion [15], and grain yield and traits that contribute to yield are widely used to assess the genetic variability and adaptation of wheat genotypes in response to moisture stress conditions. In this study, while 75% and 50% reductions in field capacity were around 20% in terms of grain weight, which is one of the main targets of breeding studies, almost half of the product decreased at 25% field capacity.

Given the complex polygenic nature of the yield, genetic advancement for high yields can be achieved by using yield-related agronomic traits for yield prediction [16]. When the genotypes are examined in terms of root development, one of the important criteria for drought resistance of plants, contrary to other characteristics, there was an increase in root length with drought application. The longest roots were 30.75 cm at 25% field capacity, which is the highest drought stress. This was followed by root length of 28.98 cm at 75% field capacity. Besides root length, root weight is also very important for drought tolerance. The lowest root weight was determined as 293.04 mg in plants with the highest drought at 25% field capacity. According to the root weight of the plants grown at 100% field capacity, there was a reduction of 33% at 75% field capacity, 35% at 50% field capacity, and 43% at 25% field capacity. The interaction between genotype and drought was significant for all root-related traits, except shallow root dry mass, at the level of 1% probability. In addition to root length, root weight is also an important factor for drought resistance. While the lowest root weight was in 25% field capacity with the highest drought stress, root weight decreased by 33% in 75% field capacity and 35% in 50% field capacity at 100% field capacity without drought stress. It was stated that drought-tolerant genotypes have more roots in the root crown region, while sensitive genotypes have fewer roots in the root crown region, most of the roots are concentrated away from the soil surface [17]. The data for 2004 and our results are similar.

The increase in root length, which is one of the most important features in drought resistance, causes plants to lower their roots deeper for water. The deeper root formation of plants due to drought stress reduces root distribution.

The results show that when there is sufficient water in the soil, the plants do not increase the lateral distribution of the roots much. When the early, mid-early and late varieties used in the study are examined in terms of drought resistance, early varieties such as Anapo, LG 59 and Golia and late varieties such as Rebelde, Refikbey are more affected by drought, while medium early varieties are more affected by drought stress. On the other hand, mid-early genotypes such as Bora, NKU Ergene, Anapo and Rumeli were less affected by drought stress. These results show that the genotype and its characteristics are very important in drought resistance, especially mid-early genotypes are less affected by drought.

The increase in root length, which is one of the most important features in drought tolerance, caused a decrease in root weight, namely distribution, with the application of drought, while plant roots went deeper for water. This shows that when there is enough water in the soil, the root development of the plants, especially the dispersal, does not increase much. When the early, medium and late varieties used in the study are examined in terms of tolerance to drought, early varieties such as Anapo, LG 59 and Golia and late varieties such as Rebelde, Refikbey are more affected by drought, while varieties with medium early maturity group such as Bora, NKU Ergene, Anapo and Rumeli are more affected by drought. These results show that the characteristics of the genotype are very important in drought resistance, especially the mid-early genotypes are less affected by drought.

Conclusion. When 24 different genotypes of bread wheat genotypes were examined in terms of drought resistance in different drought conditions, there were significant differences between genotypes. In general, the varieties in the medium maturity group were more resistant to drought, while the genotypes in the late maturity group showed the lowest resistance.

When the plants were grown in tubes with 100%, 75%, 50%, and 25% field capacity, the highest values for all properties, except plant height, were obtained in plants with 100% field capacity. According to the data obtained, Bora, NKU Ergene, Enola and Rumeli were least affected by drought, while LG 59, Adelaide and Kavlıca genotypes were most affected by drought.

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