EFFECTS OF DROUGHT STRESS ON THE BEHAVIOR OF SEVEN GENOTYPES OF DURUM WHEAT (*TRITICUM DURUM* DESF.) UNDER GREENHOUSE CONDITIONS

HASSEN, N. A.[1*] – HACINI, N.[1] – DJELLOUL, R.[1] – BENCHERIF, K.[2] – AZIZI, N. N.[1]

[1]*Laboratory of Functional and Evolutionary Ecology Research, Faculty of Nature and Life Sciences, Chadli Bendjedid University of El Tarf, PB 73, El-Tarf 36000, Algeria*

[2]*Department of Biology Sciences, Faculty of Nature and Life Sciences, Ziane Achour University of Djelfa 17000, Algeria*

[*]*Corresponding author*
e-mail: haeamel@gmail.com

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Abstract. Durum wheat is one of the major cereal crops in the world as well as in Algeria, where it occupies mainly the semi–arid regions where water deficiency is one of the important abiotic stresses. The improvement of this cereal requires stress-resilient varieties development. The present study aims to evaluate the performance of seven genotypes of durum wheat under greenhouse conditions in order to identify the mechanisms developed by the genotypes to counteract water stress. Yield components, cell turgor, and root characterization were carried out as agronomic, physiological, and morphological evaluation parameters. Two treatments of water stress were applied and compared to non-stressed pot culture. The results showed that the variety *Guemgoum rkhem* was found to be the most tolerant to water stress and Mohamed Ben Bachir and Fassi were the most sensitive. A significant impact of the different studied parameters on the tested genotypes was recorded indicating variability between them. This study pointed out the considered parameters for appropriate selection of wheat variety adapted to water stress. Despite, the present approach open the way to new perspective to identify the most appropriate wheat variety using other parameters such as selecting target genes responsible for tolerance to water stress and thus facilitate the selection process.
Keywords: *durum wheat, water stress, agronomic parameters, physiological parameters, rooting characteristics*

Introduction

Wheat, a term derived from the old Low Franconian "Bläd" (product of the earth) designates several cereal crops belonging to the genus Triticum. It represents the first cultivated cereal in the world occupying a surface of 219 006 893 ha in 2020 (FAO, 2020). It is considered as the universal cereal of the Old World agriculture and the world's foremost consumed crop plant followed by rice and maize (Wuletaw et al., 2015). Cultivated wheat is classified into two major types: (1) the hexaploid bread wheat (2n = 6x = 42, BBAADD) and (2) the tetraploid durum wheat (2n = 4x = 28, BBAA). In fact, the durum wheat, which arose by a few mutations from primitive wheat is currently the most cultivated in the present times. The hexaploid species *T. aestivum* (2n = 6x = 42, BBAADD) and *T. zhukovsky* (2n = 6x = 42, BBAAGG) have no wild progenitors, and are only found in cultivated by hybridization between cultivated tetraploid wheat and wild diploid species (Braun et al., 2010).

In Algeria, 50% of cereals agricultures areas are reserved to durum wheat with more than 1,579,080 ha in 2019 million hectares (Haddad et al., 2021). A large part of this cereal are located in semi-arid regions characterized by little and irregular precipitations,

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very low availability of minerals nutrients in the soil and unavailability of water resources (Papathanasiou et al., 2015; Hamli et al., 2018; Ladoui et al, 2020).

Climate change will have a great impact on increasing the effects of drought stress in the agricultural sector by limiting the production and productivity of the important agricultural crops (e.g., wheat, barley, etc.) (Sallam et al., 2019). Drought is one of the most abiotic stress affecting the cultivation of durum wheat in the world, especially in semi-arid areas (Semcheddine, 2015), where it severely limit plant growth as well as their productivity (Wang et al., 2003; Semcheddine, 2015). In fact, water stress affects the three main components of wheat yield: number of auricle, number of grain per ear, and the weight of 1000 grain (Assem et al., 2006; Semcheddine, 2015).

In this context, agronomic research focused on any approach aimed at better yield under low precipitation conditions (Bendada, 2012). The ability to enhance quantitatively wheat performance under water stress conditions is very important to improve production in semi-arid region. Currently, wheat improvement programs are increasingly interested in genetic approach to select the best cultivar adapted to this abiotic stress conditions. In this context, phenological, morpho-physiological and biochemical traits related to wheat yield under water stress conditions are considered (Pfeiffer et al., 2000). A root system able to extracting water from the soil would be an essential trait for drought adaptation. This characteristics impact yield production and interfere directly in the availability of water for the plant under stress conditions (El Fakhri et al, 2010).

For that, the present study aims to select the best durum wheat varieties adapted to drought stress conditions. Seven durum wheat genotypes were used between old varieties (Bidi17, Fassi, Guemgoum rkhem, Mohamed Ben Bachir) and improved ones (Simeto, Vitron, Tergui Amar 6) originating from the Mediterranean area in order to evaluate their performance under different degrees of water stress. Thus, the agronomic (1000 grain weight, vegetation height, number of grain per ear and number of ears), physiological (cell turgor) and morphological (rooting characteristics) parameters of the seven varieties were tested in order to determine their adaptabilities and to select the best varieties for water stress tolerance.

Materials and Methods

Plant materials

The plant materials consisted of 7 varieties of durum wheat (*Triticum durum*) between old and improved varieties from the Mediterranean area are described in (*Table 1*).

Table 1. *List of studied durum wheat varieties and their origin*

Génotype	Origin
V1.TARGUI AMAR 06	Algeria
V2.GUEMGOUM RKHEM	Algeria
V3.VITRON	Spain
V4.SIMETO	Italy
V5.BIDI 17	Algeria
V6.MOHAMED BEN BACHIR(MBB)	Algeria
V7.FASSI	Algeria

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Test setup

The experimental design was carried out according to 9 replicates (3 replicates to each treatment) per wheat variety with a total of 63 pots. The varieties are considered as different genotypes. Wheat seeds were germinated in plastic (10 seeds per box) boxes on blotting paper in the dark and at a temperature of 25°, before being transplanted into 5 kg pots.

The pots were filled with a substrate consisting of a mixture of soil, potting soil, and sand. A thin layer of gravel was put at the bottom of each pot to facilitate the drainage of irrigation water. The pots thus prepared were distributed at a rate of 9 pots/genotype. For each genotype 3 treatments and 3 pots/treatment (water regime) are defined.

The pots were placed in a greenhouse (photoperiod 15 h, temperature 25 °C during the day/ 12 °C during the night) and irrigated regularly, twice a week, until the third leaf was obtained, at this point water stress is applied by stopping irrigation until different levels of water stress are reached (50%, 25% of field capacity). Every day, the pots are weighed to complete the quantity of water needed to maintain the various capacities in the field until the end of the stress phase. P and K were applied as basal dose during pot preparation while N was applied in two instalments at tillering and anthesis with irrigation water.

Stress water treatments

Two levels of water stress N1 N2 were compared to a control N0 (no water stress) according to Hacini (2012).

N0: control corresponds to the field capacity.

N1: corresponds to 50% of the field capacity.

N2: corresponds to pronounced stress and equivalent to about 25% of field capacity.

Evaluation of the impact of water stress on the studied varieties

The evaluation of the genotypes response was based on three parameters:

Agronomic parameters (yield components)

- Number of ears per pot (NEP)
- Height of the plant (HT): average height in centimeters of the plants, measured from the ground to the top of the ears (barbs not included) (Megherbi et al., 2012)
- The number of grains per ear (NGE) and the thousand kernel weight (TKW) (Sayar et al., 2008)

Physiological parameters

Cell turgor: Cell turgor was measured using the method of Barrs (1968) and Hacini (2012).

The leaves are cut and weighed (weight of fresh material). The cut end is then placed in distilled water in the dark for the leaves are again weighed (turgidity weight).

- The leaves are then dried in an oven at 85°C for 24 hours and weighed (dry weight).

Relative water content was measured using the method of Barrs (1968) and Hacini (2012).

$$RWC = (pf - ps) / (pt - ps).\ 100 \qquad \text{(Eq.1)}$$

where,

-Pf = fresh weight

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-Ps = dry weight
-Pt = turgid weight.

Morphological parameters (Rooting characteristics)

The soil is separated from the roots with a moderate stream of tap water. The roots are then then washed in a tub before taking the measurements.

Number of primary roots (NRP), determined by counting roots with length longer than 1 cm (Benlaribi et al., 1990).

Longest root lenght (LRL), expressed in cm and gives durum wheat varieties a decisive accommodation under water stress (Sayar et al., 2008).

Statistical analysis

Analysis of variance (ANOVA) was performed to test the mean effects of water stress, genotype, and their interaction on physiological, morphological and agronomic parameters.

The correlations between the values of the different indices and the average grain yields obtained under normal and constrained conditions, of the different genotypes, were determined. The processing of the data obtained was carried out with the Statgraphics 19-software.

Results and Discussion

Growth parameters and yield components

The Analysis of variance of yield components reveals that water administration and genotype have highly significant effects for all the studied parameters.

Results of studied parameters recorded by the seven tested wheat genotypes under the different water stress are represented in *Table 2*. The highest PMG value was recorded with variety 2 (19.5 g) and the lowest one was obtained with variety 7 (7.07 g). As same HT was the highest in variety 2 (46.6 cm) and the lowest in variety 6 (31 cm). For TC parameter the highest value was obtained by the variety 3 (72.1%) and the lowest by the variety 6 (36.2%).

The thousand kernel weight (TKW)

The results for the thousand kernel weight (TKW) are shown in *Figure 1*. The comparison of the averages of the different genotypes showed that the genotypes V2, V1 are characterized by the most important PMG. The results of analysis of variance shows a significant effect of the variety factor, treatment, and the genotypes X treatment interaction (*Table 2*) on the thousand seed weight ($p<0.05$) (*Figure 1*).

The analysis of variance allowed to classify the varieties in two homogeneous groups; a first group composed of V2 and V1 which are the least affected by the hydric stress and the second group which subdivides the whole of the genotypes in two categories, one with the varieties V3, V4, V5 and V6 less affected and the other with V7 which is the most affected by the hydric stress. The results show that water stress affects the thousand kernel weight (TKW) t of the different durum wheat genotypes to varying degrees.

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Table 2. *ANOVA results of the comparison between treatments by variety and parameter*

Variétés	TKW	NGE	NEP	HT(cm)	TC%
1	15.96	16.6667	5.66667	34.6667	54.9756
2	19.5144	18	7.33333	46.5556	70.3444
3	11.5533	12.2222	9.11111	38.4444	72.1433
4	11.6244	12.6667	8.88889	36.7778	57.3033
5	11.3222	11.3333	7.22222	37.6667	48.6667
6	11.4067	8	4.66667	31	36.2222
7	7.07333	6.11111	4.33333	31.8889	38.5556
Test mean	12.64	12.14	6.75	36.71	54.03
Treatments effect	1575.57***	424.71***	12.95***	458.87***	59.08***
Genotypic effect	135.25***	44.12***	205.74***	82.63***	449.47***
Interaction (genotypes X treatments)	45.62***	14.53***	1.71*	23.79***	84.03***

P>0.05 NS. P≤0.05*. P≤0.01**. P≤0.001***NS nonsignificant difference * significant difference** very significant difference ***very highly significant difference PMG: 1000 grain weight NGE:number of grain/ear NEP: number of ears/pot HT (cm): Height TC %: Cell turgor

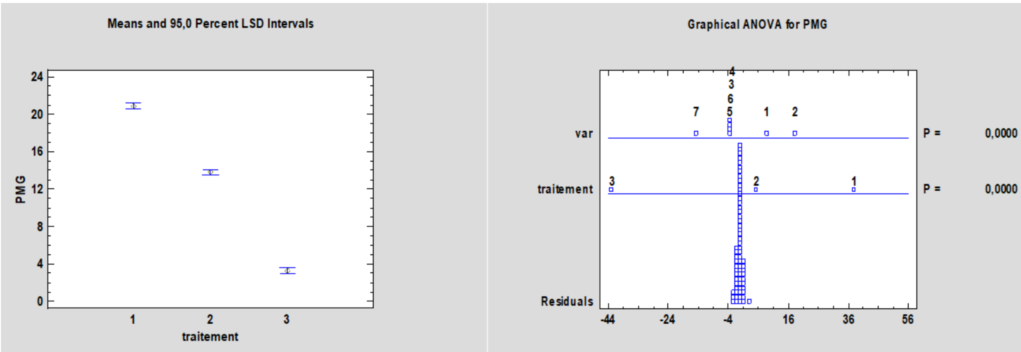

Figure 1. *Effects of genotype x treatment interaction on the thousand kernel weight (TKW). PMG: the thousand kernel weight (TKW) /VAR: Varieties*

The results of the analysis of variance relating to the number of grains per ear are illustrated in *Figure 2*. It shows that water stress significantly reduces the number of grains per ear. The two varieties V1 and V2 are the least affected by water stress in comparison with the other varieties (*Figure 2*). The varieties V3 V4 V5 V6 and V7 show empty ears for the N2 treatment.

Number of ears per pot

Analysis of variance for the number of ears per pot showed a significant difference between the studied stress levels applied as well as a marked genotypic variation (*Figure 3*).

The analysis of variance shows a non-significant effect (p 0.09) of the genotype x treatment interaction (*Table 2*) on the number of ears per pot.

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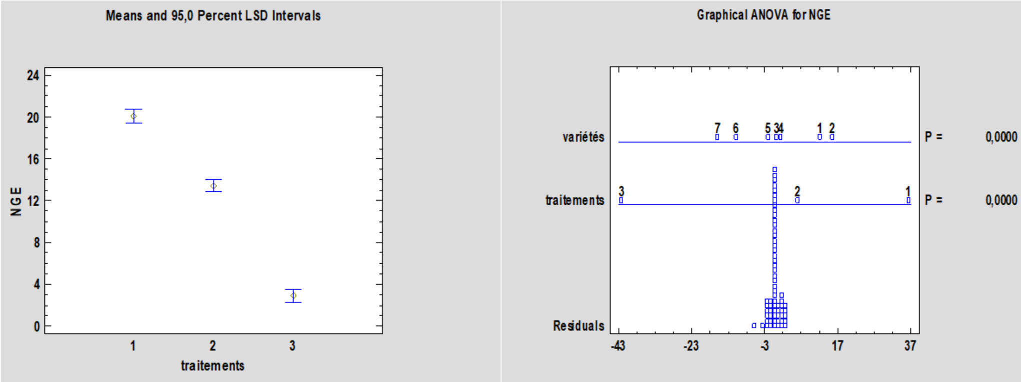

Figure 2. *effect of genotype x treatment interaction on the number of grains per ear. NGE: Number of grains per pot*

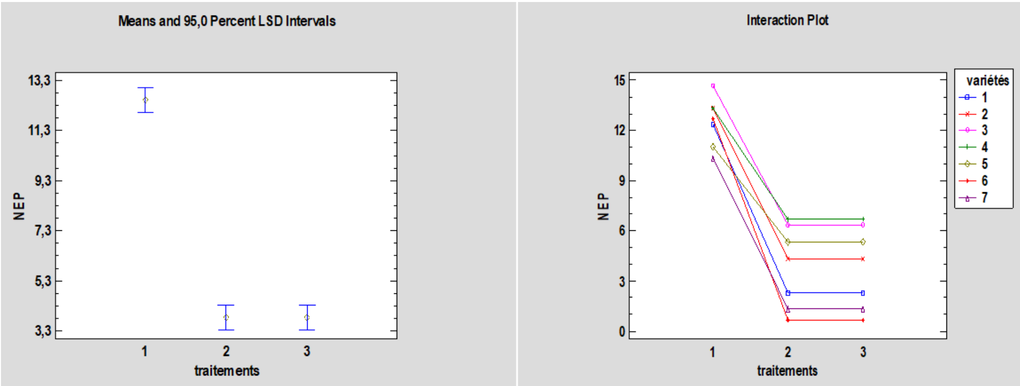

Figure 3. *Effects of genotype x site interaction on the number of ears per pot. NEP: Number of ears per pot*

Height

The analysis of variance of the tested genotypes showed a clear distinction between varieties. All the studied seven genotypes showed a reduction in height as response to applied water stress (*Figure 4*). However, genotypes V6 and V7 were the most sensitive to applied stress while genotype V2 was the most resistant (*Figure 4*).

Physiological parameters

Relative water content (RWC)

The results obtained show that under water stress the varieties V2, V3 and V4 have a higher RWC than the remaining varieties; the analysis of variance showed a significant effect of water stress on the respective responses of the different genotypes (*Figure 5*).

Rooting characteristics

Number of primary roots (NPR)

Under water stress condition, the NPR number of the emitted primary roots increased in 5 of the 7 tested varieties. Varieties V2 and V5 presented the highest number of roots (about 35%), while the increase was about 30% respectively for varieties V4 and V6. The

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difference does not exceed 16% in genotype V3 (*Table 3*). The number of primary roots decreased for varieties V1 and V7.

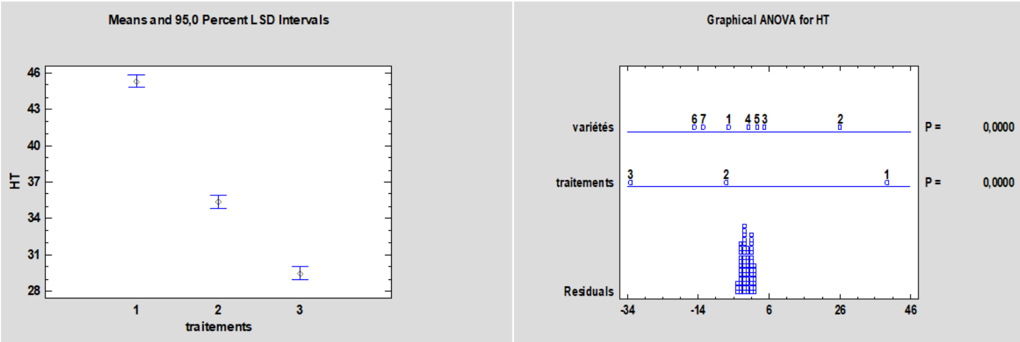

Figure 4. *Effects of genotype x treatment interaction on height. HT: Height*

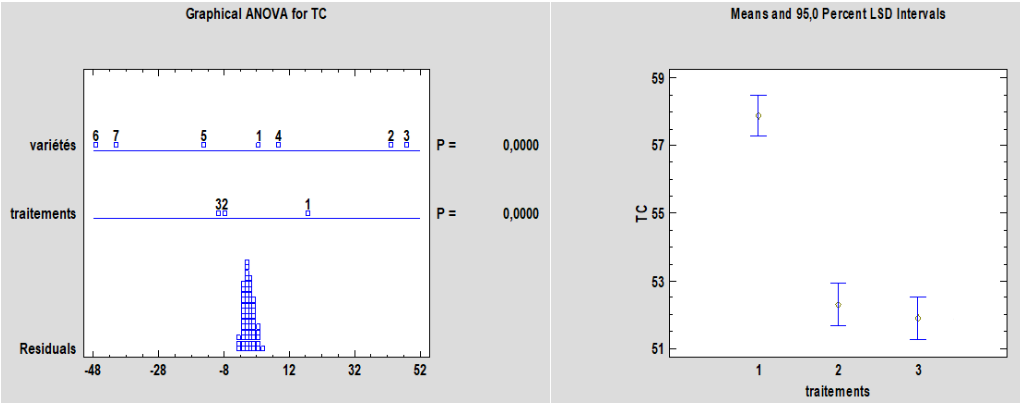

Figure 5. *Effects of genotype x treatment interaction on cell turgor. CT: Cell turgor*

Table 3. *Variation in the number of primary roots (PRN) in 7 genotypes and under two water regimes*

	Number of primary roots					
	N0	N1	Variation%	N2	Variation%	Mean
V1	26.83	24.20	-10.86	15.93	-68.42	22.32
V2	18.97	26.50	28.42	29.20	35.03	24.88
V3	18.43	24.17	23.75	21.90	15.84	21.5
V4	16.20	18.70	13.37	23.17	30.08	19.35
V5	18.23	19.13	4.7	27.50	33.71	21.62
V6	13.17	17.53	24.87	19.10	31.05	16.6
V7	18.87	16.13	-16,98	13.13	-43.72	16.04

wnws: with no water stress wws: with water stress N1: corresponds to 50% of the field capacity. N2: corresponds to pronounced stress and equivalent to about 25% of field capacity

The analysis of variance (*Figure 6*) showed a significant effect of genotype and treatment on the number of primary roots. The effect of the interaction between genotype and water regime was also significant on the NRP (*Table 4*).

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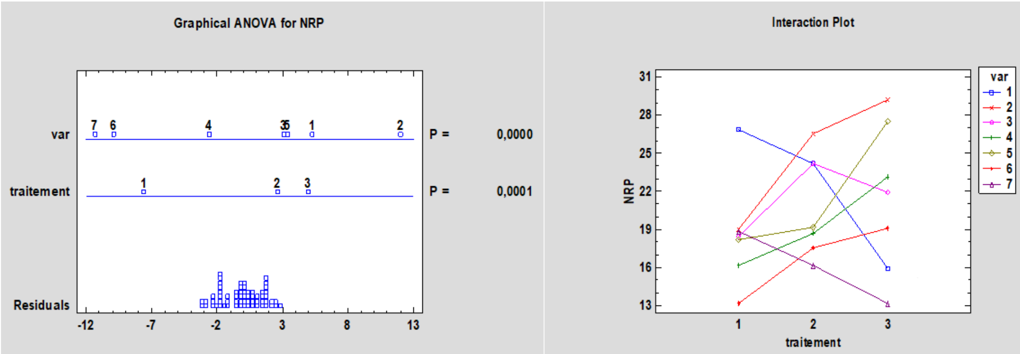

Figure 6. *Effects of genotype x treatment interaction on the number of primary roots. NRP Number of primary roots*

Table 4. *ANOVA results of the comparison between treatments by variety and parameter*

Varieties	NPR	LRL
1	22.3222	24.8889
2	24.8889	33
3	21.5	31.8889
4	19.3556	26.7778
5	21.6222	27
6	16.6	22
7	16.0444	19.4444
MOY essai	20.33	26.43
Effet traitements	12.33***	33.76***
Effet génotypique	25.16***	43.68***
Interaction (génotypes X traitements)	15.13***	1.57NS

P>0.05 NS. P≤0.05*. P≤0.01**. P≤0.001***NS non-significant difference *, significant difference** very significant difference ***very highly significant, difference

Under water stress conditions, the varieties V1 V2 V4 and V6 showed the best performance in terms of increase in LRL (between 13 and 22%) for the first water treatment N1 and (between 18 HT: Height and 27%) for the second treatment N2 (*Table 5*). The effect of water stress on this parameter was not very marked in the varieties V3 V5 V7 with an increase of about 8% for N1 and 12% for N2. Furthermore, the analysis of variance (*Table 5*) recorded a significant effect of genotype and treatment or water regime. The effect of the interaction between genotype and water regime was statistically insignificant for LRL.

Genotype x treatment interaction

The correlation test recorded a negative correlation of number of grains per ear and thousand grain weight with a correlation coefficient of (r =-0.89).

In addition, the observation of total correlations between yield components, rooting characteristics, and cell turgor attests to a negative association of cell turgor and main root length with a correlation coefficient of (r =-0.51) and the number of primary roots with a coefficient of (r =-0.52). The results also reveal a very highly significant correlation with a correlation coefficient of (r =-0.63) of the number of ears per pot and height.

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Table 5. *Variation in longest root length (LRSL) in 7 genotypes under two water regimes genotypes and under two water regimes*

LRL(cm)						
	N0	N1	Variation%	N2	Variation%	Mean
V1	20 .33	26.33	22.78	28	27.39	24.88
V2	28	34.33	18.43	36.66	23.62	33
V3	30.66	32.66	6.12	32.33	5.17	31.88
V4	23	29	20.69	28.3	18.73	26.77
V5	24.66	26	5.15	30.33	18.69	27
V6	18.66	21.66	13.85	25.66	27.28	22
V7	18	19.66	8.44	20.6	12.62	19.44

wnws: with no water stress wws: with water stress N1: corresponds to 50% of the field capacity. N2: corresponds to pronounced stress and equivalent to about 25% of field capacity

Discussion

At the best of our knowledge, the present study aimed to select the best durum wheat variety which tolerates drought stress. Seven varieties of durum wheat (*Triticum durum* Desf.) were tested under different degrees of water stress. Yield traits that breeders have used for assessing drought stress on wheat include seedling vigor, plant height, days to heading, days to maturity, spike length, number of spikelets per spike, root architectural traits, number of grains per spike, thousand kernel weight, grain yield per spike, grain yield, biological yield, and harvest index. Drought tolerance as a trait can be assessed from any of these traits or from drought indices which accurately assess the genotypic yield response to drought stress (Fernandez, 1992; Sallam et al,, 2019) in our study and under greenhouse conditions; Yield component , cell turgor, and root characterization were carried out as agronomic, physiological and morphological evaluation parameters in order to identify the mechanisms developed by the genotypes to counteract water stress. The results of our studies indicated that variety V2 was the most interest adapted in terms of number of grains per ear, PMG and height under water stress.

Yield components

Yield traits are considered to be the critical component for enhancing wheat yield, increase in grain yield can be achieved by manipulating yield traits like grains per spike, spike length and spikelets per spike (Gaju, 2009; Mirza et al, 2019). The main causes of reduction in yield and yield-related traits during stress are pollen abortion (Ji et al., 2010; Mirza, 2019), reduction in food reserves (Sinclair, 2006; Mirza, 2019) and production of sterile tillers (Duggan et al., 2005; Mirza, 2019). The stress factors especially drought negatively affects plant growth and development and causes a sharp decrease of plants productivity (Pan et al., 2002; Feras et al., 2011). The analysis of variance indicates that the thousand kernel weight (TKW) shows significant differences between varieties and between treatments which is consistent with the work of Mallek-Maalej et al. (1998) and Ayed et al. (2016). These authors state that when the stress intensifies, the different genotypes undergo a significant reduction in their thousand kernel weight, this could be explained by the deficiency of water after flowering through the effect of a decrease in 1000 grain weight due to the significant change in the speed and/or the filling time (Hacini, 2012). Kılıç et al. (1999) and Kiliç and Yağbasanlar (2010) has also reported that the thousand kernel weight (TKW) and grain yield of durum wheat is reduced in the

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drought and terminal heat stress conditions. Gooding et al. (2003) and Parvaneh et al. (2014) in their studies on intensity and duration of drought stress on wheat reported that drought stress reduced grain yield and the thousand kernel weight (TKW) by shortening the grain formation period. The variety V2 maintained interesting a high thousand grain weight.

The number of grains per spike, the parameter that contributes more directly to grain yield in durum wheat (Simane et al., 1993; Ayed et al., 2016) decreased significantly under water stress, our results agree with those of Meghrbi et al (2012) who notes that water stress alters different processes, moderating the growth of vegetative and reproductive organs, development and final yield of the crop.

Bouzerzour et al. (2002) indicates that the number of fertile spikelets is reduced when drought occurs during the spikelet differentiation phase and resulting in a reduction in the number of grains per spike. Our results indicate that the number of grain decreases according to the applied water regime for N1, NGE decreased compared to the control, for N2 five of the seven varieties tested showed empty spikes which agrees with the results of (Lakhdar and Bouzerzour, 2017) who indicate that water stress significantly but gradually reduces the number of grains per unit area.

In parallel, the number of spikes per pot decreased under water stress for all genotypes. Severe water stress from the seedling stage to maturity reportedly reduced all grain yield components, particularly the number of fertile ears per unit area by 60%, grain number per head by 48%, dry matter and harvest index (Giuanta et al., 1993). Our results agree with those observed by Semcheddin (2015) who reported that water deficit significantly reduces the number of spikes per m^2 at the grain filling stage.

The different genotypes tested showed a reduction in height following the application of water stress. According to Slami (2015) one of the first effects caused by water deficit is a reduction in vegetative growth. This result is consistent with Zhao et al. (2020) who found that water stress significantly reduced the height of winter wheat. The decrease in winter wheat height was mainly caused by photosynthesis and decreased osmotic potential. The decrease in photosynthesis affected the growth and development of the winter wheat, resulting in a height decrease (Zhao et al., 2020). The analysis of variance of the seven genotypes studied showed a clear distinction between varieties, the variety V2 showed the least sensitive for this parameter with a decrease of 36.36% and 52.03% for the treatments N1 and N2, respectively, compared to the controls. Tall straw cereal varieties are said to be more drought tolerant, due to the relationship between plant height and the development of a deeper root system. This gives a marked advantage to varieties with tall straws, from the point of view of water extraction in dry conditions, compared to varieties with short straws (Mekliche et al., 2003; Hacini et al., 2022).

Physiological parameters

Relative water content (RWC)

The relative water content or leaf turgor is a genotypic characteristic that is related to the ability of the plant to maintain a level of water in the leaf that is able to ensure the continuity of metabolic activity including, among others, photosynthesis (Araus et al., 1991; Bouzerzour et al., 1998; Hacini, 2012). The results obtained show that the varieties V2, V3 and V4 have a higher RWC than the others and they seem to be the most promising, as for a possible adaptation to the water stress.

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The analysis of variance shows that there was a very highly significant effect of water stress on the respective responses of the different genotypes. According to Hacini (2012) the physiological accommodation through this mechanism by which the plant manages to manifest a certain membrane plasticity to avoid plasmolysis, can be retained as an adaptive trait and therefore, in terms of indirect tests, can constitute a very interesting predictive tool in early selection.

Rooting characteristics

Number of primary roots (NPR)

In the literature, the ability to maintain a high number of primary roots under water stress is considered as allowing a better access to water by the plant (El Fakhri et al., 2010). Under water stress condition Benlaribi et al. (1990) attests a decrease of the number of roots in all tested genotypes El Fakhri et al. (2010) reports an increase of this parameter following water stress for all genotypes. However, our results indicate an increase of the NRP in 5 varieties and a decrease in 2 of the 7 varieties tested. Our analyses show a clear variation in the number of primary roots under water stress but do not specifically link them to a particular type of behavior (increase or decrease) that agree with those of Urbanavičiūtė et al. (2022) who notes that the development of number of leaves highly depend not only on environment conditions but also by genotype inner capacity.

Longest root length (LRL)

The LRL expresses the ability of the genotype to explore a distant soil volume and consequently the search in depth of more important quantity of water even if this depth is reached only by one main root (Ali Dib et al., 1992; Sayar et al, 2008). The lack of water stimulated all varieties to increase their LRL this was attested by Sayar et al. (2008) who found that the effect of water stress on LRL is positive and is reflected by an increase in length. Manschadi et al. (2006) and Urbanavičiūtė et al. (2022) demonstrated how the yield increases of 55 kg/ha for each millimeter of water extracted from the soil after anthesis (i.e., in grain filling stage); hence a deep root system, but also wide root system, are the most desirable in environments with terminal drought (Alahmad et al., 2009; Urbanavičiūtė et al., 2022).

The results obtained show significant genetic variability in rooting characteristics among the tested varieties. These results are in agreement with those of Benlaribi et al. (1990), Ali Dib et al. (1992) and Sayar et al (2008), who showed that rooting characteristics are genetically controlled.

Conclusion

Our present results allowed to conclude that the seven tested varieties were able to adopt different strategies according to the genotype considered, and to varying degrees, mechanisms of adaptation to drought linked to the parameters measured. The three parameters (physiological, agronomic, and morphological) are complementary and converge towards the conclusion that V2 is the most resistant genotype and genotypes V6 and V7 are the most sensitive. This study allows us to conclude that the combination of agro morphological and physiological traits considered separately cannot allow selection of genotypes that tolerate water stress in durum wheat. However, their combination can

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form the basis this selection and it opens a new perspective for the use of biochemical and physiological parameters as well as a molecular study in order to target the genes responsible for tolerance to water stress.

REFERENCES

[1] Alahmad, S.; El Hassouni, K.; Bassi, F.M.; Dinglasan, E.; Youssef, C.; Quarry, G.; Aksoy, A.; Mazzucotelli, E.; Juhász, A.; Able, J.A.; et al. (2019): A major root architecture QTL responding to water limitation in durum wheat. – Front. Plant Sci. 10: 436.

[2] Ali Dib T, Monneveux P, Araus, JL. (1992): Adaptation à la sécheresse et notion d'idéotype chez le blé dur II :Caractères physiologiques d'adaptation. – Agronomie 12: 381-393.

[3] Araus, J.L., Alegre, L., Ali Dib, T., Benlaribi, M., Monneveux, P. (1991). Epidermal and stomatal conductance in seedlings of durum wheat landraces and varieties. In: Physiology Breeding of winter cereals for stressed Mediterraneanenvironments. – Les colloques 55: 225-242.

[4] Assem, N., El Hafid, L., Haloui, B., El Atmani, K. (2006) : Effets du stress hydrique appliqué au stade trois feuilles sur le rendement en grains de dix variétés de blé cultivées au Maroc oriental. – Science et changements planétaires / Sécheresse 17(4) : 499-505.

[5] Ayed, S., Othmani, A., Sadreddine, B., Amara, H. (2016): Criblage De Quelques Genotypes De Ble dur (Triticum durum Desf.) Sous Un Stress Salin En Culture De Pot. – European Scientific Journal 12(9): 313.

[6] Barrs H. D., Weatherly P. E. (1962): A re-examination of the relative turgidity technique for estimating water deficits in leaves. – Aust. J. Biol. Sci. 15 : 413-428.

[7] Bendada, H. (2012): Contribution à la sélection de l'adaptation de quelques génotypes d'orge (*Hordeum vulgare* L.) dans les conditions agroclimatiques semi-arides de la région de Sétif. – Thèse de Doctorat, UFA Sétif 1.

[8] Benlaribi, M., Monneveux, P., Grignac, P. (1990): Étude des caractères d'enracinement et de leur rôle dans l'adaptation au déficit hydrique chez le blé dur (*Triticum durum* Desf). – Agronomie 10(4): 305-322.

[9] Bouzerzour, H., Djekoun, A., Benmahammed, A., Hassous, L. (1998):Contribution de la biomasse aérienne de l'indice de récolte et de la précocitéà l'épiaison au rendement en grain (Hordeum vulgare L.) en zone semid'altitude. – Cahiers d'Agriculture 8: 133-137.

[10] Bouzerzour, H., Benmahammed, A., Makhlouf, A., Sahraoui, H., Harkati, N. (2002): Variabilité génétique, héritabilité et corrélation entre caractères mesurés sur orge en zone semi-aride. – Céréaliculture 37: 4-13.

[11] Braun, H. J., Atlin, G., Payne, T. (2010): Multi-location testing as a tool to identify plant response to global climate change. – In: Reynolds, M. P. (ed.) Climate Change and Crop Production. CABI Publishers, Wallingford, UK, pp. 115-138.

[12] Duggan, B., Richards, R., Van Herwaarden, A. & Fettell, N. (2005) : Agronomic evaluation of a tiller inhibition gene (tin) in wheat. I. Effecton yield, yield components, and grain protein. – Australian Journal of Agricultural Research 56 : 169–178.

[13] Elfakhri, M., Mahboub, S., Benchekroun, M., Nsarellah, N. (2010): Effet du stress hydrique sur les caractéristiques d'enracinement du blé dur (*Triticum durum* Desf) Rev. – Nature et Technologie 3: 6-12.

[14] FAO (2020): Classement des états du monde par production de blé. – Food and Agriculture Organization Rome, Italy, https://atlasocio.com/classements/economie/agriculture/.

[15] Feras, A., Hareri, F., Naaesan, M., Ammar, M. A., Kanbar, O. Z. (2011): Effect of Drought on Different Physiological Characters and Yield component in Different Varieties of Syrian Durum Wheat. – Journal of Agricultural Science 3(3): 127.

[16] Fernandez, G. C. J. (1992): Effective Selection Criteria for Assessing Stress Tolerance. – In : Proceedings of the InternationalSymposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress, Taibei,Taiwan, 13–16.

[17] Gaju, O., Reynolds, M., Sparkes, D. & Foulkes, M. (2009) : Relationships between Large-Spike Phenotype, Grain Number, and Yield Potential in Spring Wheat. – Crop Science 49 : 961–973.
[18] Giunta, F., Motzo, R., Deidda, M. (1993): Effect of drought on yield and yield components of durum wheat and triticale in a Mediterranean environment. – Field Crops Research Journal 33(4): 399-409.
[19] Hacini, N., Brinis, L. (2012): Utilisation de quelques marqueurs physiologiques et biochimiques dans l'expression de tolérance au stress hydrique chez 10 génotypes de blé dur (*Triticum durum* Desf). – Rev. Sci. Technol. 25: 6-16.
[20] Hacini, N. (2012): Etude de l'interaction Génotype X Environnement et effet de l'origine de quelques cultivars de blé dur (*Triticum durum* Desf.) sur les aptitudes adaptatives et qualitatives. – Thèse de Doctorat, Université Badji Mokhtar, Annaba.
[21] Hacini, N., Djelloul, R., Desclaux, D. (2022): Study of genotype X environment interactions and agro-technological behavior of Durum Wheat varieties applied in different agro-climatic zones of Algeria. – Plant Archives 22(2): 193-200.
[22] Hamli, S., Labhilili, M., Kadi, K., Addad, D., Bouzerzour, H. (2018): Heat Shock Effects on Physiological Parameters Durum Wheat Seedlings and Relationships with Stress Tolerance Indices. – In: Kallel A., Ksibi M., Ben Dhia H., Khélifi N. (Eds) Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions. EMCEI 2017. Advances in Science, Technology & Innovation (IEREK Interdisciplinary Series for Sustainable Development). Springer, Cham, 1333-1335.
[23] Ji, X. et al. (2010): Importance of pre-anthesis anther sink strength for maintenance of grain number during reproductive stage water stressin wheat. – Plant, Cell Environ. 33: 926–942
[24] Haddad, L., Salmi, M., Benmahammed, A., Bouzerzour, H. (2021): Place de la variété locale de blé dur (*Triticum durum* L. VAR MOHAMED BEN BACHIR) parmi les variétés phares et la nouvelle obtention 'BOUTALEB' dans la région semi-aride de Sétif en Algérie. – Algerian Journal of Arid Environment 11(1): 76-89.
[25] Kılıç, H., Özberk, İ., Özberk, F. (1999): Determination of heat and drought tolerance of some durum wheat cultivars. – GAP I. Tarım Kongresi 26-28 Mayıs 1999 Şanlıurfa.
[26] Kiliç, H., Yağbasanlar, T. (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. Hort. Agrobot. Cluj 38(1): 164-170.
[27] Ladoui, K. K., Mefti, M., Benkherbache, N. (2020): Séléction de génotypes d'orge (*Hordeum Vulgare* L.) tolérants au stress hydrique par les indices de tolérance a la sécheresse. – Revue Agrobiologia 10(1): 1805-12.
[28] Lakhdar, M., Bouzerzour, H. (2017): Etude de la contribution des paramètres phénomorphologiques dans la sélection du blé dur (*Triticum durum* Desf.) dans le climat semi-aride. – Rev. Sci. Technol. Synthèse 35: 45-58.
[29] Mallek-Maalej, E., Boulasnem, F., Ben Salem, M. (1998):Effet de la salinité sur la germination de graines de céréales cultivées en Tunisie. – Cahiers d'Agriculture 7: 153-6.
[30] Manschadi, A. M., Christopher, J., deVoil, P., Hammer, G. L. (2006):The role of root architectural traits in adaptation of wheat to water-limited environments. – Functional Plant Biology 33: 823–83.
[31] Megherbi, A., Mehdadi, Z., Toumi, F., Moueddene, K., Bouadjra, S. (2012): Tolérance à la sécheresse du blé dur (*Triticum durum* Desf.) et identification des paramètres morpho-physiologiques d'adaptation dans la région de Sidi Bel-Abbès (Algérie occidentale). – Rev Acta Botanica Gallica 1: 137-143.
[32] Mekliche, A.; Boukecha, D., Hanifi-Meldiche, L. (2003):Etude de la tolérance à la sécheresse de quelques variétés de blé dur (Triticum durum Desf.). L'Effet de l'irrigation de complément sur les caractères phénologiques, morphologiques et physiologiques. – Ann.INA. 24(1 et 2).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_341354

[33] Mirza, F. Q., Rahmatullah, Q., Humaira, S. (2019): Effects of Pre-Anthesis Drought, Heat and Their Combination on the Growth, Yield and Physiology of diverse Wheat (*Triticum aestivum* L.) Genotypes Varying in Sensitivity to Heat and drought stress. – Scientific Reports 9: 6955.

[34] Pan, X.Y., Wang, Y.F., Wang, G.X., Cao, Q.D., Wang, J. (2002):Relationship between growth redundancy and size inequality in spring wheat populations mulched with clear plastic film. – Acta Phytoecol.Sinica. 26: 177-184.

[35] Papathanasiou, F., Dordas, C., Gekas, F., Pankou, C., ElissavetNinou, E., Mylonas, L., Tsantarmas, K., Sistanis, L., Sinapidou, E., Lithourgidis, A., Petrevskaa, J. K., Papadopoulosa, I., Zouliamise, P., Kargiotidouc, A., Tokatlidisc, I. (2015) : The use of stress tolerance indices for the selection of tolerant inbred lines and their correspondent hybrids under normal and water-stress conditions. – Procedia Environmental Sciences 29: 274 – 275.

[36] Parvaneh, V., Naseri, R., Moradi, M. (2014): The Effect of Drought Stress on Grain Yield, Yield Components and Protein Content of Durum Wheat Cultivars in Ilam Province, Iran. – International Journal of Biological, Veterinary, Agricultural and Food Engineering 8(6): 619-624.

[37] Pfeiffer, W. H., Sayre, K. D., Reynolds, M. P. (2000): Enhancing genetic grain yield potential and yield stability in durum wheat. – Option méditerranéennes 40: 83-93.

[38] Sallam, A., Alqudah, A. M., Dawood, M. F. A., Baenziger, P. S., Börner, A. (2019): Drought Stress Tolerance in Wheat and Barley: Advances in Physiology, Breeding and Genetics Research. – Int. J. Mol. Sci. 20: 3137.

[39] Sayar, R., Khemira, H., Bchini, H., Daaloul, A. (2008): Étude comparative de trois approches d'évaluation de la tolérance à la sécheresse chez le blé dur (*Triticum durum* Desf). – Revue des régions arides 21: 775-788.

[40] Semcheddine, N. (2015): Evaluation de la tolerance à la sécheresse chez le blé dur (*Triticum durum* Desf.) par l'étude du bilan hydrique et des paramètres phéno-morpho-physiologiques. – Thèse de Doctorat en Sciences Agronomiques, UFA Sétif 1.

[41] Sinclair, T., Jamieson, P. (2006) :Grain number, wheat yield, and bottling beer: an analysis. – Field Crops Res. 98, 60–67

[42] Simane B., Peacock J.M., Strick P.C. (1993): Differences in development plasticity growth rate among drought . resistant and susceptible cultivars ofdurum wheat (Triticum turgidum L.Var. durum) . – Plant and soil 157: 155-166.

[43] Slami, M. (2015): Caractérisation morpho-physiologique et biochimique de quelques générations F2 de blé dur (*Triticum durum* Desf.) sous conditions semi-arides. – Thèse de magister, Université Ferhat Abbas Sétif 1.

[44] Slami, M., Haddad, L., Oulmi, A., Benmahammed, A. (2015): Variabilité phénotypique et sélection des caractères agronomiques du blé dur (*Triticum durum* Desf.) sous conditions semi-arides. – European Scientific Journal 11: 21.

[45] Wang, W.X., Brak, T., Vinocur, B., Shoseyov, O., Altman, A. (2003) : Abiotic resistance and chaprones: possible physiological role of SP1, a stable and stabilising protein from Populus. – In : Vasil, I. K. (ed) : Plant biotechnology 2000 and beyond. Kluwer, Dordrecht. 439-443.S

[46] Wultaw, T., Amri, A., Ogbonnaya, F. C., Sanchez-Garcia, M., Sohail, Q., Baum, M. (2015): Wheat. – In: Singh, M., Upadhyaya, H. D. (eds.) Genetic and Genomic Resources for Grain Cereals Improvement. Elsevier. DOI: 10.1016/B978-0-12-802000-5.00002-2.

[47] Urbanavičiūtė, I., Bonfiglioli, L., Pagnotta, M. A. (2022): Diversity in Root Architecture of Durum Wheat at Stem Elongation under Drought Stress. – Agronomy 12(6): 1329.

[48] Zhao, W., Liu, L., Shen, Q., Yang, J., Han, X., Tian, F., Wu, J. (2020): Effects of Water Stress on Photosynthesis, Yield, and Water Use Efficiency in Winter Wheat. – Water 12: 2127. doi:10.3390/w12082127.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
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