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Screening of Wheat (*Triticum durum*) for drought tolerance in semiarid conditions

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Abstract

Drought is one of the most important abiotic factors that limit wheat yield around the world. The objectives of this study were performed to assess the usefulness of various indices in identifying durum wheat genotypes tolerant to drought and to determine stable genotype for grain yield. Ten durum wheat genotypes were evaluated under rain-fed and irrigated conditions. The study was repeated at 3 locations around high plains of Algeria, in order to generate 8 different environments. Regression coefficient (b_i) and seven drought tolerance indices which comprised: mean productivity (MP), tolerance index (TOL), geometric mean productivity (GMP), stress susceptibility index (SSI), harmonic mean (HMP), yield stability index (YSI) and stress tolerance index (STI) were applied. There was significant variation for grain yield among both genotypes and environments and a very strong interaction genotype x environment. Water stress reduced the yield potential by 65%. Highly significant genotypic effect was observed for: STI, MP, GMP and TOL. These indices were significantly and positively correlated with grain yield in both stress and non stress condition, which suggest using them as effective criteria for screening drought tolerance genotypes. The typological study identified Bousselem, Hoggar and Mexicali as performing and tolerant compared to Oued Zenati and Polonicum, less productive and more susceptible to stress. Dukem, Waha and Altar genotypes are moderately tolerant and have above-average performance. The study of the stability and the performance of the grain yields made it possible to distinguish Bousselem and Waha as stable and efficient genotypes regardless of the environment.

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Introduction

Durum wheat is one of the most important crops in the Mediterranean areas, mainly in the Central and West Asia and North Africa (CWANA) region (Brennan *et al.,* 2002). Among the various abiotic stresses, drought is the major factor that limits crop productivity worldwide (Tardieu *et al.,* 2014). In CWANA region, drought show large and unpredictable fluctuations within and among cropping seasons and it is the main abiotic stress limiting durum wheat production (Royo *et al.,* 1998). Most of the crops and specially durum wheat are sensitive to drought, particularly during flowering to seed development stages. Inadequate water availability during the life cycle of a crop species restricts the expression of its full genetic potential (Hajiboland *et al.,* 2015).

The response of plants to water stress depends on several factors such as developmental stage, severity and duration of stress and cultivar genetics (Beltrano and Marta, 2008). The improvement of a crop's productivity under stress conditions requires genotypes with stress tolerance and yield stability (Mohammadi and Amri, 2013). Breeding for drought resistance is complicated by the lack of fast reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes can be evaluated efficiently (Ramirez and Kelly, 1998).Development of stress tolerant varieties is always a major objective of many breeding programs but success has been limited by adequate screening techniques and the lack of genotypes that show clear differences in response to various environmental stresses.

To evaluate drought resistance genotypes, several selection indices have been suggested on the basis of a mathematical relationship between favorable and unfavorable environments. Thus, different indices have been utilized to evaluate genotypes for drought resistance based on grain yield under stress and non-stress conditions. Fischer and Maurer (1978) suggested the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between stress and irrigated environments and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions. Fernandez (1992) defined a new advanced index (STI= stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress environments. The geometric mean productivity (GMP) is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years (Fernandez, 1992). Yield stability index (YSI) was proposed by Bouslama and Schapaugh (1984) in order to evaluation the stability of genotypes in the both stress and non-stress conditions.

Genotype is considered stable if it has a high mean yield with a low degree of fluctuation in yielding ability when grown in diverse environments. Allard and Bradshaw (1964) defined stability as the genotypes adaptation to unpredictable and transient environmental conditions and the technique has been used to select stable genotypes unaffected by environmental changes. On the basis of yield under stressed and non-stressed environments, Fernandez (1992) had divided genotypes reaction into 4 categories: genotypes which have high yield in both conditions are group A; genotypes which have a high yield under non-stressed conditions named group B; genotypes which have a good yield under stressed conditions are group C and finally group D including genotypes which have a low yield in both conditions.
The present study was carried out to screen wheat genotypes with high yield potential stability under different water stress conditions and to determine suitable selection criteria for selection genotypes tolerant to drought.

Materials and methods

Experimental design

Field trials were conducted during 3 cropping seasons (2009/2012) in 3 locations around the city of Sétif (East Center and West). Locations characteristics are given in Table 1.

For the study, ten durum wheat genotypes (Table 2) were chosen (based on their reputed differences in yield performance under irrigated and non-irrigated conditions (Semcheddine *et al.,* 2014)) and tested in rain-fed and irrigated conditions.

In East location (Béni Fouda), the genotypes were tested in four levels of water, which included rain-fed treatment (E_1) and three levels of irrigation; E_2 (50 mm at booting), E_3 (50 mm at booting and 15 mm at heading), and E_4 (50 mm at booting and 30 mm at heading). In Center location (Rmada), genotypes were evaluated in rain-fed treatment (E_5) and irrigated treatment (E_6 = 60 mm at heading). Finally, in West location (Ain Arnat), genotypes were tested in rain-fed treatment (E_7) and irrigated treatment (E_8 = 60 mm at heading). Climatic data are presented in Fig. 1. For each location, the experiment was led down in a randomized complete block design with 3 replications. Genotypes were sown during December at rate of 350 seeds/m². The fertilizer was applied before sowing (100 kg ha⁻¹ of triple super phosphate 46%) and at tillering (80 kg h⁻¹ of urea 46%). Weeds were removed by hand, to avoid any negative effect of hormonal herbicides that may have differentially affected the genotypes. At maturity, a subsample (1 m), for each elementary plot was harvested manually and grain yield was determined and expressed in t ha⁻¹.

Yield Stabilities and drought indices

The study of drought tolerance is approached by the calculation of the indices between the favorable environment (irrigated treatment of the Ain Arnat location: $\mathbf{E_8}$) and the unfavorable environment (rain-fed treatment of the Béni Fouda location: $\mathbf{E_1}$) with the following relationships:

$SSI = (1-Y_S/Y_F)/(1-\bar{Y}_S/\bar{Y}_F)$ Fischer and Maurer (1978).
$MP = (Y_F+Y_S)/2$ Rosielle and Hamblin, (1981).
$TOL = Y_F - Y_S$ Rosielle and Hamblin, (1981).
$YSI = Y_S/Y_F$ Bouslama and Schapaugh, (1984).
$STI = (Y_F+Y_S)/ \bar{Y}^2_F$ Fernandez (1992).
$GMP = (Y_F \text{ x } Y_S)^{0.5}$ Fernandez (1992).
$HMP= [2*(Y_S* Y_P)]/(Y_S+Y_F)$ Kristin *et al.*(1997).

Where: SSI: Stress susceptibility index, MP: Mean Productivity, TOL: Stress Tolerance, YSI: Yield Stability index, STI: Stress Tolerance index, GMP: Geometric Mean Productivity, HMP: Harmonic Mean Productivity, Y_s and Y_F were the grain yield of each genotypes under favorable and unfavorable environment, $\bar{Y}_S$and $\bar{Y}_F$ were the average grain yield of all genotypes under favorable and unfavorable environment respectively.

Stability was estimated using the Finlay and Wilkinson (1963) method, based on the regression coefficient (b_i), a regression performance of each genotype in different locations calculating means over all the genotypes. The regression coefficient measured genotype reactivity's to the variation for the environment. So, when:

$b_i > 1$: very productive genotype but whose yield is low in an unfavorable environment;

$0 < b_i < 1$: genotype buffering the variations of the environment;

$b_i = 1$: stable genotype, therefore capable of adapting to a wide range of environments.

Statistical analysis

Data were subjected to simple analyze of variance (ANOVA), firstly on individual environment basis before combined ANOVA over environments using the SAS statistical analysis package (version 9.2; SAS Institute, Cary, NC, USA). Differences among treatments and genotypes were examined for statistical significance using the least significant difference (LSD) test. Linear correlation coefficients between all possible pairs of traits were calculated on the combined data using STATISTICA program StatSoft France (1997).

Results and discussion

Intra and inter environment variation of grain yield

Simple variance analysis (Table 3) results for grain yield made for each environment showed high significant effect of genotype ($P < 0.01$). These results suggest the existence of genotypic variability which can be exploited by environment.

The examination of grain yield averages, done by environment, indicated differences in performance between genotypes, suggesting the possibility of effective selection as indicated by Adjabi (2011).

Indeed, each environment is specified by a group of performing genotypes that characterized it. Through the eight environments, only Oued Zenati is not among the best performing genotypes. The other genotypes rank, at least once, among the best performers by positioning at the top of the ranking.

Thus, Polonicum, Kucuk and Sooty, rank among the most performers genotypes one environment in eight, Whereas, Bousselem appears there seven times. Also, we note that Mexicali holds the first place by six times, Waha and Hoggar by five times, Dukem by three times and Altar by twice (Table 4).

These results indicate that among the 10 genotypes studied, 9 genotypes were characterized by a yield potential which classifies them as the best performers. Except that the classification order is related to the environment considered.

Table 1. Experimental locations characteristics.

Parameters		locations		
		East (Béni Fouda)	Center (Rmada)	West (Ain Arnat)
Geographic position	Latitude (North)	36° 9' N	36° 08' N	36° 07' N
	Longitude (East)	5° 21'	5° 20'	5° 18'
	Altitude	1175 m	1 081 m	1075 m
Granulometry	Clay %	35	45	30
	Silt %	49	41	49
	Sand %	16	14	21
Total limestone %		0,18	0,22	0,34
Water pH		7,9	8,2	8,05
Electrical conductivity (mmohs/cm)		0,15	0,14	0,15
Bulk Density		1,40	1,35	1,51
Saturation point %		45	43	40
Field capacity %		27	25	23
Wilting point		13	12	10
Permeability (mm/h)		10,4	8,4	12,5
Biochemical characters	Organic carbon %	1,11	0,79	1,23
	Organic mater %	1,85	1,35	2,11

This means that in the selection process, some genotypes are eliminated because they have been evaluated in environments that are not favorable to them and not because they do not have the desired yield potential. Thus, the selection of the genotype, whose inter-site or intra-site yield is stable, is a selection for tolerance and adaptation.

Changes in the order of genotype ranking, according to the different environments, is confirmed by the variance analysis of grain yield, carried out on all the environments of the 8 environments, which indicates a highly significant difference between genotypes, environments and a very strong interaction genotype x environment (Table 5).

Indeed, the value of a given genotype depends not only on its genetic potential but also its ability to maintain, at an acceptable level, its performance under different environments.

Table 2. Names and origins of durum wheat used in the experiments.

Genotype	Names	Origin	Genotype	Names	Origin
1	Bousselem	Algeria	6	Altar	ICARDA/CIMMYT
2	Hoggar	Algeria	7	Dukem	ICARDA/CIMMYT
3	Oued Zenati	Algeria	8	Kucuk	ICARDA/CIMMYT
4	Polonicum	Algeria	9	Mexicali	ICARDA/CIMMYT
5	Waha	Algeria	10	Sooty	ICARDA/CIMMYT

The results of the combined variance analysis suggest that the additive model is not suitable for processing these results, as mentioned by Samonte *et al.* (2005). It is necessary, either: to resort to linear or multiplicative models as suggested by De Lacy *et al.* (1996); or use non-parametric methods, based on the calculation of the indices, as proposed by Sabaghnia *et al.* (2006). Indeed, the presence of a significant interaction means that the selection must be made by environment or by group of similar environments where the interaction is not significant, as indicated by Adjabi (2011).

Table 3. Simple analysis of variance for grain yield under different environments.

Source of variation	Mean Square								
		Béni Fouda				Sétif		Ain Arnat	
	df	E$_1$	E$_2$	E$_3$	E$_4$	E$_5$	E$_6$	E$_7$	E$_8$
Blocs	2	0.198^{ns}	0.080^{ns}	0.628^{ns}	0.305^{ns}	0.052^{ns}	0.723^{ns}	0.090^{ns}	0.226^{ns}
Genotype	9	3.418*	1.620*	6.171*	2.802*	1.482*	1.227*	2.581*	3.456*
Error	18	0.693	0.220	0.458	0.225	0.068	0.293	0.104	0.250
Total	29	--	--	--	--	--	--	--	--
CV (%)		20.99	10.42	12.80	8.06	5.74	9.17	6.48	8.22

^{ns} and * : no significant and significant effect at $P < 0.01$ respectively.

Table 4. Genotypic grain yield (t h^{-1}) under different environments.

Genotype	Béni Fouda				Sétif		Ain Arnat		Mean
	E$_1$	E$_2$	E$_3$	E$_4$	E$_5$	E$_6$	E$_7$	E$_8$	
Bousselem	6.01^{a}	5.68^{a}	7.35^{a}	7.58^{a}	5.31^{a}	6.52^{ab}	5.73^{b}	7.61^{a}	6.47^{a}
Dukem	4.76^{ab}	4.70^{abc}	5.57^{b}	6.32^{bc}	4.05^{de}	5.65^{abc}	5.37^{b}	6.03^{cd}	5.30^{cd}
Mexicali	4.24^{abc}	5.46^{ab}	6.54^{ab}	6.51^{ab}	4.39^{d}	6.81^{a}	4.35^{cd}	6.99^{abc}	5.66^{bc}
Waha	4.22^{abc}	4.61^{abc}	5.68^{ab}	6.40^{b}	5.59^{a}	6.34^{ab}	5.03^{bc}	6.39^{bcd}	5.53^{bc}
Altar	4.20^{abc}	4.72^{abc}	5.40^{b}	5.53^{bc}	4.65^{bcd}	5.28^{bc}	3.85^{d}	6.32^{bcd}	4.99^{de}
Hoggar	3.90^{bc}	4.40^{bc}	6.20^{ab}	6.36^{b}	5.12^{ab}	6.06^{abc}	6.85^{a}	7.42^{ab}	5.79^{b}
Sooty	3.88^{bc}	4.68^{bc}	5.45^{b}	5.46^{bc}	4.44^{cd}	5.79^{abc}	4.42^{cd}	5.21^{de}	4.91^{de}
Kucuk	3.72^{bc}	3.72^{c}	4.89^{b}	5.49^{bc}	3.53^{e}	6.41^{ab}	5.63^{b}	5.63^{de}	4.87^{e}
Oued Zenati	2.41^{c}	3.48^{c}	2.71^{c}	3.99^{d}	3.59^{e}	4.82^{c}	4.01^{d}	4.59^{e}	3.70^{g}
Polonicum	2.31^{c}	3.63^{c}	3.10^{c}	5.21^{c}	5.02^{abc}	5.31^{bc}	4.56^{cd}	4.64^{e}	4.22^{f}
Mean	3.96^{d}	4.50^{c}	5.28^{b}	5.88^{a}	4.57^{c}	5.90^{a}	4.98^{b}	6.08^{a}	5.14
LSD$_{1\%}$	1.95	1.10	1.59	1.11	0.61	1.27	0.75	1.17	0.40

*Column sharing the same letters indicates no significant differences.

Evaluation of drought tolerance indices

Variance analysis of drought tolerance indices doesn't show significant difference between genotypes for the indices: SSI, TOL and YSI. On the other hand, a highly significant genotypic difference is observed for the other indices (Table 6). This suggests the possibility of using indices representing a significant variation to evaluate drought tolerance in the ten genotypes studied.

The TOL index is indicative of the minimization of the yield loss between favorable and unfavorable environment and YSI measures the yield stability between these two environments for a given genotype. Whereas, the SSI index measures the decrease in genotype yield, from favorable to unfavorable environment, compared to the mean decrease observed for the group of genotypes evaluated. The genotype that minimizes this reduction is more stress-tolerant. Thus, genotypes with low SSI, TOL and high value for YSI are tolerant to water stress.

Table 5. Analysis of variance for grain yield combined all environments.

Source of variation	df	Mean Square	F_{obs}
Blocs	2	0.1436743	0.49348^{ns}
Environment	7	17.911343	61.52031*
Genotype	9	14.478547	49.72964 *
Environment * Genotype	63	1.1831752	4.0638665*
Error	158	0.2911452	--
Total	239	--	--
CV (%)		10.47	--

^{ns} and * : no significant and significant effect at *P < 0.01* respectively.

Indeed, the difference in grain yield between the unfavorable environment (represented by the rain-fed treatment of the Béni Fouda location) and the favorable environment (represented by the irrigated treatment of Ain Arnat location) was 2.12 t h^{-1}. Water stress reduced the yield potential by 65%. The index SSI varied from 0.56 to 1.44, TOL oscillated between 1.27 and 3.52 and YSI fluctuated between a minimum of 0.50 and a maximum of 0.80 (Table 7).

The indices SSI and TOL were significantly and positively correlated together ($r_{SSI-TOL} = 0.77$).

Also, YSI is significantly correlated with SSI and TOL, but negatively ($r_{SSI-YSI} = -1.00$ et $r_{TOL-YSI} = -0.77$) (Table 8). The results showed that Bousselem, Dukem and Sooty have the lowest values for SSI and TOL and high values for YSI. In contrast, Oued Zenati, Polonicum and Hoggar recorded the highest values for SSI and TOL and the lowest values for YSI. This assumes that these indices provided the same type of information, in terms of stress tolerance through the reduction of the yield between favorable and unfavorable environment.

Table 6. Analysis of variance for drought tolerance indices.

Source of variation	df	Mean Square						
		SSI	MP	TOL	STI	GMP	YSI	HMP
Blocs	2	0.034^{ns}	0.105^{ns}	0.428^{ns}	0.008^{ns}	0.069^{ns}	0.004^{ns}	0.053^{ns}
Genotype	9	0.290^{ns}	3.099*	1.353^{ns}	0.227*	3.190*	0.035^{ns}	3.311*
Error	18	0.165	0.201	1.085	0.026	0.277	0.020	0.376
Total	29							

^{ns} and * : no significant and significant effect at *P < 0.01* respectively.

The SSI and YSI indices were significantly correlated with the favorable environment ($r_{SSI-Yf} = -0.81$ et $r_{YSI-Yf} = 0.81$) and not significantly with the stressed environment ($r_{SSI-Ys} = -0.32$ and $r_{YSI-Ys} = 0.32$).

For the TOL index, its relationship to the two environments is not significant.

These results indicated that SSI and YSI are capable to identify significantly the genotypes that tolerate stress in a favorable environment and not significantly in the unfavorable environment.

Table 7. Drought tolerance indices of durum wheat genotypes under stress and non-stress conditions.

Genotypes	Y_s	Y_f	SSI	MP	TOL	STI	GMP	YSI	HMP	b_i
Oued Zenati	2,41	4,60	1,37	3,50	2,19	0,30	3,31	0,52	3,14	0,82
Altar	4,20	6,32	0,95	5,26	2,12	0,71	5,15	0,67	5,04	0,82
Sooty	3,88	5,22	0,74	4,55	1,34	0,55	4,49	0,74	4,44	0,75
Polonicum	2,31	4,65	1,44	3,48	2,33	0,29	3,28	0,50	3,09	0,94
Waha	4,22	6,40	0,93	5,31	2,18	0,72	5,16	0,68	5,02	1,02
Dukem	4,76	6,03	0,56	5,39	1,27	0,77	5,33	0,80	5,27	0,83
Mexicali	4,24	7,00	1,13	5,62	2,76	0,80	5,43	0,61	5,26	1,34
Kucuk	3,72	5,63	0,97	4,68	1,91	0,57	4,57	0,66	4,47	1,22
Hoggar	3,90	7,42	1,34	5,66	3,52	0,77	5,33	0,53	5,03	1,32
Bousselem	6,01	7,62	0,62	6,82	1,60	1,25	6,74	0,78	6,66	0,93
Moyenne	3,97	6,09	1,00	5,03	2,12	0,67	4,88	0,65	1,44	1,00
$LSD_{1\%}$	1.95	1.17	0.95	1.05	2.44	0.37	1.23	0.33		--

It appears that stress tolerance is gained at the expense of yield potential. Our work is in contradiction with Guendouz (2012), whose results, on the same genotype group as ours, have shown that the SSI and YSI indices are negatively and positively correlated with the yield of the unfavorable environment respectively, and positively and negatively to the favorable environment yield, respectively.

On the other hand, our results were not in agreement with those of Adjabi (2011) who found that the values of SSI and YSI were positively and negatively related to the yield of the favorable environment, but not to those of the unfavorable environment. Neither with those of Roseille and Hamblin (1981) which mentioned that the selection of low SSI values reduced the potential for yield in favorable environments.

Table 8. Correlation coefficients between Y_s, Y_f and drought tolerance indices.

	Y_f	Y_s	SSI	MP	TOL	STI	GMP	YSI	HMP
Y_f	1								
Y_s	$0,80^{**}$	1							
SSI	$-0,81^{**}$	$-0,32^{ns}$	1						
MP	$0,95^{**}$	$0,95^{**}$	$-0,59^{ns}$	1					
TOL	$-0,31^{ns}$	$0,32^{ns}$	$0,77^{**}$	$0,01^{ns}$	1				
STI	$0,97^{**}$	$0,90^{**}$	$-0,63^{*}$	$0,99^{**}$	$-0,09^{ns}$	1			
GMP	$0,97^{**}$	$0,92^{**}$	$-0,65^{*}$	$1,00^{**}$	$-0,07^{ns}$	$0,99^{**}$	1		
YSI	$0,81^{**}$	$0,32^{ns}$	$-1,00^{**}$	$0,59^{ns}$	$-0,77^{**}$	$0,63^{*}$	$0,65^{*}$	1	
HMP	$0,98^{**}$	$0,89^{**}$	$-0,70^{*}$	$0,99^{**}$	$-0,14^{ns}$	$0,99^{**}$	$1,00^{**}$	$0,70^{*}$	1

^{ns} ,* and ** : no significant and significant effect at $P < 0.05$ and $P < 0.01$ respectively.

The MP, GMP and HMP indices refer to the productivity between favorable and unfavorable environment for a given genotype and STI index measures the stress intensity between these environments.

Table 9. Principal components and those coefficients for each indices

Component	Variables									Cumulative (%)
	Y_s	Y_f	SSI	MP	TOL	STI	GMP	YSI	HMP	
PC1	0,967	0,927	-0,640	0,997	-0,054	0,989	0,999	0,642	0,996	87,55
PC2	-0,254	0,372	0,741	0,063	0,998	-0,033	-0,014	-0,740	-0,081	12,32

In breeding, the high values of these indices are the most desirable. These indices identify Oued Zenati and Polonicum as the least productive and most susceptible to stress. Their respective indices were: 3.50 and 3.48 for MP, 3.31 and 3.28 for GMP, 3.14 and 3.09 for HMP and 0.30 and 039 for STI. On the other hand, Bousselem, Hoggar and Mexicali were the most productive; their MP indices varied between 6.82 and 5.66.

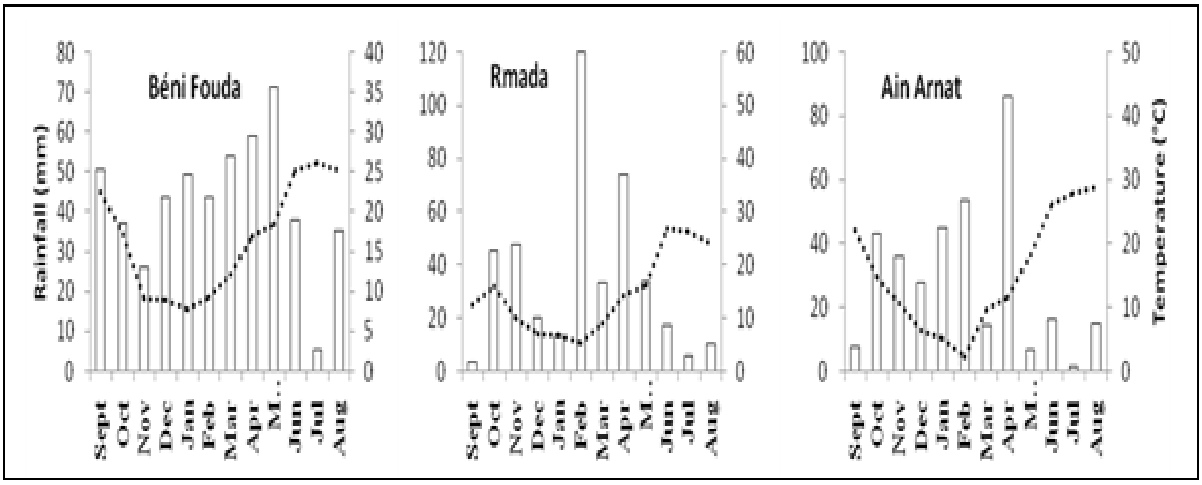

Fig. 1. Monthly accumulated rainfall (bars) and monthly mean temperatures (dashed line) in each location.

The GMP and HMP indices designated Bousselem and Mexicali as more productive and performing, in both favorable and unfavorable environment and the STI index qualified them as less susceptible to stress (Table 7).

However, intermediate values can identify medium tolerant genotypes whose performance is above average. Dukem, Waha and Altar can be considered moderately tolerant. These indices are highly and significantly correlated with each other and between the yields of the unfavorable environment ($r_{Ys\text{-}MP}$ = 0.95, $r_{Ys\text{-}STI}$ = 0.97, $r_{Ys\text{-}GMP}$ = 0.97 et $r_{Ys\text{-}HMP}$ = 0.98) and the yields of the favorable environment ($r_{Yf\text{-}MP}$ = 0.90, $r_{Yf\text{-}STI}$ = 0.97, $r_{Yf\text{-}GMP}$ = 0.92 and $r_{Yf\text{-}HMP}$ = 0.89) (Table 8). These indices provide relatively the same type of information in terms of yield performance and stress tolerance.

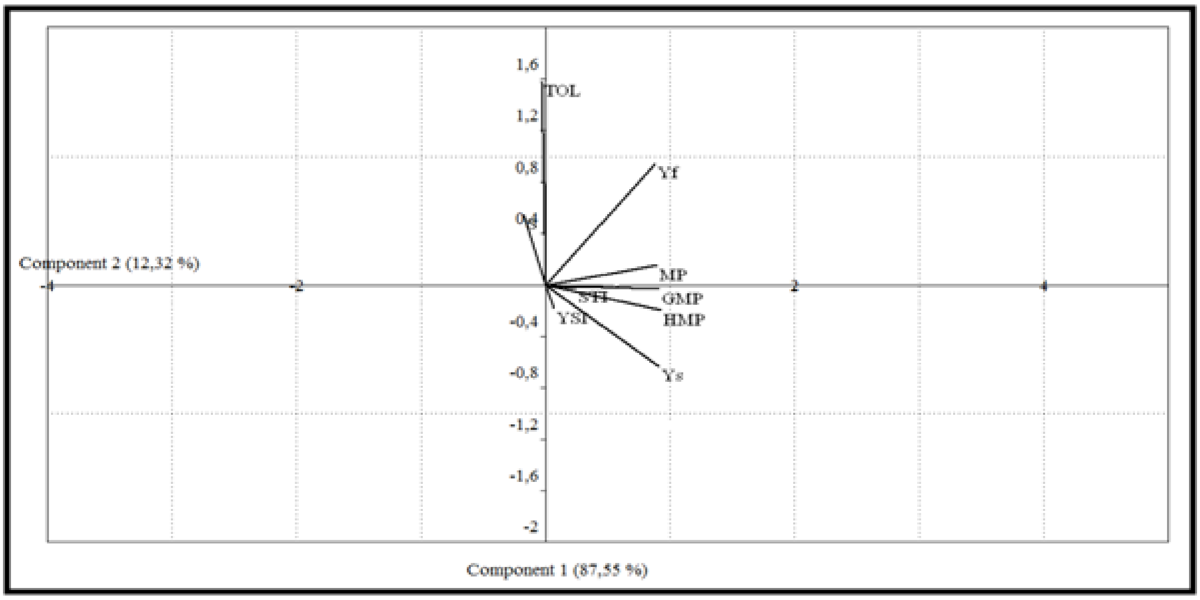

Fig. 2. Principal component analysis of drought tolerance indices.

Our results are in agreement with the work of several authors who refer to positive relationships between the yields of favorable and unfavorable environments and the MP, GMP, HMP and STI indices. For example, in durum wheat grown in fields or greenhouse and in rain-fed and irrigated conditions, Talebi *et al.*(2009), Khakwani *et al.* (2011), Ahmadizadeh *et al.* (2012) et Sayyah *et al.* (2012) report positive and significant correlations between the yield of the unfavorable and favorable environments and between the indices; MP, GMP et STI. Also, in 9 corn hybrids, tested in irrigated and dry environments, Tarabideh *et al.* (2014) founded significant and positive correlations between the grain yield of the two environments, on one side and on the other side with the indices; HMP, MP, GMP et STI.

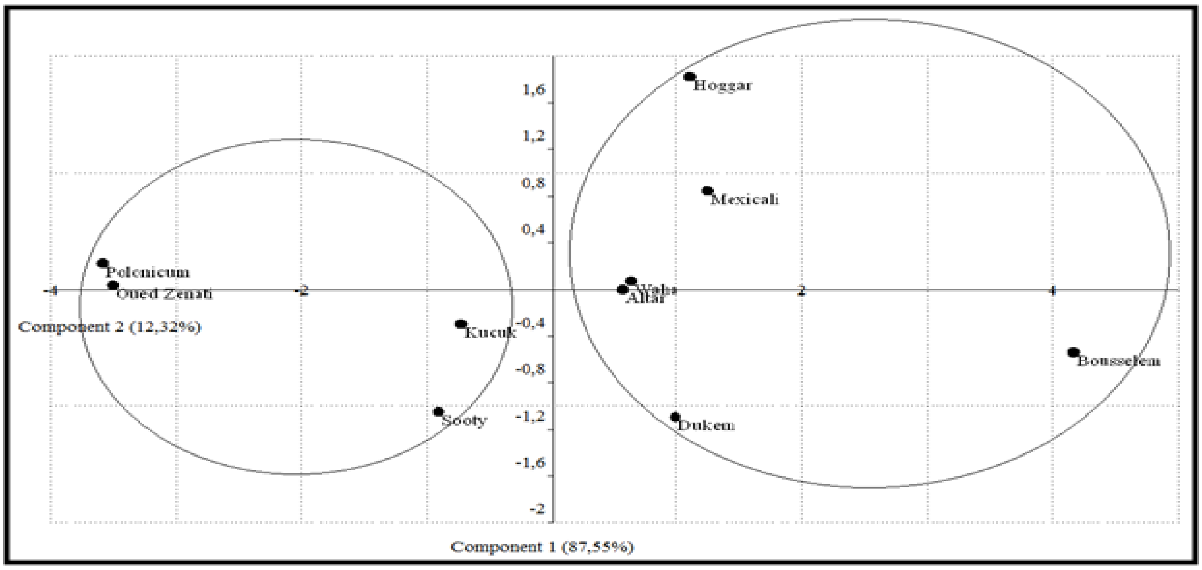

Fig.3. Similarity of genotypes according to yield potential and drought tolerance indices.

Genotypic typology

The matrix of correlation coefficients indicated similarity tendencies between the different indices studied. The existing relationships between the different indices are studied by a principal component analysis based on the values taken by the tolerance indices of the genotypes (Fig.2).

The first two main components explained 99.87% (87.55 and 12.32% for factors 1 and 2 respectively) of the total variation (Table 9).This suggests that all the variation can be explained, only by the first two factors.

The biplot of the variables (Fig. 2) grouped the indices according to the degree of similarity with respect to the information provided about stress tolerance and yield potential. The main axis 1 (PCA1) can be qualified as the axis of yield potential, tolerance and stability because it is highly and positively correlated with: the yield of both favorable (Y_f) and unfavorable (Y_s) environments, productivity indices MP, GMP and HMP and the STI and YSI indices. Tolerance, in this case,, reflected agronomic stability. Adversely, the main axis 2 (PCA2), combined the yield in favorable environment (Y_f) with the indices SSI and TOL which are opposed, on the same axis, with the yield of unfavorable environment (Y_s) and YSI index.

The biplot of individuals (Fig.3) grouped the genotypes according to their degree of similarity, on the basis of the indices and their yields potential. All along axis 1, genotypes are grouped which have a high yield potential and which are tolerant to drought.

They were Bousselem, Dukem, Mexicali, Waha, Altar and Hoggar. In contrast, on the same axis, the genotypes are grouped together; Oued Zenati, Polonicum, Sooty and Kucuk, which are characterized by low yield potential and are sensitive to stress.

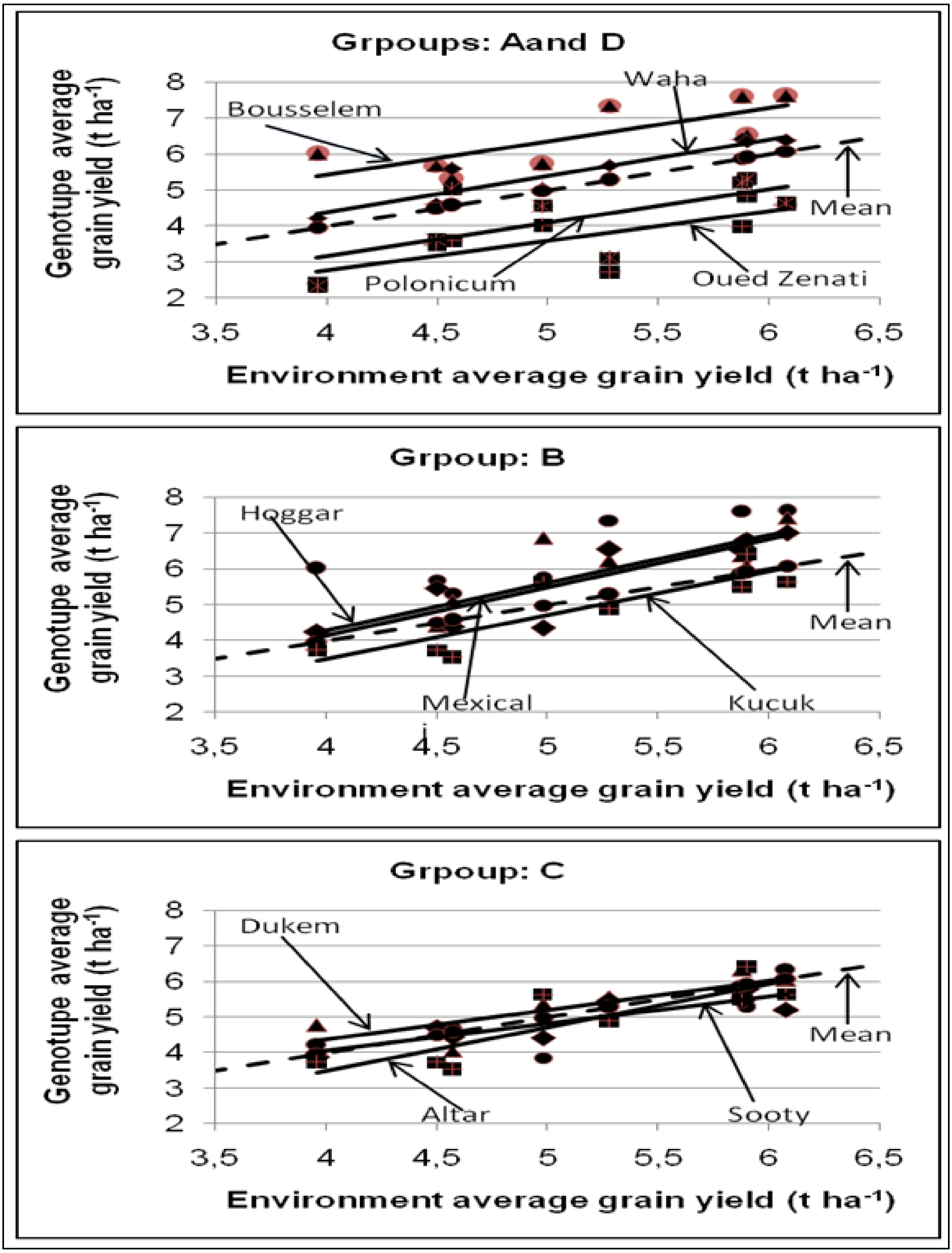

Fig. 4. Mean performance of 10 genotype over 8 environments based on yield data.

Axis 2 identified Mexicali and Hoggar as tolerant and performers in a favorable environment, unlike Bousselem, Dukem and Sooty, who designated them as tolerant but performers in an unfavorable environment.

The breeder, in his quest for adaptation to drought, is always looking for an ideal to know: stable genotype with high yield potential. It is therefore, a genotype performing in favorable environment but also, in an unfavorable environment of the region targeted by the selection, especially if this region is subject to a spatio-temporal variation (year or location) of stress. The study of yield performance on the three experimental locations (Béni Fouda, Sétif and Ain Arnat) and for all water treatments (8 treatments), by analyzing the yield curves of each genotype in relation to the mean yield curve for all genotypes, reveals a very high genotypic variability for performance and yield stability.

Regression values above 1.0 describe genotypes with higher sensitivity to environmental change (below average stability) and greater specificity of adaptability to high yielding environments. A regression coefficient below 1.0 provides a measurement of greater resistance to environmental change (above average stability), and thus increases the specificity of adaptability to low yielding environments (Wachira *et al.,* 2002).

Linear regression for the average grain yield of a single genotype on the average yield of all genotypes in each environment resulted in regression coefficients (b_i values) ranging from 0.75 to 1.34 for grain yield (Table 7).

This large variation in regression coefficients indicates different responses of genotypes to environmental changes.

In terms of the similarity of yield stability (Fig. 4), Bousselem, Waha, Polonicum and Oued Zenati are the most stable genotypes. However, Bousselem and Waha are efficient in favorable and unfavorable conditions (group A); while Polonicum and Oued Zenati are not efficient in any condition (group D), while the other genotypes are considered unstable. Indeed, the results showed that Dukem, Altar and Sooty value the unfavorable environment but with poor performances in a favorable environment (groups C), Mexicali and Hoggar perform well in a favorable environment but also value the stressed environment, as well as Kucuk, which performs less well in the constraining environment and tends to perform well in a favorable condition (group B).

Conclusion

The ability of a genotype to produce high and satisfactory yield over a wide range of stress and non-stress environments is very important. Our results showed high significant difference between genotypes for the indices: STI, MP, GMP and HMP, this suggests the possibility of using them to evaluate drought tolerance in durum wheat genotypes. The study of the stability and the performance of the grain yields made it possible to distinguish: Bousselem and Waha as stable and efficient genotypes regardless of the environment. In the other hand, Polonicum and Oued Zenati are stable and non-performing in all environments. At the opposite, the other genotypes are unstable. We take note that, Dukem, Altar and Sooty have a tendency to perform in an unfavorable environment than in a favorable environment. Finally, Mexicali, Hoggar and Kucuk, perform better in a favorable environment while enhancing the constraining environment.

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