STOMATA DIMENSION AND PHYSIOLOGICAL PARAMETERS IN DURUM WHEAT (*Triticum durum* L.) GENOTYPES UNDER RAINFED CONDITION

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Abstract

Heat stress and various precipitation regimes due to global climate change increase the importance of physiological studies in field crops. The relationship between stomatal behaviour and physiological parameters in plants is important in response to drought stress. The experiment was laid out to compare the stomata dimension and physiological parameters of advanced durum wheat genotypes under rainfed conditions. A total of 25 durum wheat genotypes were examined during the 2018-2019 growing cycles in the Edirne location in the Trakia region, Türkiye. The experiment was conducted in a randomized complete block design (RCBD) with four replications. Stoma area, perimeter, width and length were made on samples taken during the heading stage of the flag leaf. Plant height (PH), Chlorophyll content (SPAD), canopy temperature (CT) and normalized difference vegetation index (NDVI) were taken at heading stages. The results of variance analysis showed significant differences ($p<0.01$) among genotypes for stoma area, perimeters and width. According to stoma dimensions, the widest stomata were determined in G5 and G18 genotypes. Stomata number is an important parameter for drought tolerance and the highest stomata number was determined in G4 and G5 genotypes in the study. These genotypes may be more tolerant to drought due to the high number of stomata. Flag leaf area differed among genotypes. Genotypes G14, G1, G8 and G2 had higher FLA. The chlorophyll content is an important parameter for photosynthesis. The highest chlorophyll content was measured in G25, G23 and G19. Low canopy temperature is important for drought tolerance. The lowest canopy temperature was scaled by genotypes G15 and G9. Genotype G8 had a higher NDVI. It can be stated that these genotypes are more tolerant to drought than others. Different correlations were determined between stoma measurements and physiological parameters. A negative correlation was determined between NDVI and stomatal parameters in genotypes. The significant differences between genotypes showed the importance of stomatal characters for selection in adaptation to different environments. The adaptation of genotypes to different environments is determined by their physiological responses. Significant differences were determined between genotypes in the physiological parameters examined in the study, except for canopy temperature.

Keywords: *durum wheat, genotypes, stomata dimension, physiological parameters*

1. INTRODUCTION

Türkiye is one of the diversification centre of durum wheat *(Triticum durum* Desf.). Considerable divergence among genotypes can be involved in the selection of durum wheat for the advancement of varieties, developed genotypes could be used in breeding programs. Because of the diverse environmental conditions, genotype × environment interaction is the main issue in improving wheat genotypes (Öztürk, 2019; 2022). Under Mediterranean conditions, durum wheat yield is often limited by drought and high temperatures during the plant development period (Garcia del Moral et al., 2003). Since the yield potential of durum wheat is lower than bread wheat, genotypes that are well adapted to the regional conditions must be selected (Bilgin et al., 2008). Global climate change and the expansion of wheat production to less suitable production areas cause crop losses depending on the year and location. Lack of rainfall and water stress is one of the biggest problems determining plant growth and productivity in different regions (Zhao, 2015). Under drought stress, plants complete their vegetative growth period earlier in response to the stress. In drought stress, plants compete against the stress by closing their stomata and reducing the transpiration rate. Then, a plant undergoes different processes to counter drought stress by increasing the pigmentation of photosynthetic products and maintaining the root/shoot ratio to partition the overall assimilation efficiently (Noorka et al., 2013). Drought is an important abiotic stress that restricted productivity in production all over the world. Its impact increases with climate change. Drought can completely dry out the plant at different growth periods and reduce yield at every stage of plant development. Plants exposed to environmental stress such as drought give molecular, biochemical and physiological responses to overcome the effects of drought stress (Oğuz et al., 2022). Drought stress reduces grain yield. There is a strong positive correlation between yield and stomatal density and between drought-related traits and grain yield per plant. Therefore, selection based on these characteristics will be effective (Ahmed et al., 2021). Traits that increase the ability of plants to tolerate physiological processes in different periods can improve plant growth and yields. Maintaining sustainable wheat yields to meet the growing plant population requirements under changing climatic conditions is a concern for wheat researchers and breeders (Ahmed et al., 2020).

Under drought conditions in wheat, flag leaf area, chlorophyll content, relative water content, root length and root dry weight may decrease. Under drought stress conditions, the rate of leaf water loss and the number of stomata may increase. In addition, there may be an increase in the chlorophyll content, relative water content, root length and root dry weight of drought-resistant varieties. Drought-sensitive varieties could have higher values based on flag leaf water loss rate (Balkan and Gençtan, 2024). The large flag leaf area can play an important role in increasing yield under normal drought stress conditions. Stomata in plants play an important role in regulating drought conditions. Because the rate of gas exchange and transpiration in plants depends on the size of the stomatal opening and the number of stomata per unit leaf area. Having a large number of stomata and a small stomatal size can help the plant use the available water more efficiently (Shahinnia et al., 2016; Khan et al., 2018). Stomata size and number contribute to adequate water consumption. Therefore, these traits are used in selection when developing drought-tolerant wheat genotypes (Ahmed et al., 2018). Stomatal characteristics such as stomatal density and size are considered to be the most important determinants of the speed of all developmental stages in plants and water balance in the plan (Dillen et al., 2008). There may be differences between Durum wheat and Bread wheat genotypes in terms of leaf area and stoma density during early development periods. As the development period progresses, stoma density increases. Drought reduces leaf area and causes different responses depending on stomatal density. (Mansouri et al., 2016). Stoma development may vary depending on water deficiency. Variability may vary across genotypes. While stomatal density increases in some genotypes under different stress conditions, stomatal density decreases in others. It shows that the parameters play an essential role in distinguishing tolerant genotypes and should be taken into account by the breeder (Mansouri et al., 2016). Transpiration from stomata is the main cause of water loss in plants. Stomatal characteristics affecting water use efficiency in different developmental stages of plants are important factors in evaluating genotypes for drought stress. Since stomatal characteristics are related to reducing water loss from the leaf surface during periods of water stress, this is important for maintaining vitality in drought (Bilgin et al., 2011). Stomatal pore area and density in flag leaves are determined by stoma size. It is known that there is significant genetic variation in stoma size and density in leaves. In wheat, studies have determined that smaller stoma size and higher density in flag leaves are associated with drought resistance in wheat genotypes (Baloch et al.,2013; Shahinnia et al., 2016).

Heat and drought an essential stress factors limiting productivity, especially in field crops that are produced depending on rainfall. The impact of drought is constantly increasing. It affects different development periods in plants differently. For this reason, studies on plant physiology are constantly increasing in importance. In this research conducted under rainfed conditions, physiological parameters were examined in some genotypes of durum wheat genotypes. In the study, stomatal and physiological parameters were compared in durum wheat genotypes under rainfed conditions.

2. MATERIAL AND METHODS

The study was laid out under rainfed conditions at the experimental field area of Trakia Agriculture Research Institute in Edirne of Türkiye (41º 38´ 52´´ N and 26º 36´ 07´´ N, 40 m elevation). In totally, 25 durum wheat genotypes were examined during the 2018-2019 growing cycle. The experiment was conducted in a randomized complete blocks design (RCBD) with four replications. In the experiment, the parcel area was 6 m^2, with 6 rows and the distance between rows was 0.17 cm. In the experiment, 500 seeds per square meter were used and sowing was done with a plot drill.

Table 1. Cross name and pedigree number of the durum wheat genotypes.

G. No	Cross name	Pedigree number
1	Tunca-79 (LC)	
2	Stk/4/Jo/3/Jo/Cr//Cit71/5/Erg"S"/MB(D)1988-127	TE01789-2T-2T-2T-1T-0T
3	2737/DF17-72//Ber/3/Epidur	TE01732-1T-2T-1T-1T-1T-0T
4	DF9-71/3/Vz466//61-130/414-44/4/Ergene/5/Oh.winter/3/2737// Riccya/Berk	TE01968-3T-1T-1T-0T
5	G5 (LC)	
6	Ged/3/DF15-72//DF17-72*2/Knd1149/4/DF15-72//DF17-72*2/Knd1149	TE01647A-4T-1T-2T-1T-0T
7	Kkç/3/Zf/Lds//Kobak 2916/61-130	TE0562-1T-1T-1T-0T
8	Stk/4/Jo/3/Jo/cr//cit 71/5/DF15-72//DF17-72*2/Kndr 1149	TE01659-2T-1T-1T-0T
9	TE01517-0220//DF15-72/Erg	TE01811-4T-1T-1T-0T
10	Eminbey (LC)	
11	Eupoda-3/Sla-2//Minimus/3/Plata-7/Ilbor-1//Somat-3	CDSS04B00086S-11Y-0M-7Y-0M-1Y-0B
12	Stk/4/Jo/3/Jo/Cr//Cit 71/5/DF431-83	TE01660-3T-1T-1T-0T
13	D14/Bit//Cando/4/DF15-72//DF17-72*2/Knd1149/3/Caf	TE01874-1T-1T-1T-0T
14	Cando/4/DF9-72/3/Vz466//61-130/414-44/5/Erg'S'/MB(D)1988-127	TE01792-3T-3T-1T-1T-0T
15	Kızıltan (LC)	
16	Rod/3/Kkç//Üvy162/61-130/4/Cosmidur/5/Berk469/D723	TE01836-1T-1T-3T-1T-0T
17	G17	TE02072-5T-1T-4T-0T
18	Ambral/4/DF15-72//DF17-72*2/Kndr1149/3/Caf	TE01976-1T-1T-1T-1T-0T
19	CDSS07Y00142S-099Y-099M-10Y-1M-04Y-0B	
20	Ç1252 (LC)	
21	Çmk79/DF73-85/5/Vz360/Cp//Vz156/3/Kiki/4/Bu/6/MrbsH/3/ 21563/Jo//Dr.Dwarfs15/Cr/4/Riccya/Berk//Yerli/Bağacak	CDSS07Y00797D-099Y-099M-5Y-4M-04Y-0B
22	D14/Bit//Cando	
23	Odin-15/Witnek-1//Islom-1/6/Minimus/Comb Duck-2//Cham-3/3/ Fiche-6/4/Mojo/Airon/5/Somat-3.1	CDSS07B00338S-099Y-013M-4Y-1M-0Y
24	D14/Bit//Cando/4/DF15-72//DF17-72*2/Knd1149/3/Caf	TE01806-2T-1T-1T-1T-0T
25	Sooty-9/Rascon-37//Jupare C2001/3/Sooty-9/Rascon-37//Camayo/4/ Sooty-9/Rascon-37//Somat-3.1/3/Sooty-9/Rascon-37//Storlom	CDSS08Y00584S-099Y-022M-9Y-2M-0Y

Stomata parameters; stomata length (STL) and stomata width (STW), stomata perimeter (STP), stomata area (STA) and the number of stomata (STN) were experienced on flag leaves during the heading (Z55) period were measured. Physiological parameters were measured; chlorophyll content (SPAD), canopy temperature (CT) and normalized difference vegetation index (NDVI) at heading stages. Yield and agronomic measurements were also made. Grain yield (GY) (kg ha^{-1}), plant height (PH) (cm), days of heading (DH) and flag leaf area (FLA) (cm^2) were investigated.

Normalized difference vegetation index (NDVI): NDVI was scaled at the Z55 (Zadoks et al., 1974) period. Measurements were made using a hand-held Greenseeker meter (Pask et al., 2012). NDVI in genotypes can be used to estimate biomass, growth rate, yield estimation, soil cover, early plant development, leaf wilting, and detection of biotic and abiotic stress factors (Araus, 1996; Gutierrez-Rodriguez et al., 2004; Pask et al., 2012).

Chlorophyll content (SPAD): To determine chlorophyll content in genotypes SPAD-502 chlorophyll meter was used. Chlorophyll content was measured from flag leaves randomly taken from each plot at the heading stage (Z55) (Adamsen et al., 1999; Babar et al., 2006; Pask et al., 2012; Reynolds et al., 2001).

Canopy temperature (CT): Canopy temperature (CT) (°C) was measured in each plot in genotypes between 13.00-15.00 hours on sunny and without windy days (Babar et al., 2006; Reynolds et al., 2012; Pask et al., 2012). Canopy temperature measurement was made during heading (Z55) period.

Flag leaf area (cm^2): Ten flag leaves were randomly selected from each plot and leaf length (FLL) and width (FLW) were measured with a ruler. Then, flag leaf area (FLA) in genotypes was calculated using the following formula (Dodig et al., 2010).

FLA (cm^2) = (FLL × FLW) × 0.75

Stomata width (STW), length (STL) and perimeter (µm): Stomata width, length and perimeter were determined by the average of 10 measurements in samples taken from flag leaves during the heading stages (Z55).

Stomata area (STA) (μm^2): It was determined by taking the average of 10 measurements from samples taken from flag leaves.

Number of the stomata (STN): The number of stomata in durum wheat genotypes was determined by taking an average of 10 measurements under a 4x100 magnification microscope.

Statistical Analysed

In the experiment, variance analysis of the data was performed according to the method defined by Gomez and Gomez (1984). The differences between genotype means of parameters were L.S.D tested by using a 5% level of significance. Correlation coefficients between parameters were analysed according to the method described by Dewey and Lu (1959). Cluster analysis was also estimated to evaluate the status of distinction among the genotypes. A dendrogram was created based on squared Euclidean distance (Ward, 1963).

Climate Data

Accumulated rainfall for the first season was 523.4 mm between October and June. In March total mean rainfall (7.6 mm) was less than the long-term average. The mean temperature was 11.6 ºC and the mean humidity was 76.2%. The maximum temperature was 36.2 C in June, during the grain filling period, which negatively affected the grain filling period. High temperature during the grain filling period limited starch accumulation in the grain.

Table 2. Climate conditions in Edirne/Institute experimental area in 2018-2019 growing year.

Months	Precipitation (Long year)	Rainfall (mm)	Humidity (%)	Temperature (ºC)		
				Min.	Max.	Mean
October 2018	52.9	32.6	74.2	1.6	24.8	15.7
November 2018	72.4	208.8	81.8	-2.9	23.2	9.8
December 2018	61.7	16.8	86.7	-4.5	16.5	3.9
January 2019	48.1	82.4	85.7	-9.4	16.1	4.1

February 2019	46.9	18.2	76.5	-5.5	16.8	5.6
March 2019	52.2	7.6	68.6	-1.9	23.2	9.8
April 2019	51.0	60.4	72.8	-0.3	25.8	12.4
May 2019	56.0	63.4	75.1	3.8	32.2	18.2
June 2019	41.5	33.2	64.8	19.8	36.2	24.5
Total/Mean	482.7	523.4	76.2	0.1	23.9	11.6

3. RESULTS AND DISCUSSION

Variance analysis performed on the parameters examined in the study is given in Table 3. Significant difference was found ($p<0.01$) among the genotypes according to stoma parameters except stoma length. Grain yield considerably differed in genotypes. Flag leaf area and plant height differed among genotypes. Significant differences were found ($p<0.01$) between genotypes in canopy temperature, chlorophyll content and normalised difference vegetative index.

Table 3. Mean square and F ratio for stomata, grain yield, morphological and physiological parameters measured in durum wheat genotypes.

Parameters	Sum of Squares	Mean Squares	F Ratio
Stomata width (STW)	140.244	5.843**	5.731
Stomata length (STL)	24.394	1.016ns	1.226
Stomata area (STA)	26200.323	1091.680**	2.889
Stomata perimeter (STP)	519.183	21.633**	4.775
Stomata number (STN)	173.279	7219.958**	13.253
Grain yield (GY)	170448.120	7102.005*	1.723
Flag leaf area (FLA)	908.857	37.869**	9.084
Days of heading (DH)	1095.360	45.640**	25.309
Plant height (PH)	1099.960	45.832**	19.874
Canopy temperature (CT)	50.162	2.090ns	1.526
Chlorophyll content (SPAD)	715.637	29.818**	4.363
Normalised difference vegetative index (Z35 NDVI)	0.436	0.018**	2.284
Normalised difference vegetative index (Z45 NDVI)	0.149	0.006**	3.775
Normalised difference vegetative index (Z55 NDVI)	0.067	0.003**	7.660

*, ** Significant at $p<0.05$ and $p<0.01$ respectively. ns: non-significant

Analysis of variance revealed a highly significant difference among genotypes for stomata parameters except for stomata height. The variance analysis showed highly significant differences ($P<0.01$) among the durum wheat genotypes for plant height and days of heading. Plant height in genotypes is one of the traits determining adaptation to different conditions such as stress conditions and fertile environments. While short genotypes are adapted to fertile conditions, tall genotypes are better adapted to drought and heat stress.

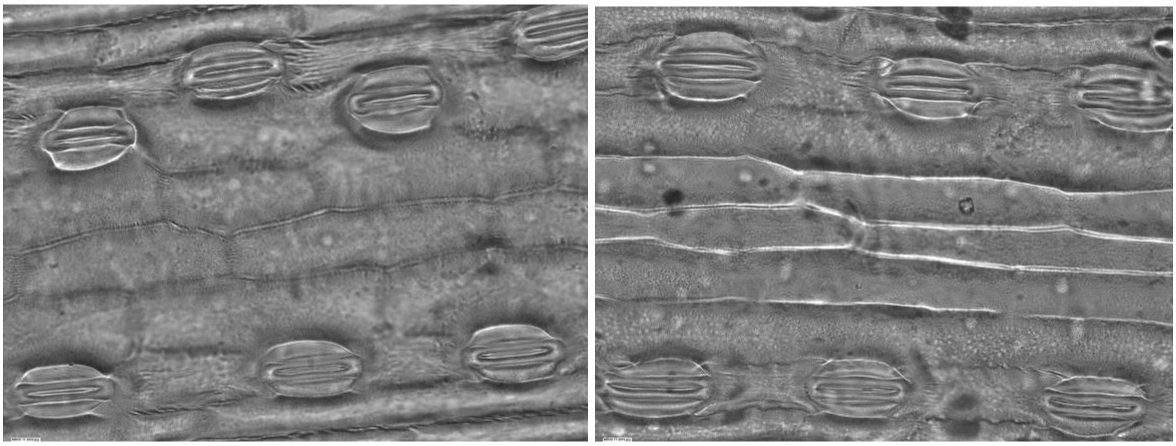


Figure 1. Stomatal samples measured durum wheat genotypes

Stoma dimensions are determined from samples taken on the flag leaf in genotypes at the heading stages. In the experiment, the widest stomata were determined in G5 and G18 genotypes. The smallest stomatal area was measured in G14. Stomata number is an important parameter for drought tolerance and the highest stomata number was determined in G4 and G5 genotypes in the study. The genotype with the longest perimeter was G10. It can be stated that these genotypes are more tolerant to drought than others.

Table 4. Stomata parameters grain yield and yield component of the genotypes

Genotype	**STW**	**STL**	**STA**	**STP**	**STN**	**GY**	**FLA**
G1	24.58c-h	12.71cde	247.0d-h	62.08def	12.48bcd	6771f	24.62a
G2	23.69f-j	14.10a	259.3c-f	61.98def	12.62bc	6852ef	23.39ab
G3	25.32bcd	13.55a-e	260.9b-f	63.45bcd	11.37f-ı	7430b-f	21.07bcd
G4	23.42g-j	12.74cde	236.6e-h	59.75e-h	13.89a	7838a-d	16.95fg
G5	25.90abc	13.70a-d	288.2ab	66.40ab	13.23ab	6945def	18.73def
G6	24.09d-j	13.71a-d	254.8d-g	61.85def	12.76bc	7540a-f	23.31ab
G7	25.22b-e	12.96a-e	256.7def	63.37cd	8.63n	7745a-e	17.73efg
G8	24.86b-f	12.49de	243.7d-h	62.04def	10.34ıjk	7520a-f	23.68ab
G9	24.83b-g	13.06a-e	258.8c-f	62.91d	9.94klm	6927ef	20.20cde
G10	27.03a	13.72a-d	285.4abc	67.07a	9.23lmn	7389b-f	22.18abc
G11	23.87e-j	13.50a-e	266.0a-d	62.55de	11.57d-h	7440b-f	21.33bcd
G12	22.91jk	13.49a-e	241.3d-h	59.78e-h	12.68bc	7161b-f	16.72fg
G13	22.73jk	14.08ab	252.0d-h	61.13d-g	11.93c-g	8365a	21.51bcd
G14	22.93ıjk	12.82b-e	225.9h	58.60gh	10.00klm	6715f	24.70a
G15	24.64b-h	12.39e	250.9d-h	62.35def	11.42e-h	7444b-f	22.48abc
G16	21.55k	13.32a-e	228.4gh	57.27h	9.03mn	7063c-f	17.39efg
G17	24.93b-f	12.75cde	256.3def	62.53de	10.13jkl	7476a-f	21.86abc
G18	26.04ab	13.87abc	290.2a	66.33abc	11.05g-j	7326b-f	18.03efg

G19	24.34d-ı	13.05a-e	251.2d-h	61.50d-g	10.82h-k	7023c-f	18.79def
G20	24.48d-h	13.25a-e	251.8d-h	62.32def	12.41b-e	7189b-f	21.01bcd
G21	25.04b-f	12.95a-e	262.2b-e	63.08d	10.58h-k	7971ab	23.87ab
G22	23.05ıj	12.87a-e	239.0d-h	59.67e-h	11.21f-ı	7098b-f	21.16bcd
G23	23.31hıj	12.60cde	233.7fgh	59.36fgh	10.91g-k	7902abc	15.46gh
G24	23.73f-j	13.82abc	256.4def	61.46d-g	11.07g-j	7697a-e	16.22fgh
G25	23.71f-j	13.42a-e	248.5d-h	60.79d-g	12.15c-f	7909abc	13.80h
Average	24.25	13.24	253.8	61.98	11.26	7389	20.25
LSD $_{(0.05)}$	1.41	1.27	27.3	3.0	1.04	90.35	2.86

STW: Stomata width (µm), STH: Stomata length (µm), STA: Stomata area (µm²), STN: Stomata number, STP: Stomata perimeter (µm), GY: Grain yield (kg ha^{-1}), PH: Plant height (cm), FLA: Flag leaf area (cm^{-2}),

In the study, it was determined that there was a significant difference between genotypes in grain yield, and a 19.7% difference was determined between the highest and lowest yield. The flag leaf area is an important consideration for photosynthesis in the plant. There was a significant difference for flag leaf areas in durum wheat genotypes. Flag leaf area varied from 13.80 to 24.70 cm^2, and genotypes G14, G1, G8 and G2 had higher flag leaf area. The flag leaf contributes more to the yield than other plant organs in wheat genotypes for photosynthetic capacity. The highest chlorophyll content was measured in lines G25, G23 and G19 (Table 4).

Mid-early genotypes are generally preferred in wheat due to precipitation and temperature fluctuations, especially during the heading and grain-filling periods. Early genotypes can escape drought and heat stress resulting from climate change. Days of the heading of the genotypes ranged from 116.3 (G23) to 128.3 (G2) and the mean was 122.1 days. Plant height in wheat is a prominent feature, especially in environmental conditions where abiotic stress factors are effective. In conditions where drought stress is effective, the excess total biomass in the plant makes a significant contribution to yield and productivity factors. Plant height varied between 115.5 and 128.5 cm across genotypes (Table 5).

Table 5. The mean physiological parameters of the durum wheat genotypes

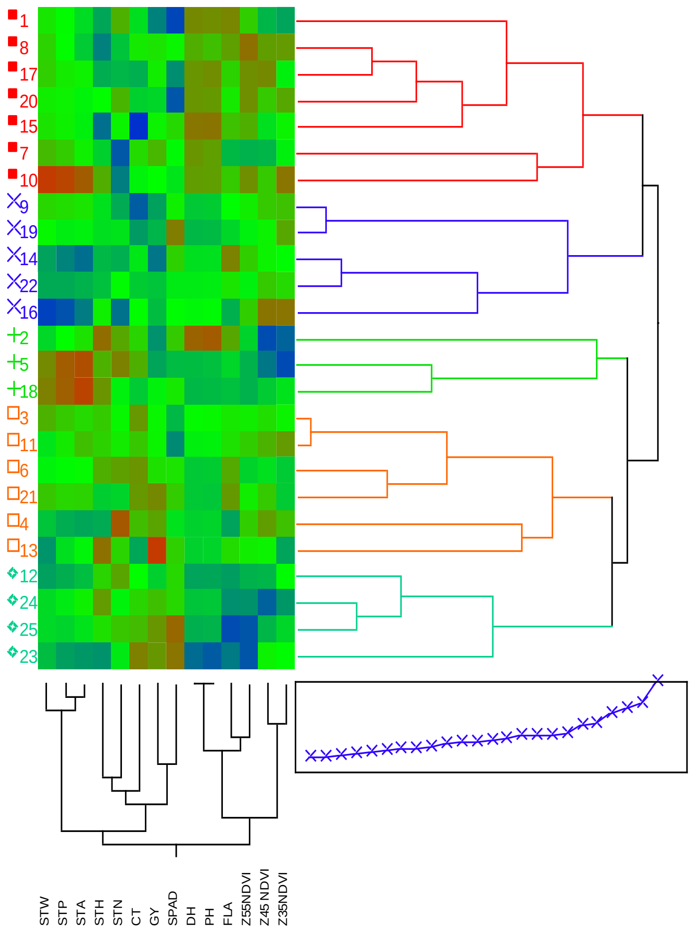
Genotype	DH	PH	CT	SPAD	NDVI (Z55)	NDVI (Z45)	NDVI (Z35)
G1	126.8abc	126.5abc	23.00a-f	50.15ı	0.78b-f	0.69e-ı	0.43def
G2	128.3a	128.5a	23.63a-d	57.73a-d	0.75f-ı	0.64ı	0.38ef
G3	122.3d	122.3d	24.15abc	53.83f-ı	0.77def	0.74a-f	0.51a-d
G4	120.3e-ı	120.3d-ı	23.83a-d	55.15d-g	0.78c-f	0.77abc	0.55abc
G5	119.5ghı	119.5f-ı	23.95a-d	53.95e-h	0.74hıj	0.66ghı	0.36f
G6	120.0e-ı	120.0e-ı	24.18ab	56.93b-f	0.75f-ı	0.71c-g	0.46b-f
G7	126.3bc	125.8bc	23.58a-d	55.90d-g	0.74hıj	0.69f-ı	0.49a-f
G8	125.3c	124.5c	23.45a-e	56.38def	0.81a	0.77ab	0.58ab
G9	120.0e-ı	120.0e-ı	21.90ef	56.58c-f	0.77def	0.75a-d	0.55abc
G10	126.0bc	125.8bc	23.18a-e	55.25d-g	0.80abc	0.75a-d	0.61a

G11	121.5def	121.5def	23.75a-d	52.33ghı	0.78a-e	0.76abc	0.58ab
G12	118.5ı	118.5ı	23.30a-e	57.35a-f	0.74ghı	0.69f-ı	0.50a-e
G13	120.3e-ı	120.3d-ı	22.53c-f	57.58a-e	0.77d-g	0.73b-f	0.43c-f
G14	120.8d-h	120.8d-h	23.08a-f	57.55a-e	0.78c-f	0.73b-f	0.50a-e
G15	127.5ab	127.5ab	21.53f	57.28a-f	0.79a-d	0.71c-g	0.51a-d
G16	121.8de	121.8de	23.30a-e	56.00d-g	0.78a-e	0.79a	0.61a
G17	126.3bc	126.5abc	22.60b-f	52.48ghı	0.80ab	0.78ab	0.49a-e
G18	119.3hı	119.3ghı	22.83a-f	56.80b-f	0.74ghı	0.70d-h	0.48b-f
G19	119.3hı	119.3ghı	22.43def	60.23abc	0.76e-h	0.73a-f	0.57ab
G20	126.3bc	126.0bc	22.88a-f	50.68hı	0.80ab	0.75a-d	0.57ab
G21	120.0e-ı	119.8e-ı	24.15abc	57.70a-d	0.77d-g	0.75a-e	0.46b-f
G22	121.3d-g	121.3d-g	22.85a-f	55.43d-g	0.76d-h	0.75a-d	0.53a-d
G23	116.3j	115.5j	24.35a	60.48ab	0.71j	0.73b-f	0.50a-e
G24	119.8f-ı	119.8e-ı	23.63a-d	57.3a-f	0.73ıj	0.65hı	0.42def
G25	119.0hı	119.0hı	23.85a-d	60.93a	0.71j	0.69e-ı	0.47b-f
Average	122.1	122	23.27	56.08	0.76	0.72	0.50
LSD $_{(0.05)}$	1.89	2.13	1.63	3.66	0.025	0.056	0.13

CT: Canopy temperature (ºC), SPAD: Chlorophyll content, NDVI: Normalised difference vegetative index, Z: Zadox

Physiological parameters canopy temperature (CT), chlorophyll content (SPAD) and normalised difference vegetative index (NDVI) were measured in the research conducted in rainfed conditions. CT and SPAD were measured in the Z55 period, and NDVI was measured in three different plant development periods. These physiological parameters enable the effective selection of genotypes under environmental conditions of drought and heat stress. The lowest canopy temperature was measured in lines G15 and G9. In the research, genotypes G8 and G16 had the higher normalised difference vegetative index. These genotypes (G8, G9, G15, G16) can adapt to different environmental conditions and can be used in breeding studies (Table 5).

Cluster analysis was used to see whether the genotypes fell into groups or clusters. Cluster analysis was performed by adopting squared Euclidean distance as a measure of dissimilarity and Ward's method as the clustering algorithm (Ward, 1963). Durum wheat genotypes were examined for fourteen parameters and a broad distinction was found for the genotypes. The cluster analysis was achieved and 25 durum wheat genotypes were grouped into 5 clusters. Based on the examined traits, the G3 and G11 genotypes were closest to each other, while the G1 and G2 genotypes were distant from each other. The fact that genotypes differ according to their genotypic and phenotypic characteristics is an important issue that allows effective selection for adaptation to different environmental conditions.



In cluster analysis, similarity rates between genotypes according to the parameters examined in the study

Number of Clusters	Distance	Leader	Joiner
24	1.40	3	11
23	1.47	9	19
22	1.67	14	22
21	1.80	24	25
20	1.89	8	17
19	2.08	6	21
18	2.15	12	24
17	2.28	8	20
16	2.38	5	18
15	2.61	3	6
14	2.76	8	15
13	2.80	14	16
12	2.99	12	23
11	3.11	1	8
10	3.38	4	13
9	3.44	7	10
8	3.45	3	4
7	3.61	9	14
6	4.42	1	7
5	4.51	2	5
4	5.46	3	12
3	5.95	2	3
2	6.32	1	9
1	8.26	1	2

Figure 2. Cluster diagram of 25 durum wheat genotypes for parameters

As expected, a positive correlation was found between stoma parameters. No relationship was observed between grain yield and stomatal parameters. Normalised difference vegetative index was negatively correlated with canopy temperature (r=-0.422) and chlorophyll content (r=-0.577). It was determined that the chlorophyll ratio was low in genotypes with long plant height and large flag leaf area. Due to chlorophyll is necessary for photosynthesis in plants, a positive relationship has been determined between grain yield and chlorophyll ratio (r=0.314). It can be stated that the expected correlation between grain yield and NDVI, FLA and CT in genotypes could not be obtained due to the influence of different factors such as yield components (Table 6).

Table 6. Coefficients of correlation among stomata and physiological parameters

Traits	STW	STL	STP	STA	STN	GY	DH	PH	FLA	CT	SPAD	NDVI Z55
STL	0.053											
STP	0.940	0.327										
STA	0.815	0.529	0.954									
STN	-0.146	0.231	-0.035	0.031								
GY	-0.040	0.051	-0.013	0.006	0.017							
DH	0.307	-0.168	0.249	0.100	-0.167	-0.251						

PH	0.296	-0.133	0.249	0.114	-0.147	-0.270	0.997					
FLA	0.218	-0.139	0.183	0.065	-0.062	-0.306	0.551	0.554				
CT	-0.038	0.225	-0.037	0.019	0.227	0.293	-0.318	-0.338	-0.221			
SPAD	-0.270	0.059	-0.282	-0.210	-0.135	0.314	-0.518	-0.522	-0.400	0.076		
NDVI (Z55)	0.173	-0.324	0.089	-0.048	-0.206	-0.206	0.605	0.605	0.675	-0.422	-0.577	
NDVI (Z45)	-0.114	-0.447	-0.237	-0.299	-0.368	0.132	0.010	-0.001	0.178	-0.159	-0.227	0.645

*, ** Significant at *P*<0.05 and *P*<0.01 respectively. STW: Stomata width, STL: Stomata length, STP: Stomata perimeter, STA: Stomata area, GY: Grain yield (kg ha^{-1}), PH: Plant height (cm), FLA: Flag leaf area (cm^{-2}), CT: Canopy temperature (ºC), SPAD: Chlorophyll content, NDVI: Normalised difference vegetative index, Z: Zadoks

4. CONCLUSIONS

Due to climate change, the ability of genotypes to adapt to changing conditions is constantly increasing in importance. Genotypes show morphological and physiological responses under stress conditions in adaptation to variable environmental conditions. Stomatal behaviour, size and number are effective in physiological responses in plants. Stoma measurements are determined on the flag leaf in genotypes at the heading stages. In the experiment, the widest stomata were determined in G5 and G18 genotypes according to stoma dimensions. Stomata number is an important parameter for drought tolerance and the highest stomata number was determined in G4 and G5 genotypes in the study. The smallest stomatal area was measured in G14. These genotypes may be tolerant to drought stress conditions due to the highest number of stomata. There was a significant difference for flag leaf areas in durum wheat genotypes. When the temperature in the plant's tissues and the canopy temperature is higher, the plant controls its temperature by allowing water to evaporate through its stomata. This is an important feature for adapting to and tolerating hot and dry conditions. Therefore, stomatal behaviour in plants is very important for adaptation to changing environmental conditions. Having a high number of stomata is preferred for drought tolerance. The difference between genotypes according to stoma measurements showed that selection could be made in terms of drought resistance. For drought tolerance, it can be explained that the genotypes G4 and G5, which have a higher number of stomata, and G5 and G18, which have wider stomata, are more resistant to drought than the others. Flag leaf area differed among genotypes. Genotypes G14, G1, G8 and G2 had higher flag leaf area. The chlorophyll content is an important parameter for photosynthesis. The highest chlorophyll content was measured in G25, G23 and G19. Low canopy temperature is important for drought tolerance. The lowest canopy temperature was scaled by genotypes G15 and G9. Genotype G8 had a higher NDVI. It can be stated that these genotypes are more tolerant to drought than others. Different correlations were determined between stoma measurements and physiological parameters. A negative correlation was determined between NDVI and stomatal parameters in genotypes. The significant differences between genotypes showed the importance of stomatal characters for selection in adaptation to different environments.

REFERENCES

Adamsen FJ, Pinter PJ, Barnes EM, La Morte RL, Wall GW, Leavitt SW and Kimball BA. 1999. Measuring Wheat Senescence with a Digital Camera. Crop Science, 39, 719.

Ahmed HGM-D, Iqbal MN, Iqbal MA, Zeng Y, Ullah A, Iqbal M, Raza H, Yar MM, Sarwar N, Imran M. 2021. Genome-Wide Association Mapping for Stomata and Yield Indices in Bread Wheat under Water Limited Conditions. Agronomy 2021, 11, 1646. https://doi.org/10.3390/agronomy11081646

Ahmed HGM-D, Sajjad M, Zeng Y, Iqbal M, Khan S.H, Ullah A, Akhtar MN. 2020. Genome-Wide Association Mapping through 90K SNP Array for Quality and Yield Attributes in Bread Wheat against Water-Deficit Conditions. Agriculture 2020, 10, 392.

Ahmed, HGM-D, Khan AS, Kashif M, Khan SH. 2018. Genetic analysis of yield and physical traits of spring wheat grain. J. Natl. Sci. Found. Sri Lanka 2018, 46, 23.

Araus JL. 1996. Integrative physiological criteria associated with yield potential. In: Reynolds MP, Rajaram S and McNab A (Eds.). Increasing yield potential in wheat: breaking the barriers. CIMMYT, Mexico, D.F.

Babar MA, Reynolds MP, van Ginkel M, Klatt AR, Raun WR, Stone ML. 2006. Spectral Reflectance to Estimate Genetic Variation for In-Season Biomass. Leaf Chlorophyll, and Canopy Temperature in Wheat. Crop Breeding and Genetics. Crop Sci. 46:1046-1057.

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.

Baloch MJ, Dunwell J, Khan NU, Jatoi WA, Khakhwani AA, Vessar NF. 2013. Morpho-physiological characterization of spring wheat genotypes under drought stress. Int. J. Agric. Biol. 15, 945–950.

Bilgin O, Korkut KZ, Başer İ, Dağlıoğlu O, Öztürk İ, Kahraman T. 2008. Determination of Variability Between Grain Yield and Yield Components of Durum Wheat Varieties (*Triticum durum* Desf.) in Thrace Region. Journal of Tekirdağ Agricultural Faculty. 2008.5 (2). P: 101-109.

Bilgin O, Başer İ, Korkut ZK, Balkan A. 2011. Investigation on Selection Criteria for Drought Tolerance of Bread Wheat (*Triticum aestivum* L.) In The North-West Turkey, Bangladesh J. Agril. Res. 36(2): 291-303, June 2011.

Dewey DR and Lu KH. 1959. A correlation and path coefficient analysis of components crested wheat grass and seed production. Agron. J. 52: 515-518.

Dillen SY, Marron N, Koch B, Ceulemans R. 2008. Genetic variation of stomatal traits and carbon isotope discrimination in two hybrid poplar families (Populus deltoides 'S9-2' x P. nigra 'Ghoy' and P. deltoides 'S9-2' x P. trichocarpa 'V24'). Ann Bot.: 102:399–407.

Dodig D, Zoric M, Kobiljski B, Surlan-Momirovic G, Quarrie S. 2010. Assessing drought tolerance and regional patterns of genetic diversity among spring and winter bread wheat using simple sequence repeats and phenotypic data. Crop. Pasture Sci. 2010, 61, 812.

Garcia del Moral LF, Rharrabti Y, Villegas D, Royo C. 2003. Evaluation of Grain Yield and Its Components in Durum Wheat under Mediterranean Conditions. Agronomy Journal. Volume: 95, Issue: 2. P: 266-274. https://doi.org/10.2134/agronj2003.2660Ci

Gomez KA & Gomez AA. 1984. Statistical Procedures for Agricultural Research. 2nd Ed. John Willey and Sons, Inc. New York. 641.

Gutierrez-Rodriguez M, Reynolds MP, Escalante-Estrada JA and Rodriguez-Gonzalez MT. 2004. Association between canopy reflectance indices and yield and physiological traits in bread wheat under drought and well-irrigated conditions. Australian Journal of Agricultural Research, 55(11), 1139–1147.

Khan A, Khaliq I, Ahmad M, Ahmed H, Khan AG, Farooq MS. 2018. Comparative Performance of Spring Wheat (*Triticum aestivum* L.) through Heat Stress Indices. Pak. J. Bot. 2018, 50, 481–488.

Mansouri D, Rassaa N, Chalh A, Bnejdi F, El Gazzah M. 2016. Stomata development variability of ten wheat genotypes under early water stress. Journal of new sciences, Agriculture and Biotechnology, 35(5), 1969-1975.

Noorka IR, Batool A, Rauf S, Teixeira da Silva J, Ashraf E. 2013. Estimation of Heterosis in Wheat (*Triticum aestivum* L.) under Contrasting Water Regimes. Int. J. Plant Breed. 2013, 7, 55-60.

Oğuz MC, Aycan M, Oğuz E, Poyraz I, Yıldız M. 2022. Drought Stress Tolerance in Plants: Interplay of Molecular, Biochemical and Physiological Responses in Important Development Stages. Physiologia 2022, 2, 180–197. https://doi.org/10.3390/physiologia2040015

Öztürk İ. 2019. Genotypes Environment Interaction and Genetic Diversity Assessment of Bread Wheat (*Triticum aestivum* L.) Genotypes. Agriculture & Food., Journal of International Scientific Publications. Volume 7, P: 60-74.

Öztürk İ. 2022. Yield and Agronomic Parameters in Durum Wheat (*Triticum durum* L.) Genotypes under Rainfed Condition. Journal of International Scientific Publications: Agriculture & Food 10, 215-223 (2022).

Pask AJD, Pietragalla J, Mullan DM and Reynolds MP (Eds.). 2012. Physiological Breeding II: A Field Guide to Wheat Phenotyping. Mexico, D.F.: CIMMYT.

Reynolds MP, Ortiz-Monasterio JI and Mc. Nab A (Eds). 2001. Application of Physiology in Wheat Breeding. Mexico, D.F., CIMMYT.

Reynolds MP, Pask AJD and Mullan DM (Eds.). 2012. Physiological Breeding I: Interdisciplinary Approaches to Improve Crop Adaptation. Mexico, D.F.: CIMMYT.

Shahinnia F, Le Roy J, Laborde B, Sznajder B, Kalambettu P, Mahjourimajd S, Tilbrook J, Fleury D. 2016. Genetic association of stomatal traits and yield in wheat grown in low rainfall environments. BMC Plant Biol. 2016, 16, 1-14.

Zadoks J, Chang T, Konzak C. 1974. A decimal code for the growth stages of cereals. Weed research 14: 415-421.

Zhao T, Dai A. 2015. The Magnitude and Causes of Global Drought Changes in the Twenty-First Century under a Low–Moderate Emissions Scenario. J. Clim. 2015, 28, 4490 – 4512.