MAS Journal of Applied Sciences
Uygulamalı Bilimler Dergisi
ISSN: 2757-5675
masjaps.com

DOI: http://dx.doi.org/10.5281/zenodo.10846009
Research Article

Investigation of the Effect of Drought Stress on Some Morphological and Physiological Traits in Bread Wheat (*Triticum aestivum* L.)

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Received: 26.11.2023 **Accepted**: 30.12.2023

Abstract

This research was carried out as a pot experiment to investigate the effects of 4 different drought stresses (FC-100%, 75%, 50%, 25%) created through field capacity (FC) on some morphological and physiological traits of bread wheat cultivars at the heading and ripening stages. In the study, 8 bread wheat varieties (Kate A1, Karahan 99, Tosunbey, Golia, Alpu 2001, Sultan 95, Konya 2002 and Eser) were used as material. The experiment was set up with 3 replications according to the split-plot experimental design, with the varieties main plots and drought stress applications sub plots. In the study, characteristics such as flag leaf area, flag leaf angle, chlorophyll content, stomata number, leaf water loss rate, relative water content, root length and root dry weight were investigated. It was determined that the effect of drought stress applications on all the examined traits was statistically significant. In drought stress applications, flag leaf area, flag leaf angle, chlorophyll content, leaf water loss rate, relative water content, stomata number, root length and root dry weight were respectively 4.01-14.02 cm^2, 20.00-40.83°, 36.87-49.07 SPAD, 13.68-17.89%, 48.56%-72.61%, 8.01-10.95, 28.92-77.79 cm and 146.04-473.46 mg. As a result, it was determined that as drought stress increased, flag leaf area, flag leaf angle, chlorophyll content, relative water content, root length and root dry weight decreased, while leaf water loss rate and stomata number increased. In addition, it was noted that drought-resistant varieties had higher values in terms of chlorophyll content, relative water content, root length and root dry weight, while drought-sensitive varieties had higher values in terms of flag leaf angle and leaf water loss rate.

Keywords: Wheat, drought stress, flag leaf, chlorophyll content, stoma, root

1. Introduction

Wheat is an important cereal crop, which ranks first among the cereal crops cultivated in the world with 219 million hectares of cultivated area and second after corn (1.1 billion tons) with a production of 808 million tons. (Anonymous, 2022). In Turkey, 19.7 million tons of wheat is produced on 6.6 million hectares. (Anonymous, 2022). Wheat is also one of the most strategic products for humanity, providing about half of the protein and more than half of the daily calories needed by one third of the world's population. Wheat, which has a wide adaptability, can be grown in ecologies between 20-65^o north and 22-45^o south latitudes. (Kün, 1996). Although wheat is generally an important crop in arid and semi-arid regions, extreme hot and dry conditions lead to significant reductions in yield and quality. Unfavorable environmental conditions and abiotic stresses cause serious economic losses by negatively affecting grain yield (Özkan, 2022). Global warming, which has been on the recent years' agenda, and the resulting drought are among the abiotic stress factors that threaten wheat production. Drought, in general terms, is a meteorological event, a period without rainfall that lasts long enough to cause a noticeable decrease in soil water content and plant growth. The occurrence of drought during a period without rainfall depends on the water-holding capacity of the soil and the rate of evapotranspiration by plants (Kalefetoğlu and Ekmekçi, 2005). The effect of drought stress on plant growth varies depending on the duration and severity of stress (Rampino et al., 2006). The water demand in wheat starts with germination and increases as growth and development progresses. Drought, especially in the period between the beginning of spike and maturity, causes irrecoverable decreases in grain yield (Ahmadi and Baker, 2001). Although the average annual rainfall in our country is 643 mm, due to the irregularity in the distribution of rainfall, significant yield decreases are observed in many regions from time to time as a result of drought. Wheat production is affected by variety, environmental factors and agronomic practices (Başaran et al., 2020). The most important subject in breeding studies for drought tolerance in plants is to know the morphological and physiological response mechanisms that plants have and use to overcome water deficiency and drought. Determining the responses of plants to drought, which occurs as a result of high temperature and deficiency of water, will form the basis for drought tolerance studies and can be used as a selection criterion in the selection of resistant plants. Mirzaee et al. (2013) reported that plants generally have different mechanisms to respond and adapt to drought stress by triggering various physiological, biochemical and morphological responses. In previous studies, drought stress decreased flag leaf area (Başer et al., 2005; Çekiç, 2007; Sangtarash, 2010), chlorophyll content (Bijanzadeh and Emam, 2010; Geravandi et al., 2011; Öztürk and Korkut, 2018), relative water content (Paknejad et al, 2007; Bijanzadeh and Emam, 2010; Geravandi et al., 2011), root length and weight (Öztürk and Korkut, 2018), but increased leaf water loss rate (Kokhmetova et al., 2003) and number of stomata per unit area (Öztürk and Korkut, 2018). In this study, it was aimed to investigate the effects of drought stress on some morphological and physiological characteristics of 8 bread wheat cultivars by applying water deficit over field capacity, to determine the cultivar or cultivars that can be used as genitors in future drought tolerance breeding studies and to determine the selection parameters that can be used in these studies.

2. Materials and Methods

2.1. Materials

This study was carried out in Tekirdağ Namık Kemal University, Faculty of Agriculture, Department of Field Crops, Research and Experimental Area under a covered porch to eliminate the effect of rainfall in 2009. In this study, 8 bread wheat varieties (Kate A1, Karahan 99, Tosunbey as resistant, Golia as medium resistant, Alpu 2001, Sultan 95, Konya 2002, Eser as sensitive) with different responses to drought stress were used as materials.

2.2. Methods

The experiment was established as a split-plot design with 3 replications according to the split-plot design with the varieties as the main plots and the drought levels (100%-FC, 75%, 50%, 25%) created over the field capacity (FC) as the sub-plots. In the experiment, specially prepared black plastic tubes with a diameter of 30 cm and a depth of 100 cm were used as pots. The tubes in which the plants were to be grown were filled with an equal amount (20 kg tube^{-1}) of field soil. The field capacity of the soil filled in the tubes was determined according to the method suggested by Bilski et al. (1987). The field capacity was accepted as 100% and drought stress was created with water constraint by determining 75%, 50% and 25% of this amount. In order to create these drought levels and then to determine the amount of water lost from the soil by evaporation for each drought level, 4 tubes filled only with soil were prepared for each drought level without plants. The amount of water to be given to these tubes was determined by subtracting the amount of moisture initially contained in the soil from the amount of water calculated for each drought level. After the areas of the tubes were calculated, sowing was done at a density of 500 seeds m^{-2}. After sowing, the tubes were watered with the amount of water determined for each drought level. At the same time, the same amount of water was added to the tubes containing no plants and used to determine the amount of water lost from the soil by evaporation for each drought level. Again, these tubes without plants were weighed every 5 days and the amount of water lost by evaporation from the soil was determined for each drought level and water was given to the tubes (all tubes with and without plants). To each tube, 20-20-0 compound fertilizer (4 kg da^{-1} pure nitrogen and 4 kg da^{-1} pure phosphorus), urea fertilizer (7.5 kg da^{-1} pure nitrogen), and ammonium nitrate fertilizer (4 kg da^{-1} pure nitrogen) were applied at the sowing, tillering, and stem elongation, respectively. Weeds growing in the tubes were removed by hand and their growth was prevented. For each drought level, flag leaf area (FLA), flag leaf angle (FLAA), chlorophyll content (CC), leaf water loss rate (LWLR), relative water content (RWC) and stomatal number (SN) values were examined on the main stem of 10 randomly selected plants when the plants in the tubes reached the heading stage (Zadoks 59th stage), and root length (RL) and root dry weight (RDW) values were examined when the plants reached the ripening stage (Zadoks 92nd stage). Flag leaf areas of the plants were measured with a portable leaf area meter "LI-COR Model LI 3000 A". Flag leaf angles were determined by measuring the angle of the flag leaves with the stem with a protractor. Chlorophyll content was determined as SPAD value by measuring with "Konica Minolta SPAD-502" portable chlorophyll meter on the flag leaves of the plants. Flag leaf water loss rate and relative water content were determined according to the methods described by Clarke and McCaig (1982) and Cseuz et al. (2002), respectively. Stomata removed from the flag leaves of the plants were counted under a 4x100 magnification microscope. After the soil in the tubes was washed, root length was determined by measuring the distance between the root crown and the most tip of the roots of the plants, and root dry weight was determined by drying and weighing these roots in an oven.

2.3. Data analyses

The data obtained from the study were subjected to analysis of variance according to the split plots experimental design. The statistical significance of the differences between the mean values of the studied traits was determined according to LSD (Least Significant Difference) test using MSTAT-C package program (Düzgüneş et al., 1987).

3. Results and Discussion

The mean values and significance groups of the varieties and drought levels in terms of the traits examined in our study are given in Table 1, and the mean values and significance groups of the variety x drought level interaction are given in Table 2.

Table 1. Mean values and significance groups obtained from varieties and drought levels for FLA, FLAA, CC, LWLR, RWC, SN, RL and RDW.

	Investigated traits							
	FLA (cm^2)	FLAA (º)	CC (SPAD)	LWLR (%)	RWC (%)	SN	RL (cm)	RDW (mg)
Varieties								
Kate A1	6.88 c	17.08 e	46.62 ab	13.30	63.13 a	10.20 a	60.71 a	348.83
Karahan 99	8.80 b	27.92 c	47.40 a	13.63	60.83 b	9.25 bc	57.75 ab	260.42
Golia	9.25 ab	31.67 b	43.13 c	18.51	61.28 b	9.56 b	51.00 c	264.00
Konya 2002	10.21 a	30.83 bc	45.19 b	16.12	58.97 bc	8.83 cd	53.08 bc	271.00
Sultan 95	6.94 c	36.25 a	39.01 e	17.08	52.55 d	10.64 a	54.08 bc	248.33
Alpu 2001	7.35 c	38.33 a	41.88 cd	15.62	61.47 b	8.67 d	50.25 c	220.67
Tosunbey	7.53 c	22.92 d	45.64 ab	17.04	68.96 a	8.53 d	63.13 a	336.25
Eser	6.97 c	37.50 a	40.88 de	16.77	57.68 c	9.50 b	51.67 bc	236.75
LSD (0.05)	1.095	3.060	1.877**	-	3.027**	0.513**	6.564**	-
Drought Levels								
%100-FC	14.02 a	40.83 a	49.07 a	13.68 c	72.61 a	8.01 d	77.79 a	473.46 a
%75	7.78 b	32.50 b	46.69 b	15.35 bc	64.14 b	8.96 c	67.58 b	252.13 b
%50	6.16 c	27.92 c	42.25 c	17.12 ab	58.62 c	9.67 b	46.54 c	221.50 b
%25	4.01 d	20.00 d	36.87 d	17.78 a	48.56 d	10.95 a	28.92 d	146.04 c
LSD (0.05)	0.623**	1.935**	1.192**	2.005**	1.629**	0.292**	2.772**	2.772**

FC: Field capacity, *: significant at %5 level, **: significant at %1 level

3.1. Flag leaf area

Variety, drought level and variety x drought level interaction were statistically significant at 0.01 level for flag leaf area.
When the variety means are evaluated, it is understood that the flag leaf area varied between 6.88-10.21 cm^2 (Table 1). The largest flag leaf area was measured in Konya 2002 variety, followed by Golia variety (9.25 cm^2), which has genotypically large leaf blades. The narrowest flag leaf area was determined in Kate A1 variety. This was followed by Sultan 95 variety with 6.94 cm^2. Flag leaf area determined at drought levels varied between 4.01-14.02 cm^2. The largest flag leaf area was measured under field capacity (100%) conditions without water stress, followed by 75% drought level with 7.78 cm^2. The narrowest flag leaf area was obtained at the 25% drought level, where water stress was the highest, followed by the 50% drought level (6.16 cm^2) (Table 1). In the variety x drought level interaction, flag leaf area varied between 3.25-20.57 cm^2. The largest flag leaf area was determined under field capacity conditions of Konya 2002 variety. This was followed by the field capacity of Golia variety with 16.97 cm^2. The narrowest flag leaf area was obtained at 25% drought level of Kate A1 variety, followed by the flag leaf area determined at 25% drought level of Eser variety with 3.45 cm^2. The most effective photosynthetic organ in grain filling in wheat is the flag leaf, and it contributes to grain weight per spike by 16.33-21.12% in bread wheat (Balkan and Gençtan, 2009) and 17.62-22.48% in durum wheat (Balkan et al., 2011). In our study, in terms of flag leaf area, it is understood that drought-resistant varieties have a larger average flag leaf area than drought-sensitive varieties except Konya 2002. It was determined that the Golia variety, which is moderately resistant to drought, had a larger flag leaf area than the varieties in both groups (except Konya 2002). The most important indicator of cell growth sensitivity to water stress is the reduction in leaf area. Leaf area in wheat is generally fixed during the heading-flowering period. Water stress during this period reduces leaf area and reduces yield (Turner and Kramer, 1980). In our research,

it was determined that there was a significant decrease in flag leaf area due to the increase in drought levels. The flag leaf area decreased by 44.51% at 75% drought level, 56.06% at 50% drought level and 71.40% at 25% drought level compared to field capacity (100%). Our findings are similar to those of Robertson and Guinta (1994), Salem et al. (1996), Öztürk (1999), Kazmi et al. (2003), Başer et al. (2005), Çekiç (2007) and Sangtarash (2010) who found that flag leaf area decreased with increasing drought stress.

3.2. Flag leaf angle

For flag leaf angle, variety, drought level and variety x drought level interaction were found to be statistically significant at the 0.01 level. The average flag leaf angles of the varieties varied between 17.08-38.33^o (Table 1). The widest flag leaf angle was measured in the Alpu 2001 variety, followed by the Sultan 95 variety, which is in the same importance group with 36.25^o. The narrowest flag leaf angle was obtained from the Kate A1 variety. This was followed by Tosunbey variety (22.92^o). It was determined that flag leaf angles measured at drought levels varied between 20.00-40.83° (Table 1). The widest flag leaf angle was measured under field capacity (100%) conditions, followed by 75% drought level with 32.50o. The narrowest flag leaf angle was determined at the 25% drought level, where drought stress was most severe, followed by the 50% drought level (27.92^o). In the variety x drought level interaction, it was determined that the flag leaf angle varied between 10.00-50.00^o. The widest flag leaf angle was obtained from the field capacity (100%) conditions of the Eser variety, followed by the field capacity conditions of the Sultan 95 variety with 48.33^o. The narrowest flag leaf angle was determined at the 25% drought level of the Kate A1 variety, followed by the 25% drought level of the Karahan 99 and Tosunbey varieties with the flag leaf angle of 15.00^o (Table 2). The narrowing of the leaf angle in plants, in other words the erection of the leaf, can be an effective mechanism to reduce solar radiation on the leaves under water stress. In our study, it is understood that drought-resistant varieties (Kate A1, Karahan 99, Tosunbey) have narrower flag leaf angle than drought-sensitive varieties (Konya 2002, Sultan 95, Alpu 2001, Eser). The moderately drought-resistant Golia variety had a wider flag leaf angle than the drought-resistant varieties and a narrower flag leaf angle than the sensitive varieties. In our research, it is noticed that the flag leaf angle decreased significantly due to the increase in water stress. Flag leaf angle decreased by 20.40% at 75% drought level, 31.62% at 50% drought level and 51.02% at 25% drought level compared to field capacity (100%). As stated by Turner and Kramer (1980), this may be a result of the measures taken by plants to reduce the negative effects of solar radiation on the leaf surface due to water stress.

3.3. Chlorophyll content

In the study, the effect of variety, drought level and variety x drought level interaction on chlorophyll content was found to be statistically significant at the 0.01 level. It is understood from Table 1 that the flag leaf chlorophyll content of the varieties varied between 39.01-47.40 SPAD. The highest chlorophyll content was measured in the drought-resistant Karahan 99 variety, followed by the drought-resistant Kate A1 variety with 46.62 SPAD. The lowest chlorophyll content was determined in the drought-sensitive Sultan 95 variety, followed by the drought-sensitive Eser variety with 40.88 SPAD. Flag leaf chlorophyll contents determined at drought levels ranged between 36.87-49.07 SPAD. The highest chlorophyll content was determined under field capacity (100%) conditions without water stress, followed by 46.69 and 75% drought level. The lowest chlorophyll content was found in the 25% drought level, where water stress is most intense (Table 1). In the variety x drought level interaction given in Table 2, it is seen that the chlorophyll content varies between 32.50-52.70 SPAD. The highest chlorophyll content was measured under field capacity (100%) conditions of Konya 2002 variety, followed by field capacity (100%) conditions of Karahan 99 variety, which is in the same significance group as 52.50 SPAD. The lowest chlorophyll content was obtained from the 25% drought level of the Golia variety, followed by the 25% drought level of the Eser variety, which is in the same significance group with 32.60 SPAD. In our research, it is seen that drought-resistant varieties have higher chlorophyll content than sensitive varieties. The moderately drought-resistant Golia variety had a chlorophyll content value between both groups. Our results are in agreement with Altınkut et al. (2001) who reported that chlorophyll content decreased more in drought sensitive genotypes than in resistant genotypes in response to water stress in wheat. In our study, it was determined that the chlorophyll content of flag leaves decreased due to the increase in drought levels. Compared to field capacity (100%) conditions, flag leaf chlorophyll content decreased by 4.85% at 75% drought level, 13.90% at 50% drought level and 24.86% at 25% drought level. Our results on the chlorophyll content of the flag leaf were similar to the findings of Çekiç (2007), Paknejad et al. (2007), Bijanzadeh and Emam (2010), Geravandi et al. (2011), and Öztürk and Korkut (2018), who explained that drought stress caused significant decreases in the chlorophyll content of the flag leaf.

3.4. Leaf water loss rate

For leaf water loss rate, drought level and variety x drought level interactions were statistically significant at 0.01 level, while the differences between variety averages were statistically not significant. The differences between the leaf water loss rates of the varieties were found to be statistically not significant and varied between 13.30-18.51%. The leaf water loss rate determined at drought levels varied between 13.68-17.89%. The highest leaf water loss rate was determined at the 25% drought level where water stress was the most severe, followed by the 50% drought level with 17.12%. The lowest leaf water loss rate was obtained from field capacity (100%) conditions (Table 1). The leaf water loss rate determined in the variety x drought level interaction varied between 10.86-23.14%. The highest leaf water loss rate was determined at 25% drought level of Golia variety. The lowest leaf water loss rate was obtained from field capacity conditions (100%) of Eser variety (Table 2). In our research, it is seen that drought sensitive varieties have higher leaf water loss rates than resistant varieties. Similar to our findings, Rampino et al. (2006) reported that drought sensitive genotypes had higher leaf water loss rates than resistant genotypes. It is known that leaf water loss rate is an important trait for plant survival under drought conditions (Rahman et al., 2000). In our study, it was observed that the increase in drought stress linearly increased the leaf water loss rate. In fact, leaf water loss rate increased by 12.20% at 75% drought level, 25.15% at 50% drought level and 30.77% at 25% drought level compared to field capacity (100%). Our findings are in agreement with the findings of Kokhmetova et al. (2003) who reported that leaf water loss rate can be used as a selection criterion in drought adaptation of wheat genotypes. In addition, Ahmadi and Baker (2001), Gupta et al. (2001) and El-Hafid et al. (1998), who reported that leaf water potential decreased due to increase in water stress in wheat and water use efficiency decreased, also supported our findings.

Tablo 2. Mean values and significance groups obtained from variety x drought level interaction for FLA, FLAA, CC, LWLR, RWC, SN, RL and RDW.

Variety	Drought Levels	FLA (cm^2)	FLAA (°)	CC (SPAD)	LWLR (%)	RWC (%)	SN	RL (cm)	RDW (mg)
Kate A1	%100-FC	12.70 c	21.67 ıj	51.63 ab	13.91 h-l	74.92 bc	7.67 kl	82.50	646.33
	%75	7.11 fg	18.33 jk	47.33 d-ı	12.21 jkl	69.07 d-g	8.89 fgh	71.33	306.33
	%50	4.47 ı-l	18.33 jk	44.70 g-l	10.94 l	66.82 e-h	11.33 bc	54.00	255.67
	%25	3.25 l	10.00 l	42.80 j-m	16.15 c-l	53.71 kl	12.89 a	35.00	187.00
Karahan 99	%100- FC	13.22 c	41.67 cd	52.50 a	12.99 ı-l	70.47 c-f	8.00 ı-l	78.00	441.67
	%75	9.25 de	30.00 fgh	51.07 abc	15.71 d-l	61.41 ıj	8.56 hıj	71.00	288.67
	%50	8.01 ef	25.00 hı	47.13 e-ı	12.55 jkl	57.55 jk	8.67 g-k	50.67	177.67
	%25	4.43 ı-l	15.00 kl	38.90 nop	13.28 ı-l	53.89 kl	11.78 b	31.33	133.67
Golia	%100- FC	16.97b	43.33 bcd	48.13 c-f	19.60 a-g	72.54 bcd	7.89 ı-l	75.00	484.67
	%75	7.89 ef	33.33 efg	47.67 d-h	14.04 f-l	61.35 ıj	9.11 fgh	58.33	220.00
	%50	8.48 ef	28.33 gh	44.23 ı-l	17.28 b-k	57.53 jk	9.45 efg	45.00	235.33
	%25	3.66 jkl	21.67 ıj	32.50 s	23.14 a	53.70 kl	11.78 b	25.67	116.00
Konya 2002	%100- FC	20.57 a	38.33 de	52.70 a	12.04 kl	69.54 d-g	7.22 l	75.00	537.67
	%75	9.51 de	35.00 ef	48.83 b-e	14.39 e-l	64.95 ghı	8.45 h-k	62.33	190.67
	%50	6.07 ghı	28.33 gh	42.27 k-n	19.38 a-h	55.99 kl	9.11 fgh	46.33	227.00
	%25	4.71 ı-l	21.67 ıj	36.97 pqr	18.66 a-ı	45.39 n	10.56 cd	28.67	128.00
Sultan 95	%100- FC	10.46 c	48.33 ab	43.03 j-m	14.11 e-l	69.47 d-g	8.56 hıj	74.33	402.33
	%75	6.82 fgh	38.33 de	40.77 mno	19.75 a-e	56.46 kl	10.44 d	71.67	235.00
	%50	5.91 ghı	38.33 de	38.00 opq	20.69 a-d	46.44 n	11.67 b	42.00	230.00
	%25	4.65 ı-l	20.00 ıjk	34.23 rs	13.78 h-l	37.85 o	11.89 b	28.33	126.00
Alpu 2001	%100- FC	13.13 c	45.00 abc	50.70 a-d	13.96 g-l	75.49 b	8.00 ı-l	73.00	321.00
	%75	7.08 fg	38.33 de	45.67 e-j	15.23 d-l	66.35 fgh	8.55 hıj	63.67	240.67
	%50	5.24 hıj	38.33 de	36.23 pqr	16.52 b-l	65.04 ghı	8.56 hıj	42.33	188.33
	%25	3.95 jkl	31.67 fg	34.90 qrs	16.75 b-k	39.00 p	9.56 ef	22.00	132.67
Tosunbey	%100- FC	14.20 c	38.33 de	48.57 b-f	11.94 kl	80.64 a	7.78 jkl	89.50	576.00
	%75	6.82 fgh	21.67 ıj	47.87 c-g	14.65 e-l	70.96 b-e	8.45 h-k	80.67	315.67
	%50	5.09 h-k	16.67 jk	44.10 ı-m	21.86 ab	67.15 e-h	9.00 fgh	50.00	241.67
	%25	4.00 jkl	15.00 kl	42.03 k-n	19.68 a-f	57.08 jk	8.89 fgh	32.33	211.67
Eser	%100- FC	10.91 d	50.00 a	45.27 f-k	10.86 l	67.81 efg	9.00 fgh	75.00	378.00
	%75	7.50 fg	45.00 abc	44.30 h-l	16.82 b-k	62.59 hı	9.22 fgh	61.67	220.00
	%50	5.99 ghı	30.00 fgh	41.37 l-o	17.75 a-j	52.44 lm	9.56 ef	42.00	216.33
	%25	3.45 kl	25.00 hı	32.60 s	21.65 abc	47.89 mn	10.22 de	28.00	132.67
LSD $_{(0.05)}$		1.761**	5.472**	3.370**	5.670**	4.605**	0.825**	-	-

FC: Field capacity, *: significant at %5 level, **: significant at %1 level

3.5. Relative water content

In our study, the effect of variety, drought level and variety x drought level interaction on the relative water content was statistically significant at 0.01 level. The mean relative water content of the varieties varied between 52.55-68.96% (Table 1). The highest relative water content was determined in the drought resistant variety Tosunbey, followed by the drought resistant variety Kate A1 in the same significance group with 66.13%. The lowest relative water content was obtained from the drought sensitive variety Sultan 95. This was followed by the drought sensitive variety Eser (57.68%). The relative water content determined at drought levels varied between 48.56-72.61%. The highest relative water content was determined under field capacity (100%) conditions, followed by 75% drought level (64.14%). The lowest relative water content was determined at 25% drought level where water stress was the most severe (Table 1). In the variety x drought level interaction, the relative water content varied between 37.85-80.64%. The highest relative water content was determined at field capacity (100%) of Tosunbey variety, followed by field capacity (100%) of Alpu 2001 variety with 75.49% relative water content value. The lowest relative water content was obtained at 25% drought level of Sultan 95 variety, followed by 25% drought level of Alpu 2001 variety (39.00%) (Table 2). Relative water content is a physiological trait associated with drought stress. In our study, drought tolerant varieties had higher relative water content than the sensitive varieties. Our results are in agreement with the results of Abbasi et al. (2003). The moderately drought tolerant variety Golia had lower relative water content than drought tolerant genotypes and higher relative water content than sensitive genotypes. In our study, the relative water content decreased with the increase in drought levels. This decrease was observed as 11.67% at 75% drought level, 19.27% at 50% drought level and 33.12% at 25% drought level compared to field capacity (100%). Similar to our findings, Ahmadi and Baker (2011), Çekiç (2007), Paknejad et al. (2007), Bijanzadeh and Emam (2010) and Geravandi et al. (2011) reported that drought stress caused significant decreases in the relative water content of flag leaves during heading.

3.5. Stomata number

In the study, variety, drought level and variety x drought level interaction were found to be statistically significant at 0.01 level in terms of stomata number. The mean number of stomata of the varieties varied between 8.53-10.64 (Table 1). Sultan 95 variety had the highest number of stomata, followed by Kate A1 variety in the same significance group with 10.20 stomata. The lowest number of stomata was counted in Tosunbey variety, followed by Alpu 2001 variety with 8.67 stomata. The number of stomata determined at drought levels varied between 8.01-10.95. The highest number of stomata was obtained at the 25% drought level where the water stress was the most severe, followed by the 50% drought level with 9.67. The lowest number of stomata was determined under field capacity (100%) conditions where there was no water stress, followed by 75% drought level with 8.96 (Table 1). When the variety x drought level interaction was evaluated, it was seen that the number of stomata varied between 7.22-12.89. The highest number of stomata was counted at 25% drought level of Kate A1 variety, followed by 11.89 stomata at 25% drought level of Sultan 95 variety. The lowest number of stomata was determined under field capacity conditions (100%) of Konya 2002 variety. This was followed by the field capacity conditions (100%) of Kate A1 variety with 7.67 (Table 2). One of the earliest responses to drought stress in plants is the changes in the number and size of stomata per unit area. Studies have shown that the number and size of stomata can be used as selection criteria for drought tolerance in wheat (Venora and Calcagno, 1991; Mut and Sezer, 2008). The varieties tested in our study were found to have different stomata numbers. This may be a result of the different genotypic characteristics of the varieties and their responses to drought stress. Similar to our findings, Öztürk and Korkut (2018) determined that under drought stress, wheat varieties had different stomata numbers. In our study, it is observed that the number of stomata increased in direct proportion to the increase in drought stress. The increase in stomatal number was 11.86% at 75% drought level, 20.72% at 50% drought level and 36.70% at 25% drought level compared to field capacity (100%) conditions. Our findings are similar to the findings of Öztürk and Korkut (2018), who determined that the number of stomata increased due to the increase in drought stress.

3.7. Root length

In the study, it was determined that variety and drought level were statistically significant at 0.01 level, while variety x drought level interaction was statistically not significant in terms of root length. The mean root lengths of the varieties varied between 50.25-63.13 cm (Table 1). Tosunbey variety had the longest roots, followed by Kate A1 variety in the same significance group with 60.71 cm. The shortest roots were measured in Alpu 2001 variety, followed by Golia variety in the same significance group with 51.00 cm. As can be seen from Table 1, the root lengths determined at drought levels varied between 28.92-77.79 cm. The longest roots were determined under field capacity conditions, followed by 75% drought level with 67.58 cm. The shortest roots were measured at 25% drought level. This was followed by 50% drought level with 46.54

cm. In our study, the variety x drought level interaction was not statistically significant for root length (Table 2).

3.7. Root dry weight

It was determined that the effect of drought levels on root dry weight was statistically significant at 0.01 level, while the effect of variety and variety x drought level interaction was statistically not significant. Although statistically not significant, the mean root dry weights of the varieties varied between 220.67-348.83 mg. The highest root dry weight was weighed in the drought resistant variety Kate A1. The lightest roots were obtained from the drought sensitive variety Alpu 2001 (Table 1). In our study, the mean root dry weight values determined at drought levels varied between 146.04-473.46 mg. The highest root dry weight was obtained under field capacity (100%) conditions, followed by 75% drought level with 252.13 mg. The lowest root dry weight was determined at 25% drought level where water stress was the most severe, followed by 50% drought level with 221.50 mg (Table 1). As can be seen from Table 2, although statistically not significant, the mean root dry weight varied between 116.00-646.33 mg in the variety x drought level interaction. The heaviest roots were obtained from field capacity (100%) conditions of Kate A1 variety and the lightest roots were obtained from 25% drought level of Golia variety. Root traits in wheat are highly influenced by soil and climatic factors as well as genotypic traits. In our study, when drought resistant varieties were compared with drought sensitive varieties in terms of root traits, it was found that drought resistant varieties had longer and heavier roots than sensitive varieties. The moderately drought resistant variety Golia was close to the drought sensitive varieties in terms of root length and higher than the drought sensitive varieties in terms of root dry weight. Our findings were in agreement with the findings of Gesimba et al. (2004) who found that drought tolerant genotypes formed more roots than sensitive and moderately tolerant genotypes. In our study, it was found that root length and root dry weight decreased significantly parallel to the increase in drought levels. According to the field capacity conditions, root length decreased by 13.13% at 75% drought level, 40.17% at 50% drought level and 62.82% at 25% drought level. Root dry weight decreased by 46.75% at 75% drought level, 53.22% at 50% drought level and 69.15% at 25% drought level. Similar to our findings, Öztürk and Korkut (2018) determined that root weight decreased as drought stress increased in wheat.

4. Conclusions

In this study conducted to investigate the effect of 4 different drought stresses (FC-100%, 75%, 50%, 25%) on some morphological and physiological characteristics of bread wheat varieties during spike and ripening periods, it was determined that the effect of drought stress varied according to the varieties, Kate A-1, Karahan 99 and Tosunbey varieties performed better than other varieties under drought stress, while Sultan 95 and Eser varieties were the most sensitive varieties to drought stress. It can be said that Kate A-1, Karahan 99 and Tosunbey varieties can be used as genitors, and flag leaf angle, chlorophyll content, leaf water loss rate, relative water content, root length and root dry weight can be used as selection parameters in drought tolerance breeding studies in wheat.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

Funding

This study was supported with the project numbered “NKUBAP 00.24.DR.08.12” by the Scientific Research

Projects (BAP) Coordinatorship of Tekirdag Namik Kemal University.

Acknowledgement

This study was produced from the doctoral thesis of the first author.

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To Cite: Balkan, A., Gençtan, T., 2024. Investigation of the Effect of Drought Stress on Some Morphological and Physiological Traits in Bread Wheat (*Triticum aestivum* L.). *MAS Journal of Applied Sciences*, 9(1): 167–177.
DOI: http://dx.doi.org/10.5281/zenodo.10846009.