

Research Article

Agronomic and Morpho-Physiological Characterization of Some Advanced Lines being Selected in Durum Wheat Cultivated in Semi-Arid Conditions

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Abstract: Knowledge of agro-physiological traits associated with drought tolerance would be useful for developing breeding materials for drought-prone environments. This study was conducted to estimate genetic variability among nine durum wheat genotypes in response to drought. Our results indicated that the effect of the campaign, genotype, and genotype \times interaction was significant for the thirteen variables measured, except for the relative water content. The variability observed was greater for grain yield, biomass, ear fertility, straw and economic yields, chlorophyll content, and cell integrity. Heritability was high for the number of grains per ear and the chlorophyll content; medium for thousand kernel weights, low for grain yield, biomass, and economic yield, and zero for the rest of the variables measured. The results also showed that the agro-morphological characters were significantly linked to each other, unlike the physiological characters which showed non-significant relation between them and with the agro-morphological characters. This suggests that among the varieties evaluated, the selection of those which are tolerant and with high yield potential should therefore be made on a case-by-case basis and not based on a specific physiological character, a marker of tolerance, highly correlated with yield grain. The nine varieties evaluated were subdivided into three divergent clusters of three varieties each. Cluster C1 consists of the least performing varieties, unlike the other two clusters which bring appreciable gains for several characteristics including grain yield, biomass, the weight of 1000 grains, straw yield, and ear fertility and a marked improvement in chlorophyll content and a significant reduction in damage to the cell membrane by thermal stress. In conclusion and following their divergence, it is suggested to use the varieties of clusters C2 and C3 in crossing with the varieties of cluster C1 to improve and reconcile stress tolerance and yield potential in the same genetic background.

Keywords: agronomic characteristics, correlation, durum wheat, heritability, hierarchical classification, morpho-physiological characteristics

1. Introduction

Durum wheat is a strategic crop for Algeria, due to the area occupied on average of 1.5 million hectares. So,

production is low and very irregular ranging from 0.42 million tons in 1986/1987 to 3.2 million tons in 2016/2017 [1]. To improve this crop, the options are limited to the extension of planted areas and the adoption of a more ambitious technical itinerary (irrigation, fertilization, weeding, dates, and optimal planting densities) and also the selection of varieties that are more productive and better adapted to very variable production conditions. Among these alternatives, varietal improvement, in terms of yield potential, resilience to abiotic stress, and technological quality, is the most efficient, as variety is the technology package most readily available to the farmers [2]. Performance potential selection uses grain yield as a selection criterion. Varieties resulting from such selection are susceptible to abiotic stress, reacting strongly to environmental variation [3]. In such cases, the multi-character selection that combines stress tolerance markers with yield potential is justified [4-5]. The identification of the characteristics that condition the yield potential under stressful conditions is the first step in this process [2, 6]. Candidate traits for such selection include ground biomass, harvest index, the precocity of epilation, translocation capacity of assimilates stored in the neck of the ear to grain, water use efficiency, relative water content, chlorophyll content, plasma membrane stability, and standard leaf area [6]. Yield improvement is associated with increased ground biomass, harvest index, the reduction of the height and standard leaf area [7-8]. Lopes et al. [9] report significant correlations of yield with the precocity of epilation, the chlorophyll content of the standard leaf, canopy temperature, and soluble sugar content of the stem. According to Aissawi et al. [10], the improved yield of varieties issued by International Maize and Wheat Improvement Center (CIMMYT) during the period 1966 to 2009, is associated with the increase in ground biomass and plant height from 70 to 100 cm and the reduction in the harvest index from 47 to 43%. Belagrouz et al. [11] report that, compared to local varieties, modern varieties, in addition to their high yield potential, are characterized by concomitant improvement in the harvest index, chlorophyll content, reducing the relative water content and plant height. These varieties are also characterized by improved efficiency in the use of water to produce grain associated with the harvest index and chlorophyll content. These authors suggest that concomitant selection for plant height and harvest index can lead to improvements in grain yield under dry conditions. Blum [12] mentions that incorporating desirable morpho-physiological characteristics into the same genetic background is a desirable approach to developing resilient varieties for arid and semi-arid environments. Candidate traits must be genetically correlated with yield, easily measurable, and have a higher heritability than the yield being selection [12].

The objective of this study was to analyze the variability of the agro-morpho-physiological traits of nine varieties of durum wheat, to determine their heritability and the degree of association with the yield conducted under semi-arid conditions.

2. Materials and methods

2.1 Site study, plant material and experimental design

The present study was conducted on nine durum wheat varieties (*Triticum durum* Desf.) to study their behavior under semi-arid conditions (Table 1). The plant material was evaluated during two campaigns 2016/17 and 2017/18, on the site of the Agricultural Experimental Station of the Technical Institute of Field Crops located at Setif province (AES-TIFC-Sétif, 36°8' N of latitude, 5°20' E of longitude and 1081 m of altitude). The experiment was conducted in a randomized block design with four replicates. The elementary parcel is 6 rows × 5 m long × 0.20 m of inter-row spacing (Figure 1). The cultivation techniques recommended for the region were followed to raise a good crop. Eight kg/ha of mono-ammonium phosphate (52% P₂O₅ + 12% N) were applied before planting and 80 kg/ha of urea (46% N) were sprayed at the tillering stage. Weeds were controlled by applications of 150 g/ha Zoom (Dicamba 66% Triasulfuron 4%) and 1.2 L/ha Traxos (22.5 g/L Pinoxaden, 22.5 g/L Clodinafo-propargyl, and 6.5 g/L Cloquintocet-mexyl) chemical herbicides.

2.2 Trait's measurements

The measurements and notations made during the crop cycle concern the plant height (PH, cm) which has been measured, at maturity, from the ground to the top of the ear, awns not included, in three locations per elementary parcel, the average of three measures is the average value of the elementary parcel. Average values of ground biomass (GB, g/m²), straw yield (SY, g/m²), economical yield (EY, g/m²), grain yield (GY, g/m²), and components were estimated

from vegetation bundles from the harvest of 2 rows 1 m long per elementary parcel. The straw yield was estimated by the difference between aerial ground biomass and grain yield. Economical yield has been estimated by the sum of grain yield plus 30% straw yield, according to Annichiarico et al. [13]. The number of spikes (NS, m²) was determined by counting spikes in 1 m of row. The grain yield (GY, g/m²) was determined by manual threshing of the ears of the vegetation bundles and the weighing of the seeds obtained. The weight obtained is expressed in g/m². The thousand kernel weight (TKW, g) and the number of grains per spike (NGS) were estimated by the number, weight, and average of seeds from a random sample of 10 spikes per elementary parcel.

The notation of physiological characters was based on the relative water content (RWC, %) that was achieved according to the Barr's method, described by Clarke and Mc Caig [14]. The sampled leaves were cut at the base of the leaf blade and weighed immediately to obtain their fresh weight (FW, mg). They were then placed in test tubes filled with distilled water and placed in a cool, dark place. After 24 hours, the leaves were removed, passed in a blotting paper to absorb water from the surface, weighed again to obtain the turgid weight (TW, mg). The samples were then heated to 80°C for 48 hours and weighed to obtain the dry weight (DW, mg). The relative moisture content is calculated by the following formula: $RWC (\%) = [(FW - DW)/(TW - DW)] \times 100$. The chlorophyll content (CHL, Unit-Spad) is determined using a chlorophyll meter; model Minolta (Konika-Minolta Chlorophyll Meter SPAD-502). Cell integrity (CI %) is determined by the method described in Saadallah et al. [15]. The temperature is 50°C (C1) for 30 minutes and the lethal temperature (C2) is 100°C for 30 minutes. The reading is done using the conductivity meter. The percentage of damaged cells is estimated by: $CI (\%) = 100 \times (C1/C2)$. The standard leaf area (SLA, cm²) is determined by the product of the length (L) by the width of the blade (W) by the coefficient of 0.607. So, (L) and (W) is measured on a sample of 5 leaves taken randomly at the epilating stage: $SLA (cm^2) = (L \times W) \times 0.607$, where (LA), (L), and (W) as defined above and 0.607 is the value of the ratio between the leaf area estimated by the product $L \times W$ and that measured by planimetry [5]. Canopy temperature (CT, °C) is measured at the heading with a Model AG-42 infrared thermometer (Tele-temp Corp. Fullerton, CA).

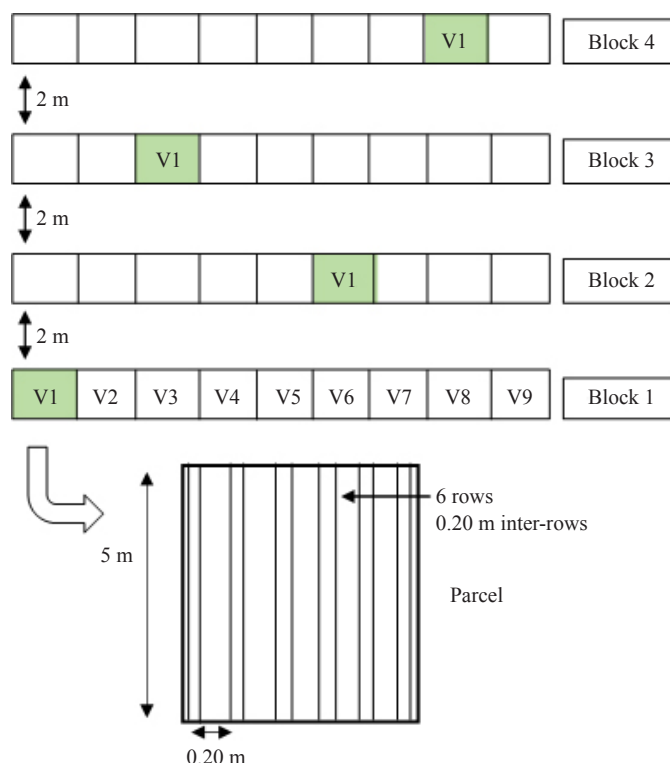


Figure 1. Experimental design consisting of four blocks. Each block consists of nine squares corresponding to the nine varieties studied. Each plot corresponds to a genotype of the durum wheat collection and consists of 6 lines 5 m long, spaced between them by 0.20 m. The letters V1 indicate the random distribution of controls (Waha)

Table 1. Name and pedigree of the durum wheat varieties used as planting material

N°	Name/Pedigree	Code	Origin
1	Waha-syn Pelicano/Ruff//Gaviota/3/Rolette (temoin)	V1	INRAA-ITGC
2	Canelo 9.1/Snitan/10/Plata_10/6/Mque/4/Usda537	V2	CIMMYT-ICARDA
3	Guemgoum Rkhem/4/Stj3//Bcr/Lks4/3/Ter-3	V3	INRAA-ITGC
4	Brak//Ajaia_8/3/Canelo_8//Sora//	V4	CIMMYT-ICARDA
5	<i>Triticum Polonicum</i> /Zenati Bouteille//Inrat69	V5	INRAA-ITGC
6	Icasyrl/3/Gcn//Stj/Mrb3	V6	CIMMYT-ICARDA
7	Icasyrl/3/Bcr/Sb15// <i>Triticum urartu</i> /4/13376/Berchl/Ossll/Stj5	V7	CIMMYT-ICARDA
8	Amedakull/ <i>Triticum dic</i> Syr Col//Loukos	V8	CIMMYT-ICARDA
9	Terbol 97-5/Gerufel2	V9	CIMMYT-ICARDA

2.3 Data analysis

Collected data were subjected to two-factor variance analysis (2 campaigns and 9 genotypes), using the ANOVA module implemented in Costas's version 6.4 [16]. The campaign's effect is tested relative to the hierarchical block effect. The genotype effect and (genotype \times campaigns) are tested by the weighted residual, in agreement with McIntosh [17]. Environmental components (σ^2e), genotypic (σ^2g), interaction components ($G \times E$) ($\sigma^2g \times e$) and phenotypic (σ^2p) of the variation are deduced from the values of the mean squares of the deviations which are taken as the estimated average expectations of the sources of genotype variation, ($G \times E$) interaction and weighted residual [18].

$$\sigma^2e = CMe \text{ residual}, \quad (1)$$

$$\sigma^2g \times e = \frac{CMe \ g \times e - \sigma^2e}{r} \quad (2)$$

$$\sigma^2g = \frac{CMe \ g - CMe \ g \times e}{r \times s} \quad (3)$$

$$\sigma^2p = \sigma^2g + \sigma^2g \times e + \sigma^2e \quad (4)$$

With

CMe = Mean square of deviations, r = number of replicates, and s = number of campaigns. The variance components were used to determine the following phenotypic, genotypic, and residual coefficients of variation:

$$CVp(\%) = \frac{100 \times \sqrt{\sigma^2p}}{\mu} \quad (5)$$

$$CVg(\%) = \frac{100 \times \sqrt{\sigma^2g}}{\mu} \quad (6)$$

$$CVe(\%) = \frac{100 \times \sqrt{\sigma^2e}}{\mu} \quad (7)$$

The degree of genotypic determination (H^2_{sl}) is estimated according to Singh and Chaudhary [19], via

$$H^2_{sl} = \frac{\sigma^2_g}{\sigma^2_g + \frac{\sigma^2_{g \times e}}{e \times r} + \frac{\sigma^2_e}{r}} \quad (8)$$

Pearson correlation coefficients between different character pairs showing a significant genotype effect which was determined using Excel (2003). The hierarchical classification into group varieties according to the degree of resemblance, was determined according to the ward method implemented in the software Past version 3 [20], using the Euclidean distances of the centered and reduced values of the variables under analysis. The statistical significance of the correlation coefficients is made about the values of the table t with n^2 degrees of freedom.

3. Results

3.1 Seasonal rainfall and temperature

Cumulative rainfall in the September to June period was 187.5 and 442.1 mm, respectively, for 2016/17 and 2017/18 (Figure 2). The two campaigns differ mainly by the large rainfall gap accumulated during the spring, 13.9 against 223.6 mm, respectively in 2016/17 and 2017/18. The 2016/17 campaigns avoided the disaster thanks to the 40 mm of oranges recorded in June (Figure 2). This variation in rainfall is a characteristic of semi-arid regions. The temperature distribution is bimodal, low in winter, and then gradually rises from April to reach 25°C, on average, in June. This temperature increase associated with the scarcity of rainfall coincides with the grain filling phase, which results in significant decreases in yield potential (Figure 2).

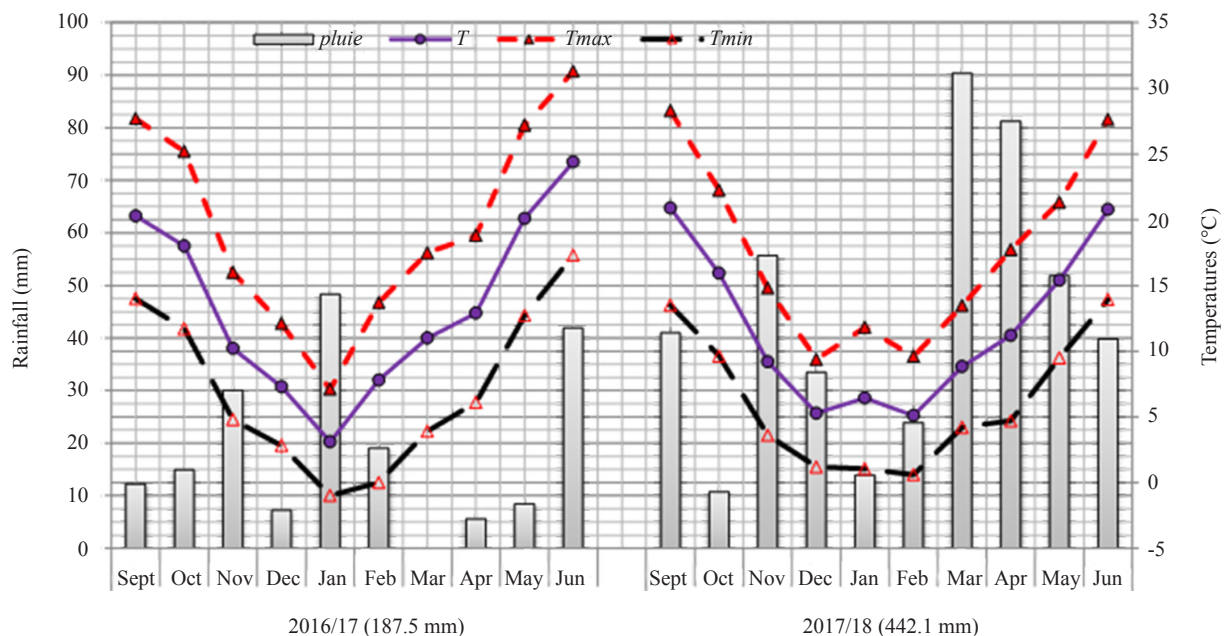


Figure 2. Rainfall and average temperatures of the AES-TIFC-Sétif experimental site for the two campaigns 2016/17 and 2017/18 (<https://www.tutiempo.net/premium/dz>)

3.2 Phenotypic variability

Phenotypic variability is required to achieve gains on targeted traits such as yield, adaptation, or stress resistance [18]. In this context, the results of the combined variance analysis indicate a highly significant campaigns average effect for the 13 variables measured. The mean genotype effect is not significant for the relative water content (RWC), the percentage of cellular damage, and the standard leaf area (LA). The (genotype \times campaigns) interaction is not significant for the number of grains per spike, the thousand kernel weight, chlorophyll content, canopy temperature, and relative water content (RWC) (Table 2). These results indicate that the values taken by the different variables analyzed differ mainly according to campaigns rather than genotypes and (genotype \times campaigns) interaction. Indeed, on average of the thirteen variables analyzed, 43.3% of the total variation is explained by the campaign's effect, 13.6% by the genotype effect, 8.1% by the interaction, and 26.9% by the residual, with large variations among variables. This suggests that to increase the chances of observing differences between varieties, it is desirable to increase the number of tests and replicate environments.

Table 2. Combined ANOVA of the different agronomic and physiological traits of durum wheat over campaigns

Source	Campaigns (C)	Repetition/Campaigns (R/C)	Genotype (G)	Genotype \times Campaigns (G \times C)	Residual (R)	Performance (P)		
DF	1	6	8	8	48	2016/17	Ecart	Ppds 5%
PH	14450.00**	63.86	42.07**	72.54**	14.98	58.28	-28.33**	4.61
GY	8253.13**	1562.23	3073.58**	1842.66**	750.99	160.30	21.41ns	22.79
GB	690822.00**	8563.53	20285.70**	18064.40**	6107.66	618.18	195.91**	53.35
NS	900259.00**	625.61	982.81**	2541.91**	381.10	332.78	223.64**	14.42
NG/S	2189.94**	23.70	108.67**	14.11ns	20.91	17.62	-11.03**	2.81
TKW	4501.58**	4.97	57.52**	20.25ns	13.14	34.02	-15.81**	1.29
SY	548059.00**	8382.96	11050.10**	14024.40**	5138.78	457.88	174.49**	52.79
EY	97931.30**	1902.20	5916.69**	3764.05**	1278.85	297.67	73.76**	25.14
CHL	178.05**	51.81	121.62**	5.97ns	18.71	41.29	3.15ns	4.15
CT	124.03**	76.78	18.15*	2.51ns	6.13	26.58	2.63ns	5.05
RWC	127.42**	14.85	61.49ns	66.20ns	33.15	84.67	2.66*	2.22
CI	21867.10**	345.64	244.03ns	329.43**	142.46	83.99	34.85**	10.72
FLA	1207.00**	1.25	11.42ns	15.93*	6.51	12.42	-8.19**	0.64

Ns, *, ** = non-significant and significant effects at the 5% and 1% threshold, respectively

DF = Degree of freedom, PH = Plant height, GY = Grain yield, GB = Ground biomass, NS = Number of spikes, NG/S = Number of grains per spike, TKW = Thousand kernel weight, SY = Straw yield, EY = Economical yield, CHL = Chlorophyll, CT = Canopy temperature, RWC = Relative water content, CI = Cellular integrity, FLA = Flag leaf area

3.2.1 Combined variance analysis

For variables with significant genotype mean effect and (genotype \times campaigns) interaction (PH, GY, BIO, NS, SY, and EY), as well as for variables with significant genotype mean effect and non-significant interaction (TKW, NGS, CHL, and CT), the ranking order of the varieties is constant from one campaign to the next, and the interaction is quantitative in nature (no cross-over). For such variables, the average genotype effect easily discriminates among the different varieties evaluated. The RWC variable, whose mean genotype effect and interaction are not significant, does not discriminate between the varieties studied due to the absence of genetic variability. The values taken by the CI and LA variables, whose average genotype effect is not significant while the interaction is significant, vary according

to the campaigns and the classification of the varieties is different from one campaign to another (interaction of a qualitative nature with cross over). For these variables, a given variety behaves as two different genotypes during the two campaigns. The average values of the different variables measured for the 2016/17 campaigns, the differences of the 2017/18 campaign values from those for the 2016/17 campaign, and the smallest significant difference at the 5% probability threshold (Ppds 5%) (Table 2). The study of these values shows that the 2017/18 campaigns were more favorable to the expression of the height (+28.33 cm), the number of grains per spike (+11.03 grains), thousand-kernel weight (+15.81 g), and the standard leaf area (+8.19 cm²). Compared to the values taken by (Ppds 5%), these inter-campaign differences are significant. The averages of these variables, in the above order, measured during 2016/17, are 58.28 cm, 17.62 grains/spike, 34.02 g, and 12.2 cm² (Table 2). Differences between campaigns in grain yield, chlorophyll content, and canopy temperature are not significant. The 2016/17 averages, of these three variables, are 160.30 g/m², 41.29 SPAD-units, and 26.58°C respectively. The 2016/17 season was more favorable to the expression of ground biomass (+195.9 g/m²), the number of spike/m² (+223.64 ears), straw yield (+174.49 g/m²), and economical yield (+73.76 g/m²), relative water content (+2.66%) and cell integrity (+34.85%).

3.2.2 Phenotypic coefficient of variation

On average for the two campaigns and the 9 varieties studied, the values of the different characteristics measured and parameters estimated are reported in Table 3. The phenotypic coefficient of variation greater than 10% is noted for grain yield, ground biomass, spike fertility, straw yield, economical yield, chlorophyll content, and cell integrity, indicating significant phenotypic variability for these variables. This variability is primarily genetic for grain yield, spike fertility, and chlorophyll content. On the other hand, in addition to the variability of genetic origin, the interaction variance ($G \times E$) contributes significantly to the observed variability of ground biomass, straw yield and economical yield, and cell integrity. The phenotype coefficient of variation is less than 10%, showing low variability in plant height, number of spikes, of thousand kernel weight, canopy temperature, and standard leaf area (Table 3).

The genetic component (σ^2_g) of the plant height, number of the spike, and thousand kernel weights, canopy temperature, and standard leaf area are zero, canceling the heritability of these traits. On the other hand, heritability is high for the number of grains per spike (72.97%) and chlorophyll content (82.41%); it is average for a thousand kernel weights (52.75%), and low for grain yield, ground biomass, and economical yield. Canelo 9.1/Snitan/10/Plata 10/6/Mque/4/Usda 537 (V2) had the highest yield (178.78 g/m²) associated with the highest number of spikes (232.75 spike/m²) and the number of grains per spike (30.42 grains/spike). Brak//Ajaia 8/3/Canelo 8//Sora// (V4) has the lowest grain yield (118.1 g/m²) associated with the lowest average values of ground biomass (447.68 g/m²), thousand kernel weight (39.04 g), straw yield (329.52 g/m²) and economical yield (217.01 g/m²) and the standard leaf area (14.53 cm²). This association of character in this variety suggests that yield is conditioned by ground biomass. The variety Icasyl/3/Bcr/Sb15//Triticum urartu/4/13376/Berchl/Ossll/Stj5 (V7) is the shortest (69.79 cm) and is distinguished by the highest average values of ground biomass (615.40 g/m²), thousand kernel weight (46.11 g), straw yield (457.99 g/m²) and economical yield (294.81 g/m²), canopy temperature (28.20°C) and cell integrity (71.15%). These results suggest that this variety is effective but sensitive to thermal stress.

The other varieties take intermediate values between the values of the extreme varieties mentioned above (Table 3). The physiological characteristics desirable for selection are dispersed in the evaluated varieties, with the highest chlorophyll content (46.16 SPAD) and lowest CI value (57.52%) observed in Triticum Polonicum/Zenati Bouteille//Inrat69 (V5), while the lowest canopy temperature (23.28°C) is measured at Terbol 97-5/Gerufl2 (V9). From the point of association of desirable traits in the same genetic background, the two most interesting varieties are Canelo 9.1/Snitan/10/Plata 10/6/Mque/4/Usda 537 (V2) and Icasyl/3/Bcr/Sb15//Triticum urartu/4/1337/6/Berchl/Ossll/Stj5 (V7). Relative to the performance of the control Waha (Figure 3), the variety V2 is distinguished by gains in grain yield (16.8%), spike fertility (20.1%), the number of spikes/m² (10.5%), and economical yield (9.1%). These gains are offset by a greater sensitivity to stress (+10.9% of CI, +3.3% of CT, and -4.5% CHL). V7 brings gains in the number of spikes/m² (8.4%), straw yield (22.1%), and economical yield (11.0%), thousand kernel weight (14.3%), and ground biomass (16.5%). These gains are also associated with stress sensitivity (+18.5% of CI, 9.7% of CT, and -13.2% of CHL).

Table 3. Average values of the different traits measured and estimated parameters corresponding to the two campaigns and the nine varieties studied

	PH	GY	BIO	NS	NGS	TKW	SY	EY	CHL	CT	CI	LA
Moy	72.44	149.60	520.23	220.96	23.13	41.93	370.64	260.79	39.72	25.27	66.56	16.51
Max	76.25	178.78	615.40	232.75	30.42	46.11	457.99	294.81	46.16	28.20	74.15	17.73
Min	69.79	118.15	447.68	200.25	20.14	39.04	329.52	217.01	32.30	23.58	57.52	14.53
Ppds 5%	3.89	27.55	78.56	19.62	4.60	3.64	72.06	35.95	4.35	2.49	12.00	2.57
σ^2_e	14.98	750.99	6107.66	381.10	20.91	13.14	5138.78	1278.85	18.71	6.13	142.46	6.51
$\sigma^2_{g \times e}$	14.39	272.92	2989.19	540.20	0.00	1.78	2221.41	621.30	0.00	0.00	46.74	2.35
σ^2_g	0.00	153.87	277.66	0.00	11.82	4.66	0.00	269.08	14.46	1.96	0.00	0.00
σ^2_p	7.13	478.07	3299.17	170.49	16.20	8.83	2023.61	899.44	17.54	3.04	48.31	2.24
CVe	5.34	18.32	15.02	8.84	19.77	8.64	19.34	13.71	10.89	9.80	17.93	15.46
CVg	0.00	8.29	3.20	0.00	14.86	5.15	0.00	6.29	9.57	5.53	0.00	0.00
CVp	3.69	14.62	11.04	5.91	17.40	7.09	12.14	11.50	10.55	6.90	10.44	9.07
H ² sl	0.00	32.18	8.42	0.00	72.97	52.75	0.00	29.92	82.41	64.40	0.00	0.00

PH = Plant height, GY = Grain yield, BIO = Ground biomass, NS = Number of spikes, NGS = Number of grains per spike, TKW = Thousand Kernel Weight, SY= Straw yield, EY = Economical yield, CHL = Chlorophyll content, CT = Canopy temperature, CI = Cellular integrity, LA = Leaf area

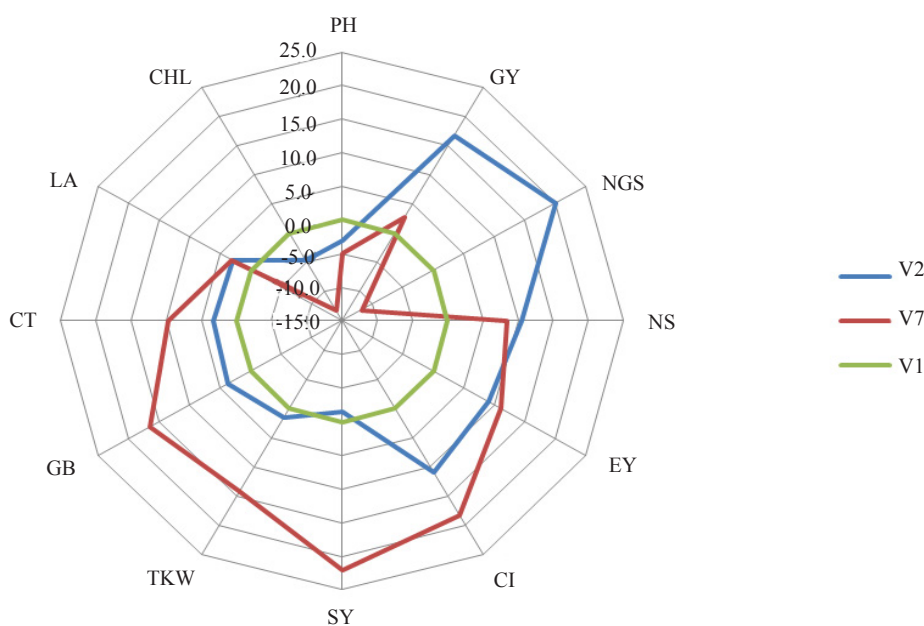


Figure 3. Relative deviations $[100 \times (\bar{Y}_i - \bar{Y}_{waha})/\bar{Y}_{waha}]$ of the performances of the varieties Canelo 9.1/Snitano10/Plata 10/6/Mque/4/Usda 537 (V2) and Icasyl/3/Bcr/Sb15/Triticum urartu/4/13376/Berchl/Ossll/Stj5 (V7) compared to the performance of the control Waha (V1). LA, leaf area; CHL, chlorophyll content; PH, plant height; GY, grain yield; NGS, number of grains per spike; NS, number of spikes; EY, economical yield; CI, cell integrity; SY, straw yield; TKW, thousand kernel weights; GB, ground biomass; CT, canopy temperature

3.3 Correlation among characters and varietal typology

The study of correlation coefficients shows that yield is significantly related to ground biomass, the number of

spikes, and the number of grains per spike, economical yield, and standard leaf area (Table 4). Ground biomass is significantly related to the number of spikes, thousand kernel weight, straw yield, and economical yield, and the standard leaf area. The number of spikes, in addition to its significant links with the plant height, grain yield, and ground biomass, is significantly related to economical yield and standard leaf area. These results show that in the 9 varieties evaluated, the agro-morphological characteristics show significant links between them. On the other hand, the physiological traits have such associations neither with each other nor with the measured agro-morphological traits, suggesting the absence of genetic linkage among the different genes that control these traits in the sample of evaluated varieties (Table 4). Among the varieties evaluated, the selection of those that are tolerant and have a high yield potential should therefore be done on a case-by-case basis and not based on a specific physiological character, a marker of tolerance, which is highly correlated with grain yield. Figure 3 shows the classification of the 9 varieties based on the mean values of the measured traits. The analysis of this figure shows that the varieties evaluated, according to their similarity, are divided into three different groups or clusters. Cluster C1 consists of varieties (V3), (V4) and (V6); cluster C2 consists of varieties (V7), (V8), and (V9). On the other hand, the “Waha” control (V1) and the (V2) and (V5) varieties form the C3 cluster (Figure 4). Typical mean values for the three clusters are given in Table 5. Cluster averages indicate that plant height, number of spikes, canopy temperature and cell integrity do not discriminate between clusters. Cluster C1, on the other hand, groups together the least performing varieties for grain yield, straw yield and economical yield, ground biomass, spike fertility, thousand kernel weights, chlorophyll content, and the standard leaf area (Table 5). Clusters C2 and C3 include varieties that perform better than those of cluster C1. These two clusters differ mainly for ground biomass, thousand kernel weight, and straw yield for which the varieties of cluster C2 are the most efficient; and the fertility of the spike for which the varieties of cluster C3 are the best (Table 5). Taking the average values of cluster C1 as index 100, the deviations of clusters C2 and C3, about these values are shown in (Figure 5). The selection of varieties in clusters C2 and C3 generates significant gains ranging from 14.6 to 30.71% for grain yield, economical yield, and ground biomass. The varieties of C2 bring a more consistent gain for straw yield (+18.54%) and thousand kernel weight (13.02%); while the varieties of cluster C3 bring a higher grain yield and spike fertility (37.02%), a clear improvement in the chlorophyll content (11.73%) and a significant reduction in damage to the cell membrane caused by thermal stress (8.12%).

Table 4. Coefficients of correlation of Pearson between the means of the two campaigns of the different pair's trait measured in the nine varieties evaluated. In bold significant correlation of coefficients

	PH	GY	GB	NS	NG/S	WTG	SY	EY	CHL	CT	CI
GY	-0.203	1.000						r5%	r1%		
GB	-0.454	0.779	1.000					0.666	0.798		
NS	-0.674	0.727	0.680	1.000							
NG/S	0.146	0.751	0.401	0.298	1.000						
TKW	-0.525	0.402	0.686	0.553	-0.244	1.000					
SY	-0.508	0.529	0.944	0.538	0.147	0.718	1.000				
EY	-0.354	0.937	0.949	0.745	0.602	0.584	0.791	1.000			
CHL	0.124	0.251	0.021	0.222	0.473	-0.507	-0.104	0.138	1.000		
CT	-0.273	0.326	0.614	0.207	0.497	0.043	0.660	0.505	0.168	1.000	
CI	-0.558	-0.259	0.078	-0.023	-0.251	0.242	0.243	-0.087	-0.612	0.363	1.000
LA	-0.317	0.930	0.877	0.691	0.552	0.599	0.697	0.956	0.126	0.326	-0.132

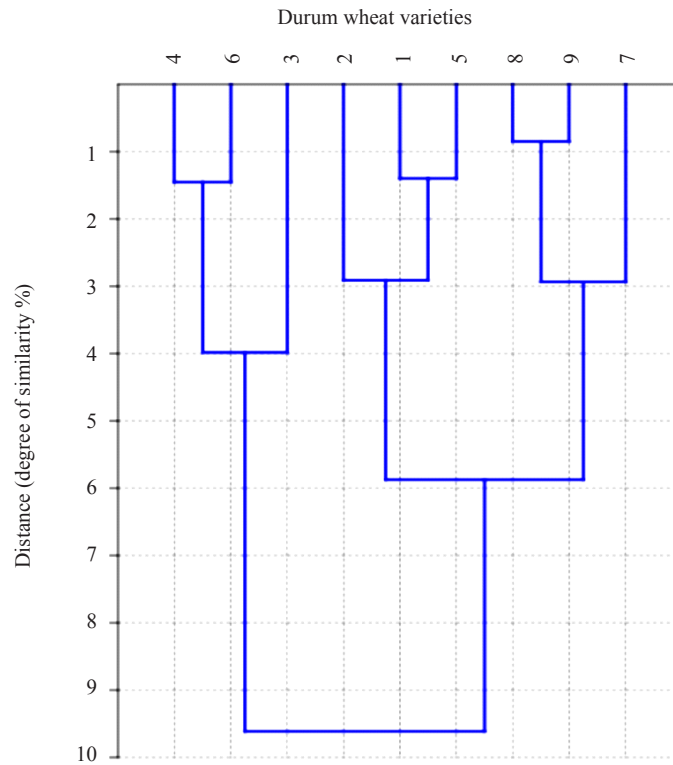


Figure 4. Hierarchical classification of the 9 varieties evaluated based on means of 11 measured traits

Table 5. Pearson correlation coefficients between the two-year averages of the different trait pairs measured in the nine varieties evaluated

Clusters	C1	C2	C3
Varieties	V3, V4, V6	V7, V8, V9	V1, V2, V5
PH	73.01	70.69	73.63
GY	125.71	158.76	164.31
GB	465.53	561.57	533.60
NS	211.83	229.92	221.13
NG/S	20.17	21.58	27.64
TKW	40.13	45.35	40.29
SY	339.81	402.81	369.29
EY	227.66	279.60	275.10
CHL	38.35	37.94	42.85
CT	24.61	25.19	26.00
CI	68.75	67.77	63.17
LA	14.99	17.41	17.13

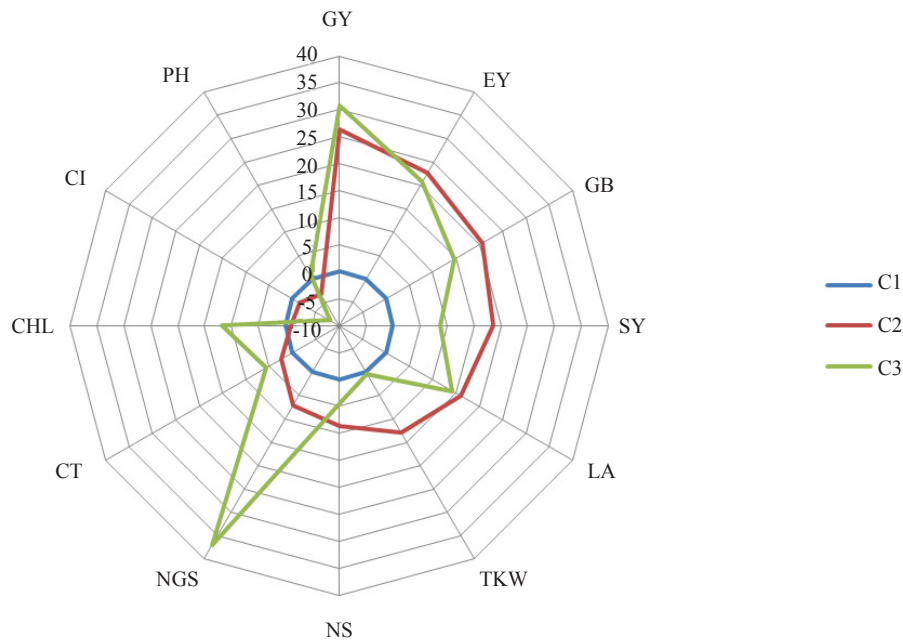


Figure 5. Deviation of the mean values of clusters C2 and C3 from the mean values of cluster C1 for the different variables measured. LA, leaf area; CHL, chlorophyll content; PH, plant height; GY, grain yield; NGS, number of grains per spike; NS, number of spikes; EY, economical yield; CI, cell integrity; SY, straw yield; TKW, thousand kernel weights; GB, ground biomass; CT, canopy temperature

4. Discussion

Durum wheat varieties grown in a dry environment must have the ability to tolerate water and thermal stress to improve their grain yield potential [21]. Water deficit and high end-of-crop temperatures reduce grain yield. This reduction is induced by the abortion of spikelet, the sterility of the pollen that affects the spike fertility, and the drying of the foliage that cancels the transfer of assimilates to the grain, affecting thousand kernels weights [22]. The development and selection of varieties adapted to such an environment, although difficult, is necessary. To do this, it is essential firstly to identify the agro-morpho-physiological characteristics associated with stress tolerance [6]. The target tolerance, defined as the genotypic ability to achieve acceptable stress performance, according to Dolferus et al. [23], must ensure the reduction of oxidative damage (cellular damage) and the protection of photosynthetic activity (foliage life and translocation of assimilates stored in the neck of the spike). Traits such as plant height, number of spikes, spike fertility, thousand kernel weight, life span, and standard leaf area are all known variations in stress adaptation [6, 24]. Chlorophyll content, relative water content, and membrane stability among other physiological traits are suggested as the markers of the plant's response to stress [6, 25-26]. Maintaining high relative water content reduces the inhibition of photosynthetic activity under stress conditions. Similarly, high chlorophyll content is an indicator of the accumulation capacity of dry matter under oxidative stress caused by water and thermal stress [25]. In this context, the results of the present study show significant campaign, genotype, and interaction effects for most of the variables measured, except for the relative water content. The 2017/18 season promoted the expression of plant height, spike fertility, thousand kernels weights, and the standard leaf area. Differences in grain yield, chlorophyll content, and canopy temperature between campaigns are not significant. The 2016/17 season was more favorable to the expression of ground biomass, the number of spike/m², straw yield and economical yields, relative water content, and cell integrity. Significant phenotypic variability is noted for grain yield, ground biomass, spike fertility, straw yield and economical yield, chlorophyll content, and cell integrity, as suggested by the phenotypic coefficient of variation with a value greater than 10%. The variability is essentially genetic for grain yield, spike fertility, and chlorophyll content. The interaction variance contributes significantly to the variability of ground biomass, straw yield, economical yield, and cell integrity. Plant height, spike number, thousand kernel weight, canopy temperature, and standard leaf area show low variability with a coefficient of variation less than 10%. The genetic component of these variables is zero, as is heritability. The

heritability of spike fertility and chlorophyll content is higher than thousand kernels weights average and that of grain yield, ground biomass, and economical yield is low. High heritability is indicative of an additive gene effect, suggesting the feasibility of effective early selection, according to Acquah [18]. The best grain yield associated with the number of spike and number of grains per spike, the highest, is observed in variety (V2); while the lowest grain yield associated with the lowest ground biomass values, thousand kernel weight, straw yield, economical yield, and the standard leaf area is noted in the (V4). These associations of variables in these extreme varieties suggest that grain yield in the sample of varieties evaluated in this study is conditioned by improved ground biomass. The highest values of ground biomass, thousand kernel weight, straw yield, economical yield, canopy temperature, and cell integrity are noted in variety (V7). The varieties (V2) and (V7) are distinguished by an association of desirable agro-morphological characters. These results are consistent with those of Fischer et al. [7] and Brancourt-Hulmel et al. [8] which indicate that improved grain yield is associated with increased ground biomass. Hamli et al. [26] mention the benefits of a standard leaf in capturing light and fixing more carbohydrates that are conducive to high yield. According to Aissawi et al. [10], improved yield, modern varieties are associated with increased ground biomass and plant height. Compared to the control, these two varieties provide significant gains for several agro-morphological traits, associated with reduced stress tolerance estimated by cell integrity tests, canopy temperature, and chlorophyll content. Correlations are analyzed to quantify the degree of genotype expression by the phenotype measured and to determine whether the selection of a given trait indirectly affects other traits not considered in the selection process [26]. A high-value correlation suggests the presence of linkage of genes with a pleiotropic effect [27]. Correlations of the present study indicate that the agro-morphological characters show significant links between them, but the physiological characters are not correlated with each other nor with the agro-morphological characters morphological, suggesting the absence of genetic linkage between the genes controlling these traits in the sample of evaluated varieties. This also suggests that among the varieties evaluated, the selection of those that are tolerant and have a high yield potential should therefore be done on a case-by-case basis and not based on a specific physiological character, a marker of tolerance, which is highly correlated with grain yield. These results contradict what is reported by Lopes et al. [9] which finds significant correlations of yield with the chlorophyll content of the standard leaf and canopy temperature. The discrepancy in results is often explained by differences between experimental sites, plant material evaluated and the sample size of the plant material tested. Indeed, the expression of phenotypic correlations is dependent on the environment according to Lopes et al. [9]. Belagrouz et al. [11] report that grain yield is associated with chlorophyll content, reduction in relative water content, and plant height. The study of the averages of the clusters formed indicates that cluster C1 groups together the least efficient varieties among others for grain yield, whereas clusters C2 and C3 group together the performing varieties and differ for ground biomass, thousand kernels weights, and the straw yield for which the varieties of the cluster C2 are the most efficient for the spike fertility for which the varieties of the cluster C3 are the best. Compared to the average values of cluster C1, the clusters C2 and C3 generate significant gains ranging from 14.6% to 30.71% for grain yield, economical yield, and ground biomass. The varieties of C2 bring a more consistent grain yield, straw yield, and thousand kernel weights; while the cluster C3 brings a higher gain for the spike fertility, a marked improvement in chlorophyll content, and a significant reduction in damage to the cell membrane caused by thermal stress. This group of varieties is interesting for its ability to maintain high chlorophyll content. It is suggested that it can be used as a genetic source for this crossing characteristic. Crosses between varieties of the cluster C1 with those of cluster C2 and/or varieties of C1 with those of C3, because of their diversity, generate transgressions in the desirable sense of selection and thus contribute to the accumulation of agronomic, morphological, and physiological traits in the same genetic background as proposed by Fellahi et al. [28]. The selected progeny of these populations or crosses will be taken back in crosses (backcross) with the parent donors of the genes controlling the desirable characteristics to promote the favorable links between yield potential and stress tolerance. Indeed, according to Anjum et al. [25], chlorophyll reduction is indicative of stress-sensitive genotypes, while tolerant genotypes minimize chlorophyll reduction and therefore inactivation of photosynthesis under stressful conditions. In this regard, Abdipur et al. [29] report that chlorophyll content is a viable indicator for assessing the integrity of the photosynthetic apparatus and propose it as a selection criterion for identifying tolerant and high grain yield genotypes, for environments with limited rainfall.

5. Conclusion

The present study reveals significant variability for several agro-morpho-physiological characteristics that can be used in a genetic improvement program. The results show that in the nine varieties evaluated, the agro-morphological characters exhibit significant links with each other contrary to the physiological characters which are not significantly linked with each other or with the agro-morphological characters. The nine genotypes tested are classified as three very divergent clusters, one of which groups the varieties that are least performing for grain yield and the characters that are linked to it. The other two clusters provide significant gain yield compared to the control of the “Waha” cultivar for several desirable characteristics, including the stress tolerance estimated by cell integrity, canopy temperature, and chlorophyll content. Crosses between divergent clusters are suggested to improve and reconcile stress tolerance and grain yield potential in the same genetic background. Two varieties, Canelo 9.1/Sniton/10/Plata 10/6/Mque/4/Usda 537 and Icasyl/3/Bcr/Sb15//Triticum urartu/4/13376/Bcrchl/Ossl/Stj5, combining several desired characteristics whose grain yield performance has been identified and proposed for immediate use as varieties by the field crop.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

References

- [1] Benbelkacem A. *Enhancing Food Security in Arab Countries' Icarda-INRA*. Project results report. 2013. p. 35.
- [2] Nouri A, Etminan A, Jaime A, da Silva T, Mohammadi R. Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turgidum* var. *durum* Desf.). *Australian Journal of Crop Science*. 2011; 5(1): 8-16.
- [3] Haddad L, Bouzerzour H, Benmahammed A, Zerargui H, Hannachi A, Bachir A, Salmi M, Oulmi A, Fellahi ZEA, Nouar H, Laala Z. Analysis of genotype × environment interaction for grain yield in early and late sowing dates on durum wheat (*Triticum durum* Desf.) Genotypes. *Jordan Journal of Biological Science*. 2016; 9: 139-146.
- [4] Sayre KD, Rajaram S, Fisher RA. Yield potential progress in short bread wheat in northern Mexico. *Crop Science*. 1998; 37: 42-46.
- [5] Fellahi ZEA, Hannachi A, Bouzerzour H. Analysis of direct and indirect selection and indices in bread wheat (*Triticum aestivum* L.) segregating progeny. *International Journal of Agronomy*. 2018; 1-11.
- [6] Fellahi ZEA, Hannachi A, Bouzerzour H. Expected genetic gains from mono trait and index-based selection in advanced bread wheat (*Triticum aestivum* L.) populations. *Revista Facultad Nacional de Agronomia Medellin*. 2020; 73: 9131-9141.
- [7] Fischer RA, Rees D, Sayre KD, Lu ZM, Condon AG, Saavedra AL. Wheat yield progress is associated with higher stomatal conductance and photosynthetic rate and cooler canopies. *Crop Science*. 1998; 38: 1467-1475.
- [8] Brancourt-Hulmel M, Doussinault G, Lecomte C, Berard P, Le Buanec B, Trottet M. Genetic improvement of agronomic traits of winter wheat cultivars released in France from 1946 to 1992. *Crop Science*. 2003; 43: 37-45.
- [9] Lopes MS, Reynolds MP, Jalal-Kamali MR, Moussa M, Feltaous Y, Tahir ISA, Barma N, Vargas M, Mannes Y, Baum M. The yield correlations of selectable physiological traits in a population of advanced spring wheat lines grown in warm and drought environments. *Field Crops Research*. 2012; 128: 129-136.
- [10] Aisawi KAB, Reynolds MP, Singh RP, Foulkes MJ. The physiological basis of the genetic Progress in yield potential of Cimmyt spring wheat cultivars from 1966 to 2009. *Crop Science*. 2015; 55: 1749-1764.
- [11] Belagrouz A, Chenafi H, Bouzerzour H, Hakimi M, Razim R, Hadj Sahraoui A. Relationships among water use

efficiency and the physio-agronomic traits in durum wheat (*Triticum durum* Desf.) cultivars assessed under rainfed conditions of the eastern high plateaus of Algeria. *Agricultural Forestry*. 2018; 64: 159-172.

- [12] Blum A. Drought resistance, is-it really a complex trait? *Functional Plant Biology*. 2011; 38: 753-757.
- [13] Annichiarico P, Bellah F, Chiari T. Defining sub-regions and estimating benefits for a specific adaptation strategy by breeding programs: A case study. *Crop Science*. 2005; 45: 1741-1749.
- [14] Clarke JM, McCaig TN. Excised leaf water relation capability as an indicator of drought resistance of *Triticum* genotypes. *Canadian Journal of Plant Science*. 1982; 62: 571-577.
- [15] Saadalla MM, Quick JS, Shanahan JF. Heat tolerance in winter Wheat: II. Membrane thermostability and field performance. *Crop Science*. 1990; 30: 1248-1251.
- [16] Costat. CoHort Software Graphics and Statistics Software for Scientists and Engineers. 2008.
- [17] McIntosh MS. Analysis of combined experiments. *Agronomy Journal*. 1983; 75(1): 153-155.
- [18] Acquaah G. *Principles of Plant Genetics and Breeding*. 2nd ed. Oxford: Wiley Blackwell; 2012.
- [19] Singh RK, Chaudhary BD. *Biometrical Methods in Quantitative Genetic Analysis*. New Delhi: Kalyani Publ.; 1985.
- [20] Hammer O, Harper DAT, Ryan PD. PAST: Paleontological statistics software package for education and data analysis. *Paleontologia electronica*. 2001; 4: 1-9.
- [21] Abbassenne F, Bouzerzour H, Hachemi L. Phénologie et production du blé dur (*Triticum durum* Desf.) en zone semi-aride (in French). *Annual of Agronomy*. 1997; 18: 24-36.
- [22] Fakhri ME, Mahboub S, Benchekroun M, Nsarellah N. Grain filling and stem accumulation effects on durum wheat (*Triticum durum* Desf.) yield under drought. *Nature Technology*. 2011; 7: 67-73.
- [23] Dolferus R, Ji X, Richards RA. Abiotic stress and control of grain number in cereals. *Plant Science*. 2011; 181: 331-341.
- [24] Chen X, Min D, Yasir TA, Hu YG. Evaluation of 14 morphological, yield-related, and physiological traits as indicators of drought tolerance in Chinese winter bread wheat revealed by analysis of the membership function value of drought tolerance (MFVD). *Field Crops Research*. 2012; 137: 195-201.
- [25] Anjum SA, Xie XY, Wang LC, Saleem MF, Man C, Lei W. Morphological, physiological, and biochemical responses of plants to drought stress. *African Journal of Agriculture Research*. 2011; 6: 2026-2032.
- [26] Hamli S, Bouzerzour H, Benmahammed A, Oulmi A, Kadi Z, Addad D. Déterminisme génétique des caractères morpho-physiologiques liés au rendement chez le blé dur en zone semi-aride des Hauts plateaux Sétifiens, Algérie (in French). *European Scientific Journal*. 2015; 11: 146-160.
- [27] Farshadfar E, Romena H, Shabani A. Evaluation of genetic parameters in agro-physiological traits of wheat (*Triticum aestivum* L.) under irrigated condition. *International Journal of Advance Biology and Biomedical Research*. 2016; 4(4): 319-326.
- [28] Fellahi Z, Hannachi A, Bouzerzour H, Boutekrabi A. Study of interrelationships among yield and yield-related attributes by using various statistical methods in bread wheat (*Triticum aestivum* L.). *International Journal of Agronomy and Plant Production*. 2013; 4(6): 1256-1266.
- [29] Abdipur M, Ramezani HR, Bavei V, Talaei S. Effectiveness of canopy temperature and chlorophyll content measurements at different plant growth stages for the screening of drought-tolerant wheat genotypes. *American-Eurasian Journal of Agricultural and Environmental Science*. 2013; 13: 1325-1338.