Plant Archives Vol. 22, No. 2, 2022 pp. 193-200 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2022.v22.no2.034

STUDY OF GENOTYPE X ENVIRONMENT INTERACTIONS AND AGRO-TECHNOLOGICAL BEHAVIOR OF DURUM WHEAT VARIETIES APPLIED IN DIFFERENT AGRO-CLIMATIC ZONES OF ALGERIA

Nesrine Hacini[1,*] Radia Djelloul[1] and Dominique Desclaux[2]
[1] Laboratory of Functional and Evolutionary Ecology Research, Faculty of Natural and Life Sciences, Chadli Bendjedid University, PO Box 73 El Tarf (36 000), Algeria.
[2] INRA Supagro-Montpellier, INRA 2, Place Viala Building, (34 060) Montpellier, Cedex 01 (France).
* Corresponding author E-mail: nes_023@yahoo.fr
(Date of Receiving : 27-04-2022; Date of Acceptance : 02-08-2022)

ABSTRACT

Cereals occupy an essential place in agricultural research programs on a global scale. In Algeria, this place is all the most important as the country wants to achieve stable production of cereals, in particular durum wheat and common wheat. However, Algerian cereal farming remains very dependent on climatic conditions and is subject to very frequent droughts. Focusing on the cereal production under conditions of water deficit, many studies have shown that cereals have mechanisms of resistance to environmental constraints favoring their growth, development, and grain yield. The present work is interested in the study of some mechanisms of resistance to drought which seem to be among the most important in the production of cereals in Algeria. The knowledge of the intra-specific variability that plants manifest for tolerance to water stress allows considering the selection of resistant genotypes. This is why several agronomic criteria (components of yields) were used through a few sufficiently simple and rapid tests in order to discriminate between genotypes for resistance to water stress in the three different climatic stages.

Keywords: climatic conditions-durum wheat, varieties, selection, adaptation, genotype X environment interaction.

Introduction

Cereal farming is an important component of Algerian agricultural and food economies (Abidi *et al.*, 2011). Cereal production is characterized by fluctuations that vary in sawtooth from one year to another. The main cause of this situation remains the drought (association of high temperature and water deficit) as is also the case in most Mediterranean countries where water often remains the limiting factor for the cultivation of cereals (Benseddik, 2000; Benbelkacem, 2000). The durum wheat improvement objective is the development of high-yielding cultivars adapted to the prevailing climatic conditions of the target region. These future varieties must have the ability to make the most of the specificities of the different terroirs and technical itineraries. They must react positively to the diversity of situations in which they are placed or in which the variation of environment places them (Nouar *et al.*, 2010; Adjabi *et al.*, 2014). According to (Descleaux *et al.*, 2005), the genotypic variation for a trait depends very closely on the distribution of environments. It is therefore essential to specify the environment in which these criteria are studied. Still according to the same author, from an agronomic point of view, adaptability refers to the yield itself, while stability refers to the variability of the yield. And one of the first criteria for adapting a genotype to a given environment is the average of the trait considered (yield in general) for this genotype (Benbelkacem *et al.*, 2013).

The analysis of spatio-temporal variability of the major components of environment and its interaction with the genotypes remain the safest and most rational path to undertake for such an approach, provided that the complexity of the process is admitted (Bahlouli *et al.*, 2005).

This approach can be done through Genotype X Environment interaction studies. It is necessary to know, for each criterion, if such interactions exist and if the varietal classification for a criterion can be different according to the experimental environments (Fischer, 1985; Hadj *et al.*, 2003; Ait Kaki, 2008). For this reason, our major concern in this study is to target varieties whose agronomic and technological performance will be optimal in different agricultural regions. This is why such a strategy requires an in-depth analysis of the Genotype x Environment interaction. In this context, our study aimed to evaluate the variability of ten varieties of durum wheat grown in Algeria, and to analyze their genetic relationship with the study site based on agro-technological traits. The conclusions drawn through this study allow us to select high-performance genotypes, and possibly identify the favorable environment, by looking for the ideal variety. Following the explanation by (Desclaux *et al.*, 2013), we explored the temporal evolution of the concept of ideotype using the prototype of durum wheat. The term

"Ideotype" was used for the first time in the field of plant improvement to describe the model characteristics of a plant (cereal) dynamic management of varietal innovations through a transdisciplinary and partnership approach (Donald, 1968). The challenge then consisted of reasoning how to take into account the capacities of adaptation to an environment for better controlling the genotype x environment interactions, with the term environment being considered in its broad sense of analyzing the adaptability and stability of six varieties of durum wheat (*Triticum durum* Desf.) using parametric statistical methods including those based on joint regression, variance and multivariate analysis.

Materials and Methods

The experimental plant material consisted of 10 local and improved durum wheat (*Triticum durum* Desf.) genotypes (Table 1). Varieties are selected by the Technical Institute of Field Crops (ITGC) and the National Institute of Agronomic Research of Algeria (INRAA) and produced in cereal production areas.

The trials were set up on the previous cultivated fallow land, at three experimental research stations of the Technical Institute of Field Crops (ITGC): (ITGC Algiers, ITGC El Khroub and ITGC Sétif). These stations represent the wet (Oued Smar), semi-arid (high plains of Constantine) and arid (high plateaus of eastern Algeria) agronomic zones, respectively.

Table 1 : The ten varieties of durum wheat tested during the three agricultural campaigns on the experimental site of the ITGC of Sétif, Algeria.

Varieties	Characteristics
V1:waha	High productivity – semi-dwarf
V2:Gta/Dur	High productivity – good quality
V3:Stk/Haul/heca-1	Mexican cress – good quality
V4:Ammar-8	Intensive advanced line
V5:Msbi-1/Quarmal	Semi-dwarf-productive
V6: Azeghar-1/6/Zna-1/5/Awl 1/4/Ruff//jo/Cr/3/F9 .3	Cross I CARDA—Good adaptation
V7: Ville mur/3/Lahn //Gs /Stk /4/Dra2/ Bcr/ 5/Bcr/Lks4 /4/	Advanced lineage–Crois. ICARDA-Cimmyt
V8:Gsb/1/4/D68-1-93A1A//RuFF/Fg/3/Mtl5/5/Wdz6/Gi/4	Var.CIMMYT –Adapted.
V9:Lahaucan	Adapted to water stress
V10:Da-6Black awns/3/Bcr//Memo/God	Good production-Good adaptation

Experimental device

The tests were installed on a previously worked fallow land at the ITGC stations (Oued Smar, El-Khroub and Sétif) which represent the diversity of Algerian soils. The experimental device is en bloc randomized to 4 repetitions; the elementary plot comprises six lines of five meters in length spaced 0.20 m apart, and 1.2 m wide. They received basic fertilization of 46 units of phosphorus (46 kg of P_2O_5/ha) and 46 units of nitrogen in cover (46 kg/ha of nitrogen) at tillering. Sowing was carried out during the period from late November to mid-December at a dose of 100 kg/ha and harvesting took place from mid-June to early July.

The cities of the different resorts are classified by wet, semi-arid and arid bioclimatic levels and by geographical region (East, Center). The three sites chosen are:

Site 1: Constantine (ITGC El Khroub).
Site 2: Oued Smar (ITGC Algiers)
Site 3: Sétif (ITGC Sétif).

At the field level, the measurements were taken on a number of morphological and technological characters concerning the morphological parameters represented by the plot yield (q/ha), the height of the plants (cm), the weight of 1000 grain (PMG), the height in cm (H) and the number of grain /m^2.

The technological parameters were measured at the technological laboratory of the Technical Institute for Field Crops. The ITGC Harrache Algiers took charge of the quality analysis, and particularly of technological analyses of these criteria: Starvation rate (in %), Speckling, TE, Sedimentation test in Sodium Dodecyl Sulfate (SDS) medium (in ml), yellow index, brown index.

The other two quality variables, namely proteins and protein yield, were measured by near-infrared spectrometry analysis, a non-destructive method that makes it possible to predict various quality parameters for pastry and semolina using only a small amount of grain. This is a comparative analysis whose principle is based on the absorption of near-infrared light by organic matter. By using calibrations in which the spectral data of the known sample are correlated with their reference analytical values, spectrometry can predict, for an unknown batch, the level of the parameter based only on the spectral fingerprint of the sample. This analysis was carried out at I.N.R.A. of Montpellier (France), precisely at the experimental station of Melgueil where calibration curves for various parameters have been developed.

The spectra corresponding to the 10 varieties (sown and harvested at the three different locations) were collected on whole grains arranged in large cells with the NIR system 6500 working by reflectance, from 400 to 2500 nm, with a pitch of 02 nm (Wehrle *et al.*, 1996; Delwiche, 1998).

Statistical analyses

The durum wheat samples were made available to us by the Technical Institutes (I.T.G.C) at each site, so we had data from 10 varieties of durum wheat that have been tested in the field. Statistical analyses were performed using MINTAB 16.0. The description of the data is based on calculating certain usual statistical parameters according to the following analyses:

A - Searching for similar varieties by principal component analysis

Principal component analysis (PCA) is an exploratory method (Dagnelie, 1986; Palm, 1998). It is used to interpret a data matrix without any particular structure, which does not a priori include any distinction, neither between variables nor between individuals.

B - Searching for classes of homogeneous varieties by hierarchical analysis or hierarchical classification

The search for groups or classes of homogeneous varieties can also be done by hierarchical classification. Several methods are proposed by Dagnelie (1986) to achieve this goal. However, we decided to use the one proposed by Bouroche and Saporta (1980), and whose algorithm is programmed in the software. This method, also taken up by Palm (2000) and Dagnelie (1986), makes it possible to determine the level of similarity or divergence between individuals or varieties and gives a breakdown of individuals or varieties into groups or homogeneous classes.

Results and Discussion

Data collection from the ten varieties

The combined analysis of variance was performed to determine the effects of the environment, genotype and their interaction on the grain yield of the ten genotypes. The results revealed highly significant differences among environments ($p < 0.01$), with a significant genotype x environment interaction ($p < 0.05$) for grain yield, reflecting a differential response of genotypes in different environments (Hannachi *et al.*, 2019).

The results of grain yield show that the highest yields were recorded at the Khroub station, followed by those of Sétif, and finally those of Oued Smar.

In the latter (Oued Smar), despite sufficient rainfall, intermittent rains during autumn did not allow good soil preparation, leading to an unfavorable seedbed and, hence, low yields. Therefore, there were differences between sites.

Similarly, the genotypic effect is also observed; varietal differences are observed between sites, but also within each site.

There were also specific responses of each variety depending on the site. We will cite the case of Waha (32 qx/ha in Oued Smar, 34 qx/ha in Sétif and 66 qx/ha in Khroub).

Indeed, it is known that the yield of a given cultivar varies from one place to another, the notion of adaptability, and from one year to another, the notion of stability (Lin *et al*., 1986). The results of several studies indicate that yield potential is weak or negatively linked to stability and adaptability (Benmahammed *et al*., 2010; Kadi *et al*., 2010; Nouar *et al*., 2012; Haddad *et al*., 2016).

For the expression of the thousand-grain weight (M.G.W.), comparison of the three study sites indicates that the genotype x environment interaction is very highly significant ($p < 0.001$).

The highest thousand-grain weight was recorded at Oued Smar, being the most favorable to the expression of the thousand-grain weight for the maximum value, followed by Sétif and Khroub sites which gave maximum values closer to that of Oued Smar. The results confirm the inversely proportional relationship between grain yield and P.M.G., as highlighted by Bouzerzour *et al.* (2002) who showed that the PMG depends on the variety as well as the water and mineral nutritional conditions at the end of the cycle. A lack of water after flowering, combined with high temperatures, leads to a reduction in the PMG by altering the speed and/or the duration of filling, thus causing scalding of the grains (Triboi, 1990; Benbelkacem and Kellou, 2000).

The number of grains/ m^2

The analysis of variance by site or locality shows a very highly significant genotypic effect ($p < 0.001$), suggesting genetic variability to be exploited in selection. The significant effect indicates that, in each site, genotypic differences exist between the different lines tested. This shows that the production capacity is different from one genotype to another and from one environment to another. The Oued Smar site offers a lower number of grains/m^2. This is due in particular to the low grain yield obtained which, moreover, has a higher P.M.G.

The results relating to the height of the plants show significant differences between the sites for the expression of the same trait, differences in classification and differences in level reached by the average values of the trait considered (Benabdellah and Bensalem, 1993) (Table 2). According to (Abidi, 2018), the results would be linked to climatic conditions which would have a positive or negative impact on the growth and development of the straws. Indeed, the differences in genotypic expression, between the three sites tested, are explained by the variation in the range of conditions between the environments, which is a source of genotype X environment interaction. 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), showing that the effect of water deficit is very harmful to the height of durum wheat stems. According to Ben Abdellah and Ben Salem (1993), varieties with high straw have a better adaptation to water deficit, explaining the results of El Khroub site followed by Sétif and Oued Smar sites at the end.

For the agronomic and technological parameters

The results relating to the speck rate indicate that the speck of durum wheat causes a dark coloring of the grain, impacting the visual quality of the resulting products. Their marketing is illustrated by the following agronomic interpretation: The effects of Among the parameters chosen for the evaluation of the technological quality of the durum wheat collection, the main reasons are the climatic differences of the three regions studied, namely, the experimental station of Oued-Smar, El-Khroub station of Constantine and that of Sétif. It should be noted that the values of this character are high, in particular at Oued-Smar and Constantine, and absent for the majority of the varieties at the Sétif station, identical to the waha variety in the three regions. These high rates in these two regions would be linked to the high humidity rate specific to the Algerian coast, which would favor the development of fungi. This hypothesis is in agreement with the work of (Desclaux *et al.*, 2006), who recently confirmed that speckle is caused by three agents: abiotic conditions, insects and fungi. According to these researchers, climatic conditions are the most favorable causal factors for the appearance of speckles. They affirm that the expression of the speckle varies considerably according to the temperature threshold. All the genotypes of the Oued Smar station and the genotypes of the El Khroub station are strongly affected by speckle, except the waha variety. The most resistant varieties to the rate of speckling are, however, those of the experimental stations of Sétif. These same varieties which are very resistant in these two environments become sensitive in other environments.

Mitadine

The results show that there is an effect of the environment on the rate of scattering. Reveal a different sensitivity of the same varieties to scattering depending on the cultivation site. This rate exceeds the recommended limit threshold, it is therefore penalizing for the value durum wheat semolina. These results would probably be linked to the effects of the environment, that is to say, climatic conditions such as rainfall and cultivation techniques, among other factors, as well as to nitrogen fertilization (Abecassis, 1991). Resistance to rutting is a trait that depends on genetic factors. It is directly related to protein content.

Proteins

Total protein synthesis reveals variations both between cultivars and within different growing areas. Explaining in part the genotypic variability, the genotypes are distinguished by a remarkable dynamism by accumulating proteins following the climatic conditions of the site. In the majority of cases, water deficit that penalizes growth more than nitrogen absorption leads to an increase in protein content. In durum wheat, water deficit can also reduce the PS and can increase the index of Brown due to increased protein content.

The analyses carried out showed a significant variation in the quality of the grain under the effect of the growing region. The varieties studied showed high variability for the protein content criterion; this is attributable, in part, to genetic effects; thus, at comparable productivity, great differences exist between the varieties. Moreover, the expression of this protein content is also closely linked to the nitrogen fertilization of the plant

Table 2 : Averages of yield and quality components

Code	Variétés	lieu	RDTqx/ha	PMG	Ngrain /m^2/	hauteur	protéine	rdtprot	Mitadina	Mouchture	TE	SDS ml	IJ	IB
V1	Waha	o s/1	32,08	39,70	8080,60	84,38	17,2	5,52	2,75	0	56	27,5	23,71	8,95
V2	GTA dur	os/2	37,08	47,07	7877,63	90,19	16,7	6,19	1,08	3,55	61,3	37	21,81	7,06
V3	Skh/hau.heca^{-1}	os/3	43,95	45,50	9659,34	87,04	18,8	8,26	1,41	2,15	58,6	46	21,77	6,67
V4	Ammar-8	os/4	36,16	43,33	8345,26	92,63	16,4	5,93	1,66	1,8	57,6	38,5	20,59	7,07
V5	MSbl_1/ourmal	os/5	33,75	45,48	7420,84	91,06	16,1	5,43	2,83	1,85	53,3	37	21,2	7,75
V6	Azeghar1/6Zan-1/5	os/6	39,58	43,61	9075,90	94,13	17,6	6,97	0,16	0,6	58,3	42	21,34	7,16
V7	Villemur/3/lahn//gs	os/7	36,66	43,82	8366,04	84,19	18,1	6,64	0,33	1,15	59,3	27	21,28	7,16
V8	Gsbl/d68-1-93-a-a1	os/8	34,58	45,50	7600,00	92,69	18,6	6,43	0,33	4,8	59,6	44	24,32	7,72
V9	Lahaucan	os/9	40,41	39,50	10230,38	89,75	17	6,87	0,5	1,9	59	41	22,02	6,91
V10	Da-6blak avns/b/ber	os/10	36,66	42,68	8589,50	92,56	13,8	5,06	2,66	0,7	57,3	31	20,45	6,98
V1	Waha	stf/1	35,97	28,83	12476,59	90	14,4	5,18	4,41	0	48,5	37,5	22,71	6,09
V2	GTA dur	stf/2	33,80	30,27	11166,17	105	14,8	5,00	0,25	0	45,5	46	19,92	6,57
V3	Skh/hau.heca-1	stf/3	43,70	32,37	13500,15	90	14,6	6,38	3	0	56	50	21,54	6,56
V4	Ammar-8	stf/4	35,09	32,26	10877,25	90	13,6	4,77	1,33	0	55	52	20,59	6,57
V5	MSbl_1/ourmal	stf/5	43,33	29,06	14910,53	85	17,2	7,45	0,33	0	55	57	22,8	6,44
V6	Azeghar1/6Zan-1/5	stf/6	37,69	33,80	11150,89	90	16,4	6,18	0,58	0	55,5	49	22,17	6,91
V7	Villemur/3/lahn//gs	stf/7	37,92	44,87	8451,08	85	13,1	4,97	3,33	0	52	35	19,22	5,67
V8	Gsbl/d68-1-93-a-a1	stf/8	44,12	31,00	14232,26	90	13,7	6,04	0,4	0	53,5	54,5	24,81	6,52
V9	Lahaucan	stf/9	34,21	32,38	10565,16	90	12,6	4,31	9,08	0	54	49,5	20,5	5,31
V10	Da-6blak avns/b/ber	stf/10	40,23	40,40	9957,92	85	13,8	5,55	2,16	0	54,5	40,5	20,28	6,32
V1	Waha	kh/1	65,62	33,69	19477,59	105	15,9	10,43	2,75	0	56	27,5	23,71	8,95
V2	GTA dur	kh/2	56,58	39,00	14507,69	100	15,17	8,58	1,08	3,55	61,3	37	21,81	7,06
V3	Skh/hau.heca^{-1}	kh/3	52,87	36,36	14540,70	100	16,6	8,78	1,41	2,15	58,6	46	21,77	6,67
V4	Ammar-8	kh/4	59,62	37,19	16031,19	95	14,6	8,70	1,66	1,8	57,6	38,5	20,59	7,07
V5	MSbl_1/ourmal	kh/5	54,87	37,26	14726,25	105	14,6	8,01	2,83	1,85	53,3	37	21,2	7,75
V6	Azeghar1/6Zan-1/5	kh/6	54,91	48,07	11422,92	105	16,4	9,01	0,16	0,6	58,3	42	21,34	7,16
V7	Villemur/3/lahn//gs	kh/7	56,41	35,66	15818,84	105	17	9,59	0,33	1,15	59,3	27	21,28	7,16
V8	Gsbl/d68-1-93-a-a1	kh/8	56,62	29,98	18885,92	90	17,8	10,08	0,33	4,8	59,6	44	24,32	7,72
V9	Lahaucan	kh/9	66,50	29,51	22534,73	95	15,3	10,17	0,5	1,9	59	41	22,02	6,91
V10	Da-6blak avns/b/ber	kh/10	68,29	39,75	17179,87	105	15,2	10,38	2,66	0,7	57,3	31	20,45	6,98

Table 3 : Correlation matrix between yield components.

	RDTqx/ha	PMG	Ngrain /m^2/	hauteur	proteine	rdtprot	Mitadinage	Mouchture	TE	SDS ml	IJ	IB
RDTqx/ha	1	-0,214	**0,873**	**0,627**	0,021	**0,930**	-0,178	0,196	0,355	-0,215	0,110	0,256
PMG	-0,214	1	**-0,645**	-0,067	0,334	-0,093	-0,120	0,290	**0,408**	**-0,411**	-0,272	0,193
Ngrain /m^2/	**0,873**	**-0,645**	1	**0,470**	-0,104	**0,776**	-0,111	0,063	0,107	0,031	0,264	0,131
hauteur	**0,627**	-0,067	**0,470**	1	-0,056	**0,560**	-0,122	0,079	0,003	-0,244	-0,124	0,267
proteine	0,021	0,334	-0,104	-0,056	1	**0,380**	**-0,575**	**0,508**	**0,540**	-0,126	**0,445**	**0,509**
rdtprot	**0,930**	-0,093	**0,776**	**0,560**	**0,380**	1	**-0,364**	**0,362**	**0,519**	-0,232	0,261	**0,403**
Mitadinage	-0,178	-0,120	-0,111	-0,122	**-0,575**	**-0,364**	1	-0,324	-0,359	-0,073	-0,265	-0,309
Mouchture	0,196	0,290	0,063	0,079	**0,508**	**0,362**	-0,324	1	**0,613**	-0,076	0,311	0,292
TE	0,355	**0,408**	0,107	0,003	**0,540**	**0,519**	-0,359	**0,613**	1	-0,205	0,221	0,315
SDS ml	-0,215	**-0,411**	0,031	-0,244	-0,126	-0,232	-0,073	-0,076	-0,205	1	0,152	**-0,505**
IJ	0,110	-0,272	0,264	-0,124	**0,445**	0,261	-0,265	0,311	0,221	0,152	1	**0,487**
IB	0,256	0,193	0,131	0,267	**0,509**	**0,403**	-0,309	0,292	0,315	**-0,505**	**0,487**	1

The correlation matrix displays, among the many connections between components, interesting results that can be integrated as additive and complementary criteria in a plant genetic improvement program.

The grain yield gives positive correlations with a major component of the yield, namely, the number of grains/m^2, a morphological parameter, the height of the genotype, and especially the protein yield parameter (0.930). Inverse correlations are observed between mitadine and proteins (Table 3).

PCA results

However, the interpretation of these components requires the calculation of the correlations between each of the main components retained with each of the 12 initial variables. These correlations are useful to specify the part of the variance, of a given initial variable, taken into account by a particular principal component, and will be used for the graphic representations of the initial variables in the circles of correlations.

Variable Scatter Analysis: Circle of Correlations

Correlation circles are graphs intended to geometrically represent the initial variables in the new coordinate system. Thus, the representation of the twelve initial variables in the plane formed by axes 1 and 2 (called the first factorial plane) is useful, given the importance of these two axes in the reconstitution of the initial variables (Fig. 1). The coordinates of the initial variables on axis 1 are the correlations of these same variables with axis 1, and the coordinates on axis 2 are the correlations of these variables with axis 2 (Fig. 1)

The visual representation indicates the direction of increasing interactions of the variables which are the closest examples of technological variables (proteins, index of brown, index of yellow speck, PMG). The parameters plot yield (q/ha), the height of the plants (cm) and number of grain /m2, which present a relationship between characters, are interesting for the breeder who seeks to identify the effect of characters. As a result, and among the variables measured, the metadine and the SDS seem to be positively linked. These different links are significant.

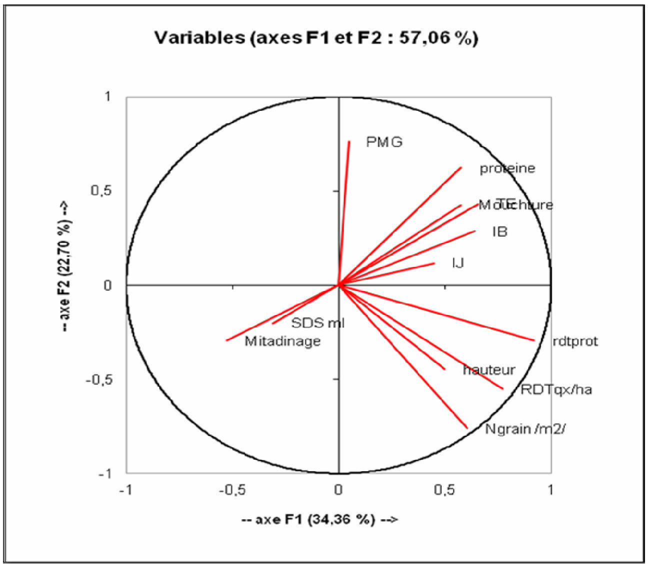

Fig. 1 : Graphic representation of the 13 variables inside the circle of correlations of the factorial plane 1-2 obtained from the data of the three sites

The graphical representation in A.C.P. (Fig. 2) gives very good representativeness of the variables (57.06%) for the two main axes.

In general, the circle of correlations shows greater participation of the "components of yield" variables compared to the quality variables. Indeed, the number of grains/m2, the yield qx/ha, and the protein yield have the highest coefficients of determination.

The P.M.G. is a variable that stays in the opposite plane to the return components. The mitadine, SDS, IJ, and IB variables are moderately represented and, therefore, have less impact on the expression of both yield and technological quality.

Analysis of the scatterplot varieties: graph of individuals

The objective is to analyze the link between variables to consult the variety/site relationship. Grouping per site is very marked in figure 3: we can clearly see the importance of the site in relation to the variety. The 10 durum wheat varieties studied in each site showed very significant effects of the Genotype x Environment interaction for most of the parameters tested.

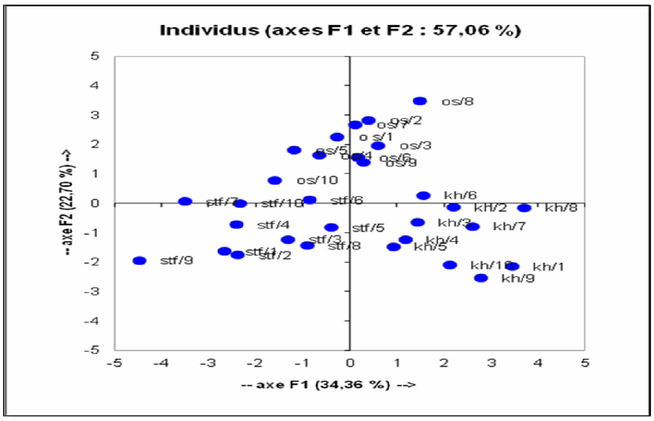

Fig. 2 : Graphical representation of individual points (varieties) in the factorial plane 1-2 obtained from the data of the three sites

Hierarchical analysis

The use of numerical classification methods, in addition to the analysis of variance, is uncommon (Dagnelie, 2003). The bibliography concerning this approach is also relatively limited (Bautista *et al.*, 1997). This means grouping methods are very numerous and very diversified. But fortunately, it appears that, in terms of classification of means, the results obtained are on the whole less dependent on the methods used (Dagnelie, 2003).

Graphic representations of individuals: The hierarchical classification has made it possible to structure this diversity (Fig. 3) and clearly shows a site effect. The three sites exerted their environmental stress on the genotypes and led them to respond specifically. This also shows the difference between these sites, both in terms of soil heterogeneities and in terms of agro-climatic data, which are dissimilar in terms of meteorological factors. The first group includes the varieties of Oued Smar with two varieties of Setif (V7 and V10); on the other hand, a second group includes varieties from El Khroub and setif by recording the majority of the varieties well adapted to the two environments. The complete dendrogram makes it possible to visualize the progressive regrouping of the varieties, explaining that the two sites of the arid and semi-arid zones are the most favorable for the agronomic and technological development of the varieties studied, and giving similar and almost identical results explaining that varieties respond to the same way. According to (Desclaux *et al.*, 2013 and Desclaux *et al.*, 2016)

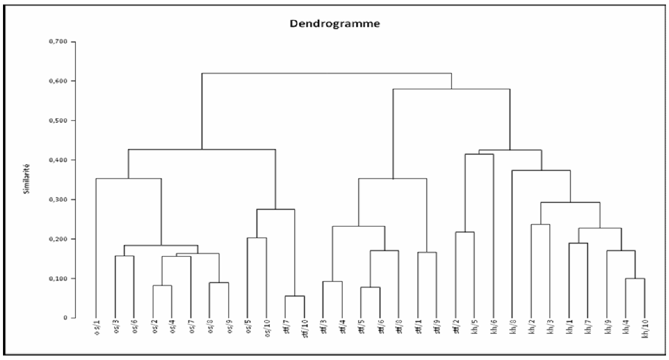

Fig. 3 : Ascending hierarchical classification (CHA) of the durum wheat varieties studied based on the variables measured. Dendrogram of the grouping of the 10 durum wheat varieties obtained, using the simple link method and the Pearson square distance, on the data from the three sites**.**

Conclusion

The main objectives of this work were the characterization of durum wheat (*Triticum durum* Desf.), a cereal of expression recognized as diverse according to their varieties and their geoclimatic site of cultivation, thus determining which are the most efficient varieties from the point of view of productivity and various specific parameters, as well as exploring agronomic and technological behavior in association with the tolerance of plants to water deficit. Statistical processing and cross-analysis of these criteria should allow varietal selection based on the most efficient genotypes, both in relation to the parameters and the study sites.

The main objectives of our study include the study of the Genotype x Environment interaction and the characterization of genetic diversity to analyze the degree of resemblance between the ten varieties of durum wheat based on agro-technological parameters. This information will help identify the best cultivars that could be used as progenitors in future breeding programs.

The results, obtained on the 10 varieties of durum wheat in the three study areas and supported by the statistical analysis, highlight at the level of the correlation matrix many correlations both indicative and revealing as to the respective responses of performance and quality components.

Indeed, grain yield is highly and positively correlated with yield; this is even somewhat expected because a high yield is linked to good growing conditions; nitrogen fertilization is one of them.

The P.M.G. is negatively correlated with grain number. Thus, in light of the results obtained in this study, which in fact dealt with the yield potential under three different environments, we can summarize the main points as follows:

- Regarding the yield components and the grain yield, the number of grains/M^2 is a key element in the development of the grain yield.
- The fact that the quality indices (I.J., I.B., SDS) are not affected or significantly altered, would indicate the genotypic aptitudes of the cultivars to enjoy this very little variable trait under different environments. The prevailing climatic conditions at the time of the study were also not favorable to cause changes of any kind in these technological parameters. The quality parameter was found to be well correlated with yield.
- The results are relevant and indicate that, compared to the Algerian local control variety waha, the varieties and lines studied offer great opportunities to carry out a breeding program aiming at increasing yield potential and climate resilience for semi-arid regions in order to obtain sustained increases in yields. The results obtained underline the diversity of behavior in the 10 varieties of durum wheat with respect to the development of proteins. These genotypes show different responses to nitrogen assimilation in the three test stations, efficient but also tolerant and stable according to the responses of the ten varieties.

Acknowledgments

We would like to express our thanks to the managers of the Technical Institute for Field Crops (ITGC), more particularly to INRAA (Algeria) for providing us with all the means necessary for the installation and monitoring of our trial. Our thanks also go to the I.N.R.A. of Montpellier (France), at the experimental station of Melgueil. This work is a tribute to our friend professor Ait Kaki Yasmina, was and remains in the retina of our memory.

References

Abecassis, J. (1991). *Nouvelles possibilités* d'apprécier la valeur meunière et la valeur semoulière des blés. Ind. Céréales, 81: 25-37.

Abidi, L.; Achouch, A.; Benmoussa, M. and Snoussi, S.A. (2011). Etude de l'intéraction génotype-environnement sur les paramètres agronomiques et technologiques de quelques variétés de blé dur (*Triticum durum* Desf.).

Adjabi, A.; Bouzerzour, H. and Benmahammed, A. (2014). Stability Analysis of Durum Wheat (*Triticum durum* Desf.) Grain Yield. *Journal of Agronomy*, 13: 131-139.

Ait Kaki, Y. (2008). Etude comparative des potentialités technologiques des blés durs algériens anciens et récents : Relation de la qualité de ces blés par différentes stratégies d'études : Critères technologiques (infra rouge), Biochimiques (électrophorèse bidimensionelle) et moléculaire PCR. Thèse de Doctorat d'Etat en Sciences, Université Badji Mokhtar Annaba. pp: 1-21.

Annicchiarco, P. (1992). Cultivar adaptation and recommendation from alfalfa trials in Northern Italy. *Genetics and Breeding*, 46: 269-278.

Bahlouli, F.; Bouzerzour, H.; Benmahammed, A. and Hassous, K.L. (2005). Selection of high yielding and risk efficient durum wheat (*Triticum durum* Desf.) cultivars under semi arid conditions. *Pakistan Journal of Agronomy*, 4: 360-365.

Bautista, E.M.; Faaberg, K.S.; Mickelson, D. and Mc Gruder, E.D. (2002). Functional properties of the predicted helicase of porcine reproductive and respiratory syndrome virus. *Virology*, 298: 258-270.

Ben Abdallah, N. and Ben Salem, M. (1993). Paramètres morphophysiologiques de sélection pour la résistance à la sécheresse des céréales. *In*: Ben Salem M. et Monneveux P. Ed. INRA, Paris, pp: 173-190.

Benbelkacem, A. and Kellou, K. (2000). Evaluation du progrès génétique chez quelques variétés de ble dur (*Triticum turgidum* L.var. *durum*) cultivées en Algérie. *Options Méditerranéennes*. Pp :105-110.

Benbelkacem, A.; Brinis, L. and Nachit, M.M. (2000). Yield stability and physiological traits of Algerian durum wheat in dryland Algeria. Pages 153-155 *in* Proceedings of the Ninth International Wheat Genetics Symposium, Vol. 2, 2- 7 Aug 1998, Saskatoon, Canada, A.E. Slinkard, ed.

Benbelkacem, A. (2013). Rapport national des activités du projet Inraa-Icarda 2012-2013. Pp: 45. Crostan, R.P. & Williams, J.T. (1981). A world survey of wheat genetic resources. IBRGR, Bulletin /80/59, 37 p.

Benmahammed, A.; Nouar, H.; Haddad, L.; Laala, Z.; Oulmi, A. and Bouzerzour, H. (2010). Analyse de la stabilité des performances de rendement du blé dur (*Triticum durum* Desf.) sous conditions semi-arides. *Biotechnologie, Agronomie, Société et Environnement*, 14: 177-186.

Benseddik, B. and Benabdelli, K. (2000). Impact du risque climatique sur le rendement du blé dur en zone semi-aride. Approche éco-physiologique". *Sécheresse,* 11(1): 45-51.

Bouroche, J.M. and Saporta, G. (1980). "L'analyse des données". Collection Que Sais-Je, PUF.

Bouzerzour, H.; Benmahammed, A.; Benkharbache, N. and Hassous, K. (2002). Contribution des nouvelles obtentions à l'amélioration et à la stabilité du rendement d'orge (*Hordeum vulgare* L.) en zone semi-aride d'altitude. *Revue Recherche Agronomique de l'INRAA*, 10: 45-58.

Cox, M.C.; Qualset, C.O. and Rains, D.W. (1986). Genetic variation for nitrogen assimilation and translocation in Wheat. III. Nitrogen translocation in relation to grain yield and protein. *Crop Science,* 26: 737-740.

Dagnelie, P. (1982). *Analyse statistique à plusieurs variables*. Les presses agronomiques de Gembloux. 362.

Dagnelie, P. (1999). *Statistique théorique et appliquée*. Tome 2. Inférence Statistique à une et à deux dimensions. Bruxelles. Université D & L. 659.

Dagnelie, P. (2003). Principes d'expérimentation : planification des expériences et analyse de leurs résultats. Gembloux, Presses agronomiques, 397 p.(2)

Delwiche, S.R. (1998). Protein content of single kernels of wheat by Near-infrared reflectance spectroscopy. *Journal of Cereal Science*, 27: 241-254.

Desclaux, D.; Chiffoleau, Y. and Nolot, J.M. (2005). Amélioration de la valeur technologique et comerciale du blé dur vers une réduction des taux de mouchture et de mitadin. Rapport de projet de recherche INRA Montpellier, France.

Desclaux, D.; Samson, M.F.; Compan, F.; Poirier, *S.;* Roumet, P.; Abecassis, J.; Bonicel, J.; Morel, M.H.; Braun, P.; Caron, D.; Martinez, M.; Debaeke, P.; Mas, J.F.; Gorretta, N. and Roger, J.M. (2006). Amélioration de la valeur technologique et commerciale du blé dur : vers une réduction des taux de moucheture et de mitadin, PSDR recherches pour et sur le développement régional. Colloque régional du 21 juin, Campus lntra. Agro, Montpellier, pp: 1-4.

Desclaux, D.; Chiffoleau, Y. and Nolot, J.M. (2013). Du concept d'Ideotype à celui de Realtype: gestion dynamique des Innovations Variétales par une approche transdisciplinaire et partenariale. Exemple du blé dur pour l'AB. *Innovations Agronomiques*, *INRA*, 32: 455-466.

Desclaux, D.; Huang, H.Y.; Bernazeau, B. and Lavene, P. (2016). Agroforestry: new challenge for field crop breeding? In: Book of abstract 3rd European agroforestry conference, Montpellier, France, 23–25 May 2016. ISBN: 978-2-87614-717-1, EAN: 9782876147171

Donald, C.M.T. (1968) The Breeding of Crop Ideotypes. Euphytica, 17: 385-403.http://dx.doi.org/10.1007/bf00056241

Fischer, R.A. (1985). Number of kernels in wheat crops and the influence of solar radiation and temperature. *J. Agric. Sci*. 108: 447–461.

Haddad, L.; Bouzerzour, H.; Benmahammed, A.; Zerargui, H.; Hannachi, A.; Bachir, A.; Salmi, M.; Oulmi, A.; Fellahi, Z.; Nouar, H. and Laala, Z. (2016). Analysis of Genotype × Environment Interaction for Grain Yield in Early and Late Sowing Date on Durum Wheat (*Triticum durum* Desf.) Genotypes. *Jordan Journal of Biological Sciences*, 9(3): 139-146.

Hadj, Y.; Taïbi, H.; Khaldoun, A. and Mekliche, A. (2003). Etude comparative de la tolérance à la sécheresse de 08 variétés de blé dur (*Triticum durum* Desf.) et de 04 variétés d'orge (*Hordeum vulgare* L.) analyse de la stabilité du rendement avec multilocal. ITGC, *Céréaliculture*, 38(1): 26-31.

Hannachi, A.; Fllahi, Z. and Bouzerzour, H. (2019). Analyse de l'adaptabilité et la stabilité de quelques variétés de blé dur (*Triticum durum* Desf.) aux conditions sud méditerranéennes. *Revue Agriculture*. 10(2): 56-67.

Kadi, Z. (2012). Sélection de l'orge (*Hordeum Vulgare* L.) pour la tolérance aux stress abiotiques. *Thèse de doctorat sciences, Université Sétif 1, 134 pages.*

Lin, C.S.; Binns, M.R. and Lefkovitch, L.P. (1986). Stability analysis: Where do we stand. *Crop Science*, 26: 894-900.

Mansouri, A.; Oudjehih, B.; Benbelkacem, A.; Fellahi, Z. and Bouzerzour, H. (2018). Variation and Relationships among Agronomic Traits in Durum Wheat [*Triticum turgidum* (L.) Thell. ssp. *turgidum* conv. *Durum* (Desf.) MacKey] under South Mediterranean Growth Conditions. *Stepwise and Path Analyses*, 1-11.

Mekliche, A.; Boukecha, D. and 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).

Nouar, H.; Haddad, L.; Laala, Z.; Oulmi, A.; Zerargui, H. Benmahammed, A. and Bouzerzour, H. (2010). Performances comparées des variétés de blé dur: Mohammed Ben Bachir, Waha et Boussalam dans la wilaya de Sétif. *Céréaliculture*, 54: 23-28.

Nouar, H.; Bouzerzour, H.; Haddad, L.; Menad, M.; Hazmoune, H. and Zerargui, H. (2012). Genotype ×

environment interaction assessment in durum wheat (*Triticum durum* Desf.) using AMMI and GGE models. *Advances in Environmental Biology*, 6: 3007-3015.

Palm, R. (2000). L'analyse de la variance multivariée et l'analyse canonoque discriminante: principes et applications. Notes tat. Inform. (Gembloux), 40 p.

Triboï, E.; Martre, P.; Girousse, C.; Ravel, C. and Triboï-Blondel, A.M. (2006). Unravelling environmental and genetic relationships between grain yield and nitrogen concentration for wheat. *European Journal of Agronomy*, 25: 108-118.

Wehrle, K.; Seibel, W.; Gerstenkorn, P. and Kuhn, M. (1996). Méthodes rapides d'évaluation qualitative du blé dur. Première partie: Etudes par spectroscopie NIR. Getreide Mehl Und Brot, 50(3): 181-185.