Journal of Animal & Plant Sciences, 35(1): 2025, Page: 197-208
ISSN (print): 1018-7081; ISSN (online): 2309-8694
https://doi.org/10.36899/JAPS.2025.1.0015

SCREENING OF DROUGHT TOLERANT LEVEL OF SOME WHEAT CULTIVARS (*Triticum Durum* Desf.) UNDER WATER STRESS

L. Yorulmaz[1], S. Ipekesen[1*], M. Oner[2], C. Akinci[1] and B. T. Bicer[1]

[1]Dicle University, Agriculture Faculty, Department of Field Crops, Diyarbakir, Turkey.
[2]Diyarbakir Agriculture Vocational High School, Diyarbakir, Turkey.
[*]Corresponding author's E-mail: sibelisikten@gmail.com

ABSTRACT

Wheat is an important agricultural crop in Turkey's agricultural production system; however, recently drought stress is one of the most important reasons for the decrease in yields in wheat production regions of Turkey. Therefore, it is important to identify genotypes or cultivars that are less affected by drought stress. The aim of this study was to determine the performance of ten wheat genotypes against water stress. Water stress was applied from seed emergence to seed maturity accounting for 100% and 50% field capacity. Nine agro-morphologic traits were evaluated under semi-controlled greenhouse conditions. The experiment was arranged in Randomized Complete Block design with four replications. Data analysis were realized parameters such as the heading time, plant height, spike length, the number of fertile spikelet/plant, the number of grains per spike, grain weight per plant, SPAD values at heading (51.06) and flowering stages and protein ratio. Water stress reduced heading time (66.45 days), plant height (36.36 cm), spike length (3.72 cm), the number of fertile spikelet/plant (9.99), the number of grains per spike (5.82), grain weight per plant (0.25 g). SPAD values at heading (51.06) and flowering stages (52.44) and protein ratio (23.07%) was increased under water-stressed conditions. Anzele genotype was the highest tolerant to water stress for grain number spike^{-1} (11.13) and grain weight plant^{-1} (0.48 g). Burgos genotype had the best performance for protein ratio (27.47%) under water stressed conditions. The variations among cultivars for examined traits indicated that Anzele and Burgos cultivars could be considered for breeding programs in future.

Keywords: *Triticum durum*, water stress, field capacity, grain weight.

INTRODUCTION

The food demands of the increasing human population will be challenging to meet in the future since drought, brought about by global warming, causes serious yield losses in agricultural production. Unfortunately, the effects of heatwaves and drought stress on agricultural production are predicted to become more intense and widespread in the next years (Bezak and Mikos, 2020).

Given the growing threat of drought to agriculture, it is critical to understand its impact on staple crops like durum wheat (*Triticum durum* Desf.). The drought stress can reduce the production of wheat by an average of 50-60% compared to under irrigated areas or rainfed conditions. Indeed, durum wheat is an essential food source including carbohydrates, dietary proteins, fiber, energy etc. (Boukid *et al.,* 2019). If the drought continues in wheat cultivation especially during the flowering and grain-filling period stages (Farooq *et al.* 2015; Hussain *et al*., 2016; Bassi *et al.,* 2017), production will assume to decline. Therefore, it will be inevitable that people who consume wheat will suffer from food deficiency.

Drought stress can induce morphological, biochemical, physiological and molecular changes in crops; however, these effects can vary from crop to crop depending on drought severity. Durum wheat breeding programs are intensive on agronomical, physiological and biochemical traits. To understand the effects of drought on wheat yield, the time of drought occurrence, duration and severity are important. Water stress of wheat during the germination, flowering, and grain-filling stages negatively affects wheat grain yield and yield-related traits (Ali, 2019). At the early plant development stage, drought can reduce plant height, leaf area and number of fertile tillers. At reproduction stage, it can reduce yield-affected parameters of wheat cultivars such as pollen abortion and sterile tillers (Qaseem *et al*., 2019), the number of grains per spike, chlorophyll content (Mehraban *et al*., 2019; Baser *et al*., 2024), grain weight, plant height (Pour-Aboughadareh *et al*. 2020) and protein content (Javed *et al*. 2022).

Wheat production can be drastically affected by drought stress that essential abiotic factor in arid and semi-arid zones (Singh *et al*., 2024). The changes in agronomical, physiological and biochemical traits cause disruptions in wheat growth and reduce the final yield. Therefore, steps to reduce wheat loss caused by inadequate rainfall, which is among the negative effects of climate change, on agricultural production must be emergently applied (El-Hendawy *et al*., 2015). Especially, the improvement of new cultivars with high drought tolerance is significant for breeding research to improve grain yield (Guerrini *et al*., 2020).

This study aimed to evaluate the drought tolerance of various wheat genotypes by assessing key agro-morphological traits under water stress conditions. In the study, two drought-levels including 100% and 50% field capacity were applied. The purpose of testing the 50% drought level was to investigate the impact of water levels below the field capacity, which block healthy growth and development of plants on plant performance. Indeed, for healthy growth and development, irrigation should be typically performed before the soil water level falls to half of the field capacity (Far Focus, 2010). Therefore, the 50% field capacity drought level in our study will serve as an important reference for evaluating the performance of durum wheat.

MATERIALS AND METHODS

The experiment was carried out under semi-controlled greenhouse conditions at Dicle University, Agriculture Faculty, Department of Field Crops, Diyarbakir, Turkey (37° N latitude, 40° 27'E longitude and at an altitude of 675 meter above average sea level). A set of 10-durum wheat genotypes were examined under 100% and 50% field capacity conditions in the 2023 growing season. Names, properties and origins of 10 durum wheat genotypes were given in Table 1.

Daily temperature and humidity data during the growing season in the greenhouse is presented in Figure 1. In semi-controlled greenhouse conditions, the average temperature during vegetation was 19.9 °C, and the average humidity was 42.9% (Figure 1).

Table 1. Names, properties and origins of 10 durum wheat cultivars

Name	Origins	Properties	
Fırat-93	Turkey	Tolerant	Mid-earlier
Burgos	Turkey	Resistant	Mid-earlier
YM-16	Turkey (local)	Non-defined	Mid-earlier
Anzele	Turkey	Non-defined	Mid-earlier
Cyprus-2	Cyprus	Non-defined	Mid-earlier
Ovidio	Turkey	Non-defined	Mid-earlier
Seckin-21	Turkey	Non-defined	Mid-earlier
Sena	Turkey	Non-defined	Mid-earlier
Sham-1	Turkey	Non-defined	Mid-earlier
Svevo	Turkey	Non-defined	Earlier

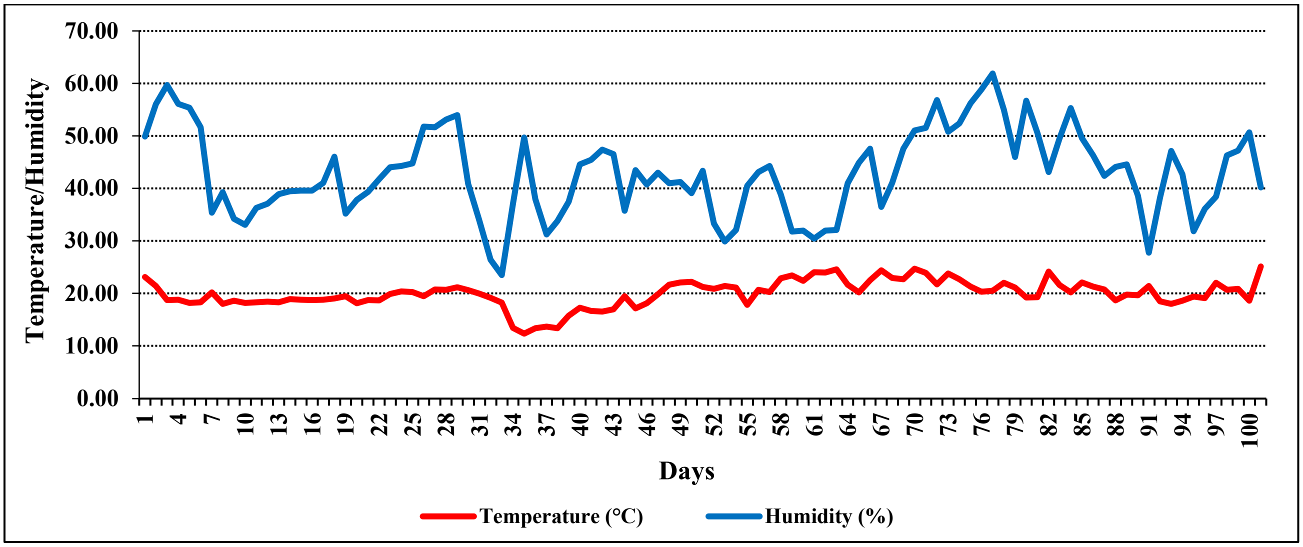

Figure 1. Temperature and humidity data daily during growing season in greenhouse.

The experimental soil was clay-loam textured with pH 8.15. It was low in organic matter (0.77%), nitrogen (0.10%), phosphor (P_2O_5; 14.80 kg/ha) and Ec value (0.042 dS/cm), however, soil was rich in iron (8.86 ppm), potassium (K_2O; 644.3 kg/ha), magnesium (637.58 ppm) and calcium content (9.37 ppm).

In the study, two drought-levels including 100% field capacity and 50% field capacity were applied. Six-litter pots were used in the experiment. The pots soil was dried at 105°C for 24 hours and 6 kg of soil and sand (2:1) was filled into pots. The water-holding capability of the soil was calculated from the wet and dry weight values. Pots were wholly saturated by water to determine the field capacity; they were kept for 48 hours until water infiltration finished. After 48 hours, the pots were weighed to determine the wet soil weight. The difference between the wet soil weight and the dry soil weight was determined field capacity (Bilski and Foy, 1987). Afterwards, 50% of the field capacity of pots was calculated. 100% field capacity was 1865 litter, and field capacity½ was 932 litter.

The experiment was conducted according to the Randomized Completed Block design in split plots with four replications accounting for the total number of pots of 80 (4 replications/10 genotypes/2 treatments). The experimental area was continuously controlled due to semi-controlled greenhouse conditions. The grains were kept in the fridge at +4 °C for one month to meet the vernalization requirement before the sowing. Before sowing, the grains were sterilized for 10 minutes with a 20% bleach solution washed three times with distilled water and left to stand for 45 minutes in distilled water. The grains were sterilized for 10 minutes with a 20% bleach solution washed three times with distilled water and left to stand for 45 minutes in distilled water, and four grains were sown in each pot on October 26, 2023. Fertilizers were treated 6 g m^2 N and 6 g m^2 P (60 kg ha^{-1} N+ 60 kg ha^{-1} P) at sowing and 6 g m^2 N urea (60 kg ha^{-1} N) at stem elongation stage fertilized each pot.

All pots were irrigated until 90-95% all grains germinated. Drought stress was started at germination stage. Four pots for each genotype were irrigated at 100% field capacity, and four pots for each genotype were watered at 50% of field capacity until physiological maturity. The pot weights were controlled at stress and control group every day, and the amount of irrigation water was completed at 100% and 50% field capacity levels. 68±4 days were recorded on from number of days after sowing to heading time (Zadoks growth scale/Z59), and number of days from sowing to physiological maturity was 99 days (Zadoks growth scale/Z92) (Zadoks, 1974). irrigation was ended at physiological maturity, plants were harvested on February 3, 2024.

In four plant samples of each cultivar and treatment, the agro- morphological traits were record on heading time, plant height, chlorophyll content, spike length, number of spikelet/plant, number of grains spike^{-1}, grain weight plant^{-1} (Koc and Genc 1990) and protein ratio (NIT System Infratec). Heading time was calculated as the number of days from the emergence date until the ears emerged from the flag leaf sheath. Plant height was measured from the ground to the tip of the main spike of the plant. Chlorophyll content (SPAD) in leaves of wheat from the flag leaf was measured by minolta 502-SPAD during heading and flowering stages between 11.00 a.m. and 1.00 pm in sunny days. SPAD (chlorophyll content) was measured only two times at the heading and flowering stages. Spike length was measured from the lowest node of the plant on the main spike axis to the tip of the top spikelet (excluding the awn). The number of spikelet/plant was counted the spikelet per plant, and the number of grains spike-1 counted grains per spike. Grain weight plant-1 was recorded by weighing the grains obtained from the spike sample on a 0.01 g sensitive scale. After the harvest 10 g grain samples collected from each replication were homogenized and used for protein analysis. Grain protein content (N × 5.7, DM) was measured by NIT System Infratec 1241 Grain Analyzer (Foss, Hillerod, Denmark).

Statistical Analysis: The analysis of variance was performed using JMP-PRO 17 according to Randomized Complete Block design under split-plot arrangement. Heat map matrix based on pairwise correlation coefficients of traits were performed in same software. Means were compared by Fisher's least significant difference method ($P \leq 0.05$ and $P \leq 0.01$). Having the best performance, cultivars determined biplot analysis technique obtained from sector, polygon and mega environments using Genstat 12th software. This technique identified superior cultivars representing examined parameters.

RESULTS

The effect of water stress on grain and some yield parameters was examined for different durum wheat cultivars. The results of variance analysis are presented in Table 2, and mean values of durum wheat cultivars for agro-morphological traits under non-stressed and water-stressed conditions are given in Table 3. Effect of water stress treatment on all traits was statistically significant, also, cultivar and cultivar × treatment interaction were statistically significant for all traits, except for SPAD value (at heading stage) and spike length.

Heading time was significantly affected by water stress ($P \leq 0.01$). Water stress generally was cause early heading of durum wheat cultivars. Under non-stressed conditions, the latest heading time was in Firat-93 (71.00 days), the earliest heading time was in Sena (65.25 days), followed by Cyprus-2 (65.50 days). Under water-stressed conditions, the latest heading time was recorded in Ovidio (72.50 days), the earliest heading time was in Svevo and Sena with 64.50 days. According to cultivar × treatment interaction, heading time was delayed by water stress in Ovidio (72.50 days), followed by Firat-93 (71.00 days), in contrast to Svevo and Sena, for which the earliest heading time (64.50 days) was recorded under water-stressed conditions (Table 3).

Table 2. The results of variance analysis based on mean square of examined traits

Variance Sources	**DF**	**Heading time**	**SPAD value at heading stage**	**SPAD value at flowering stage**	**Plant height**	**Spike length**
Cultivar	9	20.3278**	33.6788**	57.1729**	51.8939**	0.36455
SE$_G$	30	1.06667	3.18142	2.90479	2.79653	0.17308
Treatment	1	48.05**	27.1445*	27.2611**	3550.1**	17.3911**
Cultivar × Treatment	9	13.3833**	5.15811	18.9389**	106.857**	0.37032
SE	30	1.88333	4.11275	2.4925	2.637	0.200450
CV (%)		**2.04**	**4.01**	**3.04**	**3.77**	**10.69**
		Number of fertile spikelet/plant	**Grain number spike^{-1}**	**Grain weight plant^{-1}**	**Protein ratio**	
Cultivar	9	4.21155**	74.6855**	0.14169**	24.7332**	
SE$_G$	30	0.46928	0.6016	0.00277	0.0405	
Treatment	1	63.729**	2188.58**	8.74668**	1173.67**	
Cultivar × Treatment	9	3.95218**	87.7982**	0.16783**	14.8606**	
SE	30	0.73123	74.6855**	0.14169	24.7332	
CV (%)		**7.85**	**7.33**	**11.00**	**1.49**	

*, **; significant at P≤0.05 and P≤0.01 levels, respectively. SE; Standard error, SE$_G$; Standard error of genotypes, CV; Coefficient of variation.

Water stress significantly affected on chlorophyll content (SPAD) both heading and flowering stages (P≤0.01). Our results showed that, under non-stressed conditions, chlorophyll content varied between 46.10 (Cyprus-2) and 52.92 (Ovidio). Under water-stressed conditions, it was ranged from 46.15 (Cyprus-2) to 53.17 (Seckin-21). As shown in Table 3, chlorophyll content varied between 46.10 and 53.57 at the heading stage for cultivar × treatment interaction. At the flowering stage, under non-stressed conditions the highest chlorophyll content was found in YM-16 (56.25), followed by Anzele (55.35). In contrast, the lowest value was recorded in Burgos and Cyprus-2 with 46.68 and 46.38, respectively. Under water-stressed conditions, the maximum chlorophyll content was in Seckin-21 (56.60), the minimum was in Cyprus-2 (47.00). As shown in cultivar × treatment interaction, the highest chlorophyll content was recorded in Seckin-21 (56.60) under water-stressed, followed by YM-16 (56.25) under non-stressed conditions. The lowest chlorophyll content was found in Burgos (46.68) and Cyprus-2 (46.38) under non-stressed conditions.

Plant height was significantly affected by water stress (P≤0.01). Under non-stressed conditions, the tallest cultivars were Svevo (56.64 cm) and Ovidio (55.42 cm), however, the shortest cultivar Sham-1 (41.94 cm). Under water-stressed conditions, plant height was remarkably decreased in all cultivars. Among cultivars, Svevo was recorded in the tallest cultivar with 40.19 cm. Plant height of Ovidio was decreased by almost half (28.75 cm) under water-stressed conditions, and it was recorded as the shortest cultivar. Cultivar × treatment interaction showed that Svevo (56.64 cm) and Ovidio (55.42 cm) had the highest plant height under non-stressed conditions. Ovidio (28.75 cm) was the lowest value for plant height under water stressed conditions (Table 3).

Spike length was reduced by water-stressed (P≤0.01). Under non-stressed conditions, spike length ranged from 4.20 cm to 5.01 cm. However, spike length was decreased under water-stressed conditions, and it was varied between 3.38 cm and 4.23 cm (Table 3). As shown in Table 3, spike length ranged from 3.38 cm to 5.01 cm for cultivar × treatment interaction. Our results showed that, under the non-stressed condition, the maximum number of fertile spikelet / plant was found in Ovidio (13.00), followed by Burgos (12.96), YM-16 (12.75) and Firat-93 (12.67). In contrast, the minimum counts were recorded in Sena (8.92). Under the water-stressed condition, the maximum number of fertile spikelet / plant was counted in Burgos (11.00), in contrast, the lowest number of fertile spikelet / plant (8.91) was in Firat-93 (Table 3). As shown in cultivar × treatment interaction, the highest number of fertile spikelet / plant was recorded in Ovidio (13.00) and Burgos (12.96) under non-stressed conditions. However, the lowest counts were in Firat-93 (8.91) under water-stressed conditions, followed by Sena (8.92) under non-stressed conditions.

Table 3. Traits of durum wheat cultivars under non-stressed and water-stressed conditions.

Cultivars	**Heading time (days)**		**SPAD value at heading stage**		**SPAD value at flowering stage**	
	Non-stress	**Water stress**	**Non-stress**	**Water stress**	**Non-stress**	**Water Stress**
Anzele	67.25 efg	66.50 fgh	49.70	50.65	55.35 ab	50.13 fg
Burgos	70.25 bc	66.25 fgh	48.55	50.00	46.68 h	50.83 ef
Cyprus-2	65.50 hı	66.25 fgh	46.10	46.15	46.38 h	47.00 h
Firat-93	71.00 ab	65.50 hı	47.92	51.85	49.95 fg	52.65 de
Ovidio	69.00 cd	72.50 a	52.92	52.77	53.60 bcd	53.80 bcd
Seckin-21	67.75 def	66.75 fgh	52.82	53.57	50.98 ef	56.60 a
Sena	65.25 hı	64.50 ı	48.75	52.02	52.53 de	53.13 b-e
Sham-1	67.75 def	66.00 ghı	50.72	51.62	52.75 cde	53.38 bcd
Svevo	68.50 de	64.50 ı	48.62	50.62	48.35 gh	51.93 def
YM-16	67.75 def	65.75 ghı	52.90	51.4	56.25 a	55.05abc
LSD (0.05)	C×T: 0.04**		C×T: ns		C×T:0.06**	
	Plant height (cm)		**Spike length (cm)**		**Number of fertile spikelet/plant**	
	Non-stress	**Water stress**	**Non-stress**	**Water stress**	**Non-stress**	**Water stress**
Anzele	49.89 c	36.75 ıj	4.20	3.38	10.83 de	9.25 gh
Burgos	49.27 c	33.06 k	4.96	3.56	12.96 a	11.00 cde
Cyprus-2	46.25 d	37.00 hıj	4.96	4.23	12.13 ab	10.35 ef
Firat-93	54.58 ab	35.83 ıj	5.01	3.60	12.67 ab	8.91 h
Ovidio	55.42 a	28.75 l	4.87	3.40	13.00 a	10.08 efg
Seckin-21	52.56 b	35.44 j	4.65	3.81	11.81 bcd	10.31 efg
Sena	41.56 ef	38.16 ghı	4.06	4.02	8.92 h	10.20 efg
Sham-1	41.94 e	39.13 gh	4.67	4.00	10.63 ef	10.00 e-h
Svevo	56.64 a	40.19 efg	4.58	3.63	12.06 abc	10.13 efg
YM-16	48.73 c	39.31 fgh	4.60	3.60	12.75 ab	9.66 fgh
LSD (0.05)	C×T:0.06**		C×T: ns		C×T:0.03**	
	Grain number spike^{-1}		**Grain weight plant^{-1} (g)**		**Protein ratio (%)**	
	Non-stress	**Water stress**	**Non-stress**	**Water stress**	**Non-stress**	**Water stress**
Anzele	15.03 d	11.13 e	0.85 e	0.48 g	12.05 n	22.96 e
Burgos	22.68 a	3.73 ı	0.98 d	0.15 k	16.79 j	27.47 a
Cyprus-2	17.83 c	8.63 f	0.85 e	0.40 h	15.81 k	18.06 h
Firat-93	19.94 b	3.50 ı	1.14 b	0.18 jk	14.82 l	19.38 g
Ovidio	17.37 c	6.25 gh	1.07 bc	0.16 k	17.31 ı	22.96 e
Seckin-21	13.98 d	5.25 h	0.99 de	0.20 jk	15.15 l	24.28 c
Sena	11.98 e	3.78 ı	0.77 f	0.20 jk	15.16 l	23.95 cd
Sham-1	3.24 ı	6.19 gh	0.34 hı	0.26 ıj	15.53 k	23.70 d
Svevo	17.35 c	3.13 ı	0.85 e	0.18 jk	17.22 ı	25.50 b
YM-16	23.52 a	6.73 g	1.29 a	0.32 hı	14.26 m	22.43 f
LSD (0.05)	C×T:0.03**		C×T:0.002**		C×T:0.0008**	

*, **; significant at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively. Levels not connected by same letter are significantly different. Abbreviations: ns; non-significant. C; Cultivar, T; Treatment.

Number of grains per spike was strongly affected by water-stress ($P \leq 0.01$). Number of grains per spike was remarkably decreased by water-stressed compared to non-stressed conditions. Under non-stressed conditions, number of grains per spike was maximized in YM-16 (23.52), followed by Burgos (22.68). In contrast, number of grains per spike was sharply decreased in Sham-1, and this cultivar had produced minimum grains per spike (3.24). Under water-stressed conditions, number of grains per spike was significantly decreased in all cultivars ($P \leq 0.01$). Anzele produced the highest number of grains per spike (11.13), however, Sena had the lowest counts (3.78), followed by Burgos (3.73), Firat-93 (3.50) and Svevo (3.13), respectively. As shown in cultivar × treatment interaction, the highest number of grains per spike was in YM-16 (23.52) under non-stressed conditions, followed by Burgos (22.68). The lowest counts were recorded in Sena (3.78), Burgos

(3.73), Firat-93 (3.50) and Svevo (3.13), respectively (Table 3).

The grain weight was significantly affected by water stress, and grain weight was significantly decreased under water stress ($P \leq 0.01$). Under non-stressed conditions, the maximum grain weight was found in YM-16 (1.29 g), in contrast, Sham-1 (0.34 g) exhibited the minimum grain weight. Under water-stressed conditions, the maximum grain weight was in Anzele (0.48 g), however, the minimum values were in Burgos (0.15 g) and Ovidio (0.16g), respectively. As shown in to cultivar × treatment interaction, the highest grain weight was recorded in YM-16 (1.29 g) under non-stressed conditions, followed by Firat-93 (1.14 g) and Ovidio (1.07 g), respectively. The lowest values were in Burgos (0.15 g) and Ovidio (0.16g) under water-stressed conditions (Table 3).

Under non-stressed conditions, protein ratio was the lower than under water- stressed conditions. Our data showed that Ovidio (17.31%) had the maximum protein ratio under the non-stressed condition, followed by Svevo (17.22%). However, Anzele (12.05%) showed minimum protein ratio. Under water-stressed conditions, protein ratio increased in all cultivars. The maximum protein ratio was recorded in Burgos (27.47%), and minimum value was in Cyprus-2 (18.06%). As shown in cultivar × treatment interaction, the examined cultivars tended to significantly increase the protein ratio under water stressed conditions, and this increase was well marked in Burgos (27.47%), followed by Svevo (25.50%). However, Anzele performed the lowest value for protein ratio (12.05%) under non-stressed conditions (Table 3).

Relation between examined traits: We used two heat maps depending on pairwise correlation to display the effects of different field capacity conditions on the relationships among the examined traits (Figure 4). In the graph, red colors indicated high correlations and blue colors indicate low correlations.

Grain weight was correlated positively with heading time, plant height, number of spikelet/plant and grain number spike^{-1}. Protein ratio was negatively correlated with SPAD value at heading stage, while correlated positively with spike length. Number of spikelet/plant yield had significantly positive correlation with heading time, plant height and spike length. Grain number spike^{-1} correlated positively with heading time, plant height and number of spikelet/plant. Spike length positively correlated with heading time and plant height, while correlated negatively with SPAD values. SPAD value at heading stage was positively correlated with SPAD at flowering stage under the non-stressed condition.

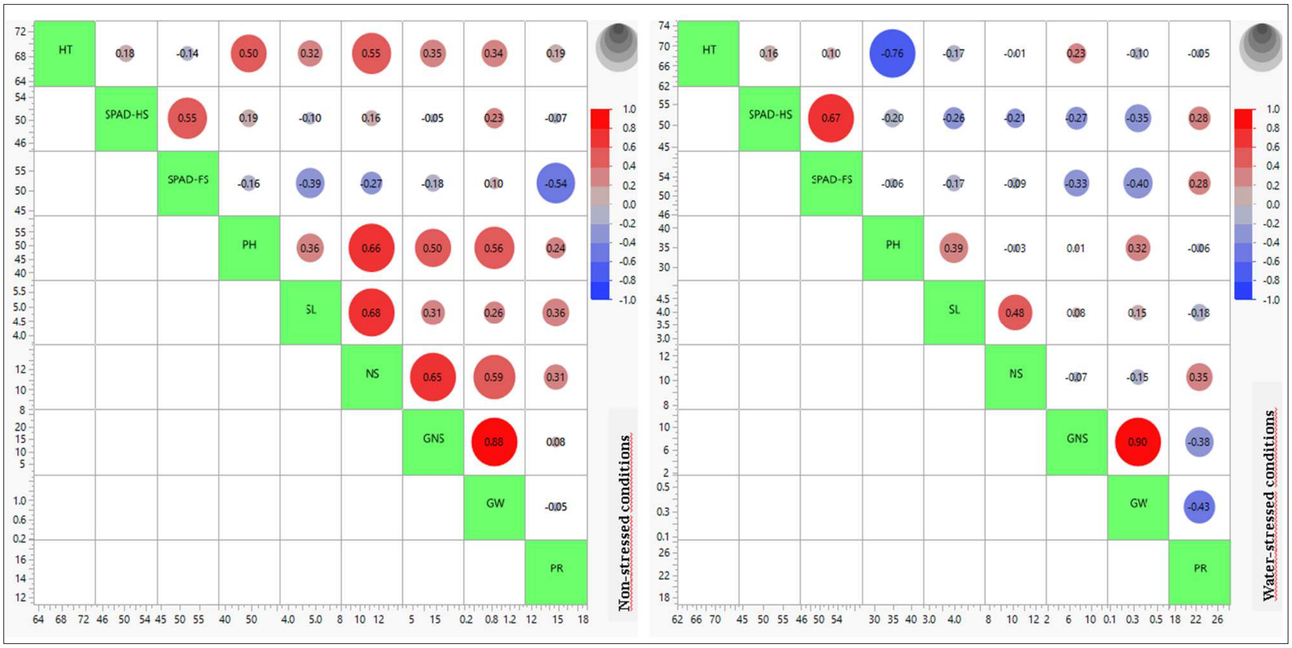

Figure 2. Heat map indicating the relation among examined traits based non-stressed and water–stressed conditions. The size of each circle indicates the correlation intensity between two traits. Abbreviations: HT; Heading time, SL; Spike length, SPAD-HS; SPAD value at heading stage, SPAD-FS; SPAD value at flowering stage, PH; Plant height, NS; Number of spikelet/plant, GNS; Grain number spike^{-1}, GW; Grain weight plant^{-1}, PR; Protein ratio.

Grain weight strongly significant correlated with grain weight. Protein ratio was positively significant correlated with number of spikelet/plant, while correlated negatively with grain number spike^{-1} and grain weight. Plant height strongly negative correlated with heading time. Spike length positively significant correlated with plant height. SPAD value at flowering stage was positively significant correlated with SPAD value at heading stage under water-stressed conditions (Figure 2).

Identifying and clustering superior cultivars under different field capacity: The biplot model supplies breeders visually to assay the data by designing a biplot constituted mean performance and stability (Yan and Tinker, 2006; Yan and Holland 2010). Under non-stressed conditions, the total variation of (PC1+PC2) was 68.90%, and PC1 and PC2 accounted for 43.83 and 25.07%, respectively. SPAD value at flowering stage negatively correlated with other traits. Vectors representing traits with narrow angles indicate positive correlation between traits. Accordingly, as the angle of view narrows, the correlation increases between traits. The cultivar numbered 10 (YM-16) had the best mean for SPAD value at flowering stage, while the cultivar numbered 2 (Burgos) had the best mean for number of spikelets spike^{-1} and protein ratio. Additionally, cultivar numbered 5 (Ovidio) performed the best mean for grain weight plant^{-1}, plant height, grain number spike^{-1}, number of spikelets spike^{-1} and heading time (Figure 3).

Under water-stressed conditions, the total variation of (PC1+PC2) was 66.44%, and PC1 and PC2 accounted for 40.40 and 26.04%, respectively. Grain number spike^{-1}, grain weight per plant^{-1}, plant height and spike length correlated negatively with other traits. Heading time SPAD at heading and flowering stages, protein ratio and number of spikelet/plant had a positive correlation with each other. The cultivar numbered 5 (Ovidio) had the best mean for heading time, while the cultivar numbered 6 (Seckin-21) SPAD values. The cultivar numbered 7 (Sena) had the best performance for number of spikelets spike^{-1} and protein ratio. The cultivar numbered 3 (Cyprus-2) had the best mean for plant height and spike length, while cultivar 1 numbered (Anzele) had the best mean for grain number spike^{-1} and grain weight plant^{-1} (Figure 3). The cultivars of Ovidio, Seckin-21, Sena, Cyprus-2 and Anzele were tolerant to water stress compared to other cultivars for related traits.

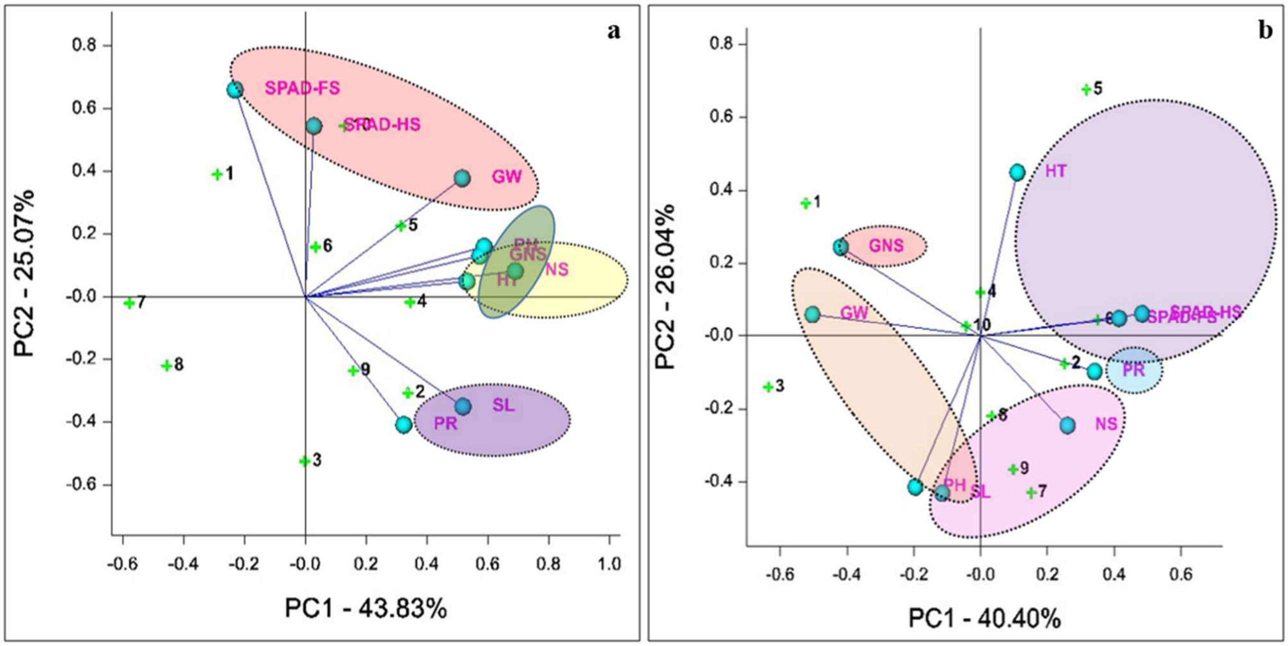

Figure 3. Principal component of PC1 and PC2 showing groupings of durum wheat cultivars depend on traits under non-stressed and water-stressed conditions. a; 100% field capacity (non-stressed conditions), b; 50% field capacity (water stressed conditions), 1; Anzele, 2; Burgos, 3; Cyprus-2, 4; Firat-93, 5; Ovidio, 6; Seckin-21, 7; Sena, 8; Sham-1, 9; Svevo, 10; YM-16. HT; Heading time, SL; spike length, SPAD-HS; SPAD value at heading stage, SPAD-FS; SPAD value at flowering stage, PH; Plant height, NS; Number of spikelet/spike, GNS; Grain number spike^{-1}, GW; Grain weight plant^{-1}, PR; Protein ratio.

According to cluster analysis, the durum wheat cultivars were classified into two groups (Figure 4). Under non-stressed conditions, the first group included Anzele, Sena and Sham-1 cultivar, while the second group included other cultivars. A slight similarity was between cultivars in the first group for all traits. In the second group, YM-16, Ovidio and Seckin-21 cultivars showed similar values for SPAD value at heading and flowering stages, and grain weight, while cultivars Firat-93 and Burgos for heading time, number of spikelets spike^{-1}, protein ratio and spike length. Under water-stressed conditions, cultivars Anzele and Cyprus-2 took part in the first group, while the other cultivars took part in the second group. Similar values for plant height and spike length were in Cyprus-2, and grain number spike^{-1} and grain weight plant^{-1} were in Anzele cultivar. The Ovidio and Burgos cultivars showed similar heading time, while Seckin-21 and YM-16 showed similar SPAD values. Sena, Sham-1 and Svevo cultivars had similar number of spikelet/plant and protein ratio (Figure 4).

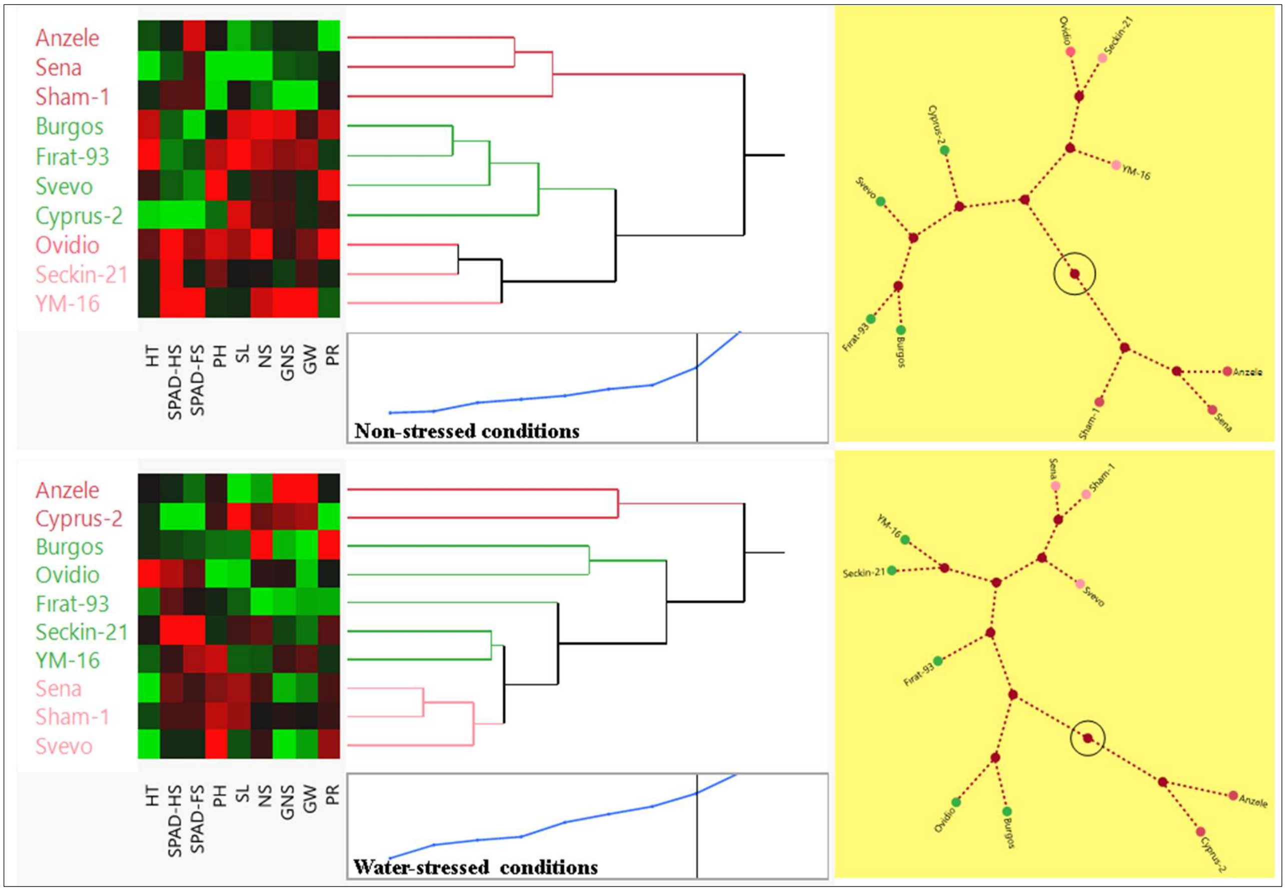

Figure 4. Dendrogram of the cluster analysis of 10 durum wheat cultivars based on examined traits under non-stressed and water-stressed conditions using by Ward's method.

DISCUSSION

Crops respond to water stress via morphological, physiological, and biochemical changes (Mohiuddin *et al*., 2021). However, the effect of stress is changed based on its degree, duration, phase of crop development, genotype, and their interaction (Ru *et al*., 2023). This study results showed that stress was bring out significant changes the measured traits. At heading and flowering stages, stress was in general decreased the all parameters recorded except for SPAD value and protein ratio (Table 3; Figure 2). These results were similar to the findings of some researchers who recorded the negative effect of water stress on morphological and quality parameters (Pandey *et al*., 2014). However, the response to stress varied depending on the region where the cultivars were grown (Chaouachi *et al*., 2023).

Our results revealed that Seckin-21, Svevo, Burgos and Anzele were the most tolerant to water stress, but Sena, Cyprus-2, Ovidio and Firat-93 were the most sensitive cultivars for some traits such as heading time (Table 3; Figure 2). Heading time was delayed by water stress in Ovidio. Our findings were similar to the findings of Dorrani-Nejad *et al*. (2022) who reported that drought stress promoted early heading. Early heading is a heritable trait, and the earliness trait is ensured high yields in environments where drought stress occurs (Dorrani-Nejad *et al*., 2022). Therefore, early-headed cultivars could be used in breeding programs under drought stress conditions.

At heading stage, chlorophyll content (SPAD) value was high in Seckin-21 (56.60) under water stress (Table 3; Figure 2). Javed *et al*. (2022) stated that the chlorophyll index (SPAD) ranged from 50.0 to 54.0 under drought stress conditions. Some researchers also noted that SPAD value was changed by drought stress, drought stress that occurred at the time of heading, SPAD was especially correlated with final yield (Akram *et al*., 2014; Mohammadi *et al*., 2016). Indeed, plants can meet their water requirement when the soil water level is the closest to field capacity. However, if soil water level is fall below field capacity, photosynthesis efficiency, stomatal conductivity and chlorophyll content are decreased.

Plant height was increase in Svevo under water stress (Table 3; Figure 2). The capacity of tall wheat cultivars for absorbing water from the soil is higher than short cultivars, and this is a significant advantage to stored dry matter in the stem of crops and grain yield at terminal drought (Monneveux *et al*., 2012). Mkhabela *et al*. (2019) and Tatar *et al*. (2020) stated that plant height could be reduce under drought-stress conditions at differ developmental stages of wheat, especially the grain-filling stage.

Spike length was responded to water-stress, but differences among cultivars were no significant (Table 3; Figure 2). Although Ahmadizadeh *et al*. (2011) noted that effect of stress conditions on spike length was high, Mkhabela *et al*. (2019) reported that the effect of drought stress on spike length was not significant.

The number of fertile spikelet/plant was reduced under water-stress conditions, and the highest number of fertile spikelet/plant was in Burgos (Table 3; Figure 2). Earlier researchers reported that drought stress was affect the number of fertile spikelet/plant (Kilic and Yagbasanlar, 2010). Vahamidis *et al*. (2019) reported that when drought severity was increase, number of fertile spikelet/spike was reduced. Eskandari and Kazemi (2010) stated that effect of drought stress on number of fertile spikelet/plant was no significant.

The number of grains per spike is sensible to water stress (Ahmadizadeh *et al*., 2011) because of decreased endosperm size and pericarp thickness under drought stress (Kaur *et al*., 2011). Moreover, drought stress significantly is blocked grain filling due to insufficient germ development (Schmidt *et al*., 2020). At heading stage, drought was caused a great number of flowers to abortion, but terminal drought, at last development stage, is increased the number of small grains per spike (Zahra *et al*., 2021). Zhao *et al*. (2020) stated that the effects of severe and moderate drought stress on grain weight were about 23.22% and 14.28% respectively.

Grain yield per plant loss after exposure to drought stress is caused by drought response of cultivars and yield-related parameters. The number of grains per spike and grain weight was increase in Anzele cultivar under water-stressed conditions compared to other genotypes (Table 3; Figure 2). Similarly, Zhang *et al*. (2022) stated that grain yield per plant loss after exposure to drought stress is essentially detected by drought tolerance of genotypes, and Zhoumai 18 had less yield loss compared to 12-song and Yumai-14 varieties due to its higher drought tolerance. In our study, the good performance of the Anzele cultivar compared to other cultivars might be due to high tolerance under water-stressed conditions.

Protein ratio was increased under water-stressed conditions, and the highest protein ratio was in Burgos (Table 3; Figure 3). The earlier researchers reported that the effect of drought at different plant growth stages on the seed quality of wheat was important (Rekowski *et al*., 2021; Eser *et al*., 2024). Eser *et al*. (2024) noted that the pre-heading stage drought was significantly affected grain yield, but the post-heading stage drought was affected the seed quality. Rekowski *et al*. (2021) also stated that the protein ratio was significantly increased by well-watered conditions, although it was a minor increase under severe stress. In our research, the number of grains per plant under drought was low, but the protein ratio was high, which was similar to the findings of Zörb *et al*. (2006).

Relationships among traits were significant (Figure 4). Aisawi *et al*. (2015) reported that the positive and significant correlation detected between number of grains per spike and grain yield per plant. Ata *et al*. (2014) noted that association of traits significantly deviated in drought stress compared to normal environment, and the maximum positive correlation determined between grain yield per plant and plant height.

Conclusion: Drought stress negatively impacted the durum wheat cultivars tested, though the divergent cultivars behaved differently. Water stress decreased agro-morphological traits and also changed protein ratio of durum wheat cultivars. Seckin-21 had the best tolerance to water stress for SPAD value at the flowering stage. Svevo was the tallest cultivar compared to other cultivars. Burgos had high spikelet per spike and protein ratio under water stress. Anzele had the high grain number per plant and grain weight. Having the best performance to water stress, cultivars for examined traits could be considered for breeding programs in future.

Declaration of Originality and Copyrights: We declared that the current article was original and had not been submitted for publication, in part or whole, to any other national or international journal.

Funding: The research was conducted without any funding.

Conflict of interest: The authors declared that they have no conflict of interest.

REFERENCES

Ahmadizadeh, M., A. Nori, H. Shahbazi and M. Habibpour (2011). Effects of drought stress on some agronomic and morphological traits of durum wheat (*Triticum durum* Desf.) landraces under greenhouse condition. Afr. J. Biotechnol. 10(64): 14097-14107. https://doi.org/10.5897/AJB11.2322.

Aisawi K.A.B., M.P. Reynolds, R.P. Singh and M.J. Foulkes (2015). The physiological basis of the genetic progress in yield potential of CIMMYT spring wheat cultivars from 1966 to 2009. Crop Sci. 55: 1749-1764. https://doi.org/10.2135/cropsci2014.09.0601.

Akram M., R.M. Iqbal and M. Jamil (2014). The response of wheat (*Triticum aestivum* L.) to integrating effects of drought stress and nitrogen management. Bulg. J. Agric. Sci. 20(2): 275-286. https://www.agrojournal.org/20/02-07.pdf.

Ali, O.A.M. (2019). Wheat responses and tolerance to drought stress. In: Hasanuzzaman, M., Nahar, K., Hossain, M. (eds) Wheat Production in Changing Environments. Springer, Singapore. https://link.springer.com/chapter/10.1007/978-981-13-6883-7_5.

Ata, A., B. Yousaf, A.S. Khan, G.M. Subhani, H.M. Asadullah and A. Yousaf (2014). Correlation and path coefficient analysis for important plant attributes of spring wheat under normal and drought stress conditions. World 4(8). https://core.ac.uk/reader/234654650.

Baser, I., S. Akseki, D. Gocmen, A. Balkan and O. Bilgin (2024). The effects of water stress on grain yield and yield components in bread wheat. C. R. Acad. Bulg. Sci. 77(6): 924-935. https://doi.org/10.7546/CRABS.2024.06.16.

Bassi, F. and M. Sanchez-Garcia (2017). Adaptation and stability analysis of ICARDA durum wheat elites across 18 countries. Crop Sci. 57: 2419-2430. https://doi.org/10.2135/cropsci2016.11.0916.

Bezak, N. and M. Mikoˇ s (2020). Changes in the compound drought and extreme heat occurrence in the 1961-2018 period at the European Scale. Water 12(12): 3543. https://doi.org/10.3390/w12123543.

Bilski, J.J. and C.D. Foy (1987). Differential tolerance of oat cultivars to aluminium in nutrient solutions and inacid soil of Poland. J. Plant Nutr. 10:129-141. https://doi.org/10.1080/01904168709363563.

Boukid, F., M. Dall'Asta., L. Bresciani, P. Mena and D. Del Rio (2019). Phenolic profile and antioxidant capacity of landraces, old and modern Tunisian durum wheat. Eur. Food Res. Technol. 245: 73. https://doi.org/10.1007/s00217-018-3141-1.

Chaouachi, L., M. Marín-Sanz, Z. Kthiri, S. Boukef, K. Harbaoui, F. Barro and C. Karmous (2023). The opportunity of using durum wheat landraces to tolerate drought stress: screening morpho-physiological components. AoB Plants 15(3): 22. https://doi.org/10.1093/aobpla/plad022.

Dorrani-Nejad, M., A. Kazemipour, A.A. Maghsoudi-Moud and R. Abdolshahi (2022). Wheat breeding for early heading: does it improve grain yield under drought stress and well-watered conditions. Environ. Exp. Bot. 200: 104902. https://doi.org/10.1016/j.envexpbot.2022.104902.

El-Hendawy, S., N. Al-Suhaibani and A.E.A. Salemet (2015). Spectral re-flectance indices as a rapid and non-destructive phenotyping tool for estimating different morphophysiological traits of contrasting spring wheat germplasms under arid conditions. Turk. J. Agric. For. 39: 572-587. https://doi.org/10.3906/tar-1406-164.

Eser, C., S. Soylu and H. Ozkan (2024). Drought responses of traditional and modern wheats in different phenological stages. Field Crops Res. 305: 109201. https://doi.org/10.1016/j.fcr.2023.109201.

Eskandari, H. and K.K. Kazemi (2010). Response of different bread wheat (*Triticum aestivum* L.) genotypes to post-anthesis water deficit. Not. Sci. Biol. 2(4): 49-52. https://doi.org/10.15835/nsb245002.

Far Focus (2010). Irrigation management for cropping a growers guide. 1st Ed. Foundation of Arable Research; Lincoln (New Zeland), 4(2010).

Farooq, S., M. Shahid, M.B. Khan, M. Hussain and M. Farooq (2015). Improving the productivity of bread wheat by good management practices under terminal drought. J. Agron. Crop Sci. 201: 173-188. https://doi.org/10.1111/jac.12093.

Genstat (2009). Genstat for Windows (12th Edition) Introduction. Vsn International, Hemel Hempstead.

Guerrini, L., M. Napoli, M. Mancini, P. Masella, A. Cappelli, A. Parenti and S. Orlandini (2020). Wheat grain composition, dough rheology and bread quality as affected by nitrogen and sulfur fertilization and seeding density. Agronomy 10: 233. https://doi.org/10.3390/agronomy10020233.

Hussain, M., M. Waqas-ul-Haq, S. Farooq, K. Jabran and M. Farooq (2016). The impact of seed priming and row spacing on the productivity of different cultivars of irrigated wheat under early season drought. Exp. Agric. 52: 477-490. https://doi.org/10.1017/S0014479716000053.

Javed, A., N. Ahmad, J. Ahmed, A. Hameed, M.A. Ashraf, S.A. Zafar and E.F. Ali (2022). Grain yield, chlorophyll and protein contents of elite wheat cultivars under drought stress. J. King Saud Univ. Sci. 34(7): 102279. https://doi.org/10.1016/j.jksus.2022.102279.

Kaur, V., R. Behl, S. Singh and S. Madaan (2011). Endosperm and pericarp size in wheat (*Triticum aestivum* L.) grains developed under high temperature and drought stress conditions. Cereal Res. Commun. 39(4), 515-524. https://doi.org/10.1556/crc.39.2011.4.6.

Kilic, H. and T. Yagbasanlar (2010). The effect of drought stress on grain yield, yield components and some quality traits of durum wheat (*Triticum turgidum* ssp. durum) cultivars. Not. Bot. Horti Agrobot. Cluj-Napoca. 38(1): 164-170. https://doi.org/10.15835/nbha3814274.

Koc, M., and I. Genc. (1990). Studies on nitrogen uptake and nitrogen harvest index in three bread wheat genotypes. Doğa-Tr. J. of Agric. and For. 14: 280-288. https://www.cabidigitallibrary.org/doi/full/10.5555/19910744601.

Mehraban, A., A. Tobe, A. Gholipouri, E. Amiri, A. Ghafari and M. Rostaii (2019). The effects of drought stress on yield, yield components, and yield stability at different growth stages in bread wheat cultivar (*Triticum aestivum* L.). Pol. J. Environ. Stud. 28(2): 739-746. https://doi.org/10.15244/pjoes/85350.

Mkhabela, S.S., H. Shimelis, A.O. Odindo and J. Mashilo (2019). Response of selected drought tolerant wheat (*Triticum aestivum* L.) cultivars for agronomic traits and biochemical markers under drought-stressed and non-stressed conditions. Acta Agric. Scand. Sect. B - Soil Plant Sci. 69(8): 674-689. https://doi.org/10.1080/09064710.2019.1641213.

Mohammadi R., E. Farshadfar and A. Amri (2016). Path analysis of cultivar×environment interactions in rainfed durum wheat. Plant Prod. Sci. 19(1): 43-50. https://doi.org/10.1080/1343943X.2015.1128100.

Mohiuddin, M., M.A. Hossain, M.M. Rohman, M.N. Uddin, M.S. Haque, J.U. Ahmed, A. Hossain, M.M. Hassan and M.G. Mostofa (2021). Multivariate analysis of morpho-physiological traits reveals differential drought tolerance potential of bread wheat genotypes at the seedling stage. Plants 10(5): 879. https://doi.org/10.3390/plants10050879.

Monneveux, P., R. Jing and S.C. Misra (2012). Phenotyping for drought adaptation in wheat using physiological traits. Front. Physiol. 3: 429. https://doi.org/10.3389/fphys.2012.00429.

Pandey, G.C., S. Sareen, P. Siwach and R. Tiwari (2014). Molecular characterization of heat tolerance in bread wheat (*Triticum eastivum* L.) using differences in thousand-grain weights (dTGW) as a potential indirect selection criterion. Cereal Res. Commun. 42(1): 38-46. https://doi.org/10.1556/crc.2013.0041.

Pour-Aboughadareh, A., R. Mohammadi, A. Etminan, L. Shooshtari, N. Maleki-Tabrizi and P. Poczai (2020). Effects of drought stress on some agronomic and morpho-physiological traits in durum wheat cultivars. Sustainability 12(14): 5610. https://doi.org/10.3390/su12145610.

Qaseem, M.F., R. Qureshi and H. Shaheen (2019). Effects of preanthesis drought, heat and their combination on the growth, yield and physiology of diverse wheat (*Triticum aestivum* L.) cultivars varying in sensitivity to heat and drought stress. Sci. Rep. 9(1): 6955. https://doi.org/10.1038/s41598-019-43477-z.

Rekowski, A., M. A. Wimmer, S. Tahmasebi, M. Dier, S. Kalmbach, B. Hitzmann and C. Zörb (2021). Drought stress during anthesis alters grain protein composition and improves bread quality in field-grown Iranian and German wheat cultivars. Appl. Sci. 11(21): 9782. https://doi.org/10.3390/app11219782.

Ru, C., X. Hu, D. Chen, W. Wang and J. Zhen (2023). Photosynthetic, antioxidant activities, and osmoregulatory responses in winter wheat differ during the stress and recovery periods under heat, drought, and combined stress. Plant Sci. 327: 111557. https://doi.org/10.1016/j.plantsci.2022.111557.

Schmidt, J., J. Claussen, N. Wörlein, A. Eggert, D. Fleury, T. Garnett and S. Gerth (2020). Drought and heat stress tolerance screening in wheat using computed tomography. Plant Methods 16(15): 1-12. https://doi.org/10.1186/s13007-020-00565-w.

Singh, H., P.K. Kingra, R.K. Pal and S. Singh (2024). Impact of abiotic stresses on wheat yield and strategies for mitigation: a comprehensive review. Agric. Res. J. 61(2): 155-166.

https://doi.org/10.5958/2395-146X.2024.00022.8.

Tatar, O., U. Cakalogullari, F.A. Tonk, D. Istipliler and R. Karakoc (2020). Effect of drought stress on yield and quality traits of common wheat during grain filling stage. Turk. J. Field Crops. 25(2): 236-244. https://doi.org/10.17557/tjfc.834392.

Vahamidis, P., A.J. Karamanos and G. Economou (2019). Grain number determination in durum wheat as affected by drought stress: An analysis at spike and spikelet level. Ann. Appl. Biol. 174(2): 190-208. https://doi.org/10.1111/aab.12487.

Yan, W. and J.B. Holland (2010). A heritability-adjusted GGE biplot for test environment evaluation. Euphytica 171: 355-369. https://doi.org/10.1007/s10681-009-0030-5.

Yan, W. and N.A. Tinker (2006). Biplot analysis of multienvironment trial data: Principles and applications. Can. J. Plant Sci. 86: 623-645. https://doi.org/10.4141/P05-169.

Zadoks, J.C., T.T. Chang and C.F. Konzak (1974). A decimal code for the growth stages of cereals. Weed Res., 14: 415-421. https://doi.org/10.1111/j.1365-3180.1974.tb01084.x.

Zahra N., A. Wahid, M.B. Hafeez, A. Ullah, K.H. Siddiquen and M. Farooq (2021). Grain development in wheat under combined heat and drought stress: Plant responses and management. Environ Exp. Bot. 188: 104517. https://doi.org/10.1016/j.envexpbot.2021.104517.

Zhang X., Z. Wang, Y. Li, R. Guo, E. Liu, X. Liu, G. Fengxue, Y. Ziguang, L. Shuying, Z. Xiuli and X. Mei (2022). Wheat genotypes with higher yield sensitivity to drought overproduced proline and lost minor biomass under severer water stress. Front. Plant Sci. 13: 1035038. https://doi.org/10.3389/fpls.2022.1035038.

Zhao W., L. Liu, Q. Shen, J. Yang, X. Han, F. Tian and J. Wu (2020). Effects of water stress on photosynthesis, yield, and water use efficiency in winter wheat. Water 12(8): 2127. https://doi.org/10.3390/w12082127.

Zörb C., G. Langenkämper, T. Betsche, K. Niehaus and A. Barsch (2006). Metabolite profiling of wheat grains (*Triticum aestivum* L.) from organic and conventional agriculture. J. Agric. Food Chem. 54: 8301-8306. https://doi.org/10.1021/jf0615451.