academicJournals

Vol. 10(9), pp. 919-925, 26 February, 2015
DOI: 10.5897/AJAR2015.9492
Article Number: ECDE29551018
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Spatial variation of quality traits in Algerian durum wheat cultivated in different environments

Nora Derbal[1], Abdelkader Benbelkacem[2]* and Ali Tahar[1]

[1]Plant Biology and Environment Research Laboratory, Biology Department, Annaba University, 23000 Algeria.
[2]National Agronomic Research Institute of Algeria, Hacen Badi, BP. 200, Algiers, Algeria.

Received 9 January, 2015; Accepted 9 February, 2015

Wheat covers more than 2.5 million hectares in Algeria and is the main staple food crop and income generation for resources-limited farmers. Area cropped in wheat is expanding however, the quality is not well known and varies from region to region. Improvement of durum wheat quality is a major concern in Algeria to better cope with the consumers' needs. Local landraces are highly appreciated for local bread and couscous, while the newly released cultivars quality is often affected by environmental factors. Four local durum varieties were studied in three different regions of Algeria (a sub littoral and two high plateau areas) during 2010/2011cropping season. Protein content, yellow berry and black spots on the grain levels, grain moisture level, thousand kernel weight and grain yield were analyzed. Results showed globally a P<0.01level of spatial variation among all traits, this demonstrated a strong influence of environmental conditions on the majority of durum quality traits; varietal effects were observed in all traits except grain yield at Guelma and Setif. Protein content was higher in Tiaret reaching 17.3%. Grain yield is higher at Setif (4.5 t/ha), one to two tons per hectare more to Guelma and Tiaret. Kernel weight is higher in the high plateau areas 55.87 and 51.2 g. Yellow berry level was high at Guelma and low in the high plateaus. In rainfed conditions of semi arid areas an average production of 3.6 million tons of good quality levels of durum wheat (protein levels >12.5%, low yellow berry and black points levels) has been obtained.

Key words: Durum wheat, rainfed conditions, quality, spatial variation, high plateau, littoral area.

INTRODUCTION

Algeria is the largest country in Africa, covering more than two million square kilometers and 238 million ha but only 3.4% is arable land. Most agricultural activities are in the north of the country. The dominant crops are annual, and mainly field crops such as cereals, forages, food legumes and potatoes. Cereals are the predominant crops grown by Algerian farmers, covering annually 3 to 3.5 million ha, nearly 40% of Algeria's total agricultural land. However, the country depends on imports for 45% of its food because annual cereal production in Algeria is about 3.2 million tons (Benbelkacem, 1996) while the demand is around 8 million tons. During the last decade, wheat represents on average 67.1% of all cereal production. Yields are low due to several abiotic and

*Corresponding author. E-mail: benbelkacem@mail.com, Tel: +213 661 307 148. Fax: +213 332 451 317.

biotic stresses. Scarcity and poor quality of underground water resources, low and erratic rainfall, drought recurrence, high and low temperatures and salinity are the key constraints to agricultural production.

Durum wheat (*Triticum turgidum* L. var. *durum*) is the traditional wheat crop in North Africa. It is used mainly for bread and couscous and freeke - made from immature green seed that is dried, grilled and broken and different sorts of traditional cookies (Abecassis et al., 1990; Desclaux et al., 2005; Kezih et al., 2013). In Algeria, durum wheat is sown annually over 1.2 million ha, with an average consumption of around 75 kg/person/year (Djermoun, 2009). Forty percent of the grain production is used for bread-making, mainly processed at the household level. The local genotypes of durum wheat, still grown by some farmers in the mountainous areas, are highly appreciated for their excellent bread-making and couscous quality. Improving durum wheat grain quality has become, in recent years, one of the main breeding goals in many Mediterranean countries, due to the increase in market demand for good quality durum wheat.

In Algeria, most of breeding efforts are concentrating on maximum yield potential under highly favorable environment but quality aspects have lower priority. A Multi-disciplinary approach has been adopted to promote newly selected varieties for different semi-arid targeted environments (durum and bread wheat, barley and triticale), this research resulted in cultivars able to withstand drought and heat but also responsive to improved moisture supply.

The released varieties during the late seventies have allowed a grain yield gain of at least 35% over the landraces, but their grain quality is highly affected by the environmental factors. The improvement of durum wheat quality to fit different end-uses (bread, couscous, pasta, local cakes, freeke) is an important objective of the research conducted by the National Agricultural Research Institute of Algeria (INRAA) and the collaborating International Centers, CIMMYT and ICARDA (Nachit et al., 1995).

The strong influence of environment and of genotype-environment interactions on grain quality hampered the improvement of durum wheat quality. Several approaches have been carried out on bread wheat to evaluate effects of genotype, environment and their interaction (Peterson et al., 1992; Annicchiarico et al., 2006). However, very little information is available on the relative importance of the effects of genotype, environment, and genotype-environment interaction on the quality characteristics of durum wheat grown in the Mediterranean region. Michelena et al. (1995) studied the stability of 16 durum wheat varieties for different quality parameters under northern Spain conditions and found that spatial and temporal variation was very important for many traits. Juan-Aracil and Michelena (1995) reported that the three order interaction latitude x site x year was the main factor that affected quality parameters. In some other studies from Italy (Mariani et al., 1995; Nachit et al., 1995; Boggini et al., 1997; Novaro et al., 1997) a high influence of environment and genotype-environment interaction in determining durum wheat quality has been reported. This study was carried out in different wheat growing regions of Algeria that differ in climate, soil type and agronomic systems to overview the spatial variation in cereal quality traits of the four more widely cultivated durum wheat varieties conducted in three contrasting sites of Algeria during the 2010/2011.

MATERIALS AND METHODS

Sites description

Two high plateau sites (Setif in eastern and Tiaret in western Algeria), and one interior sub-littoral area (Guelma) representing cereal growing areas of Algeria, have been targeted.

(i) Guelma: situated between latitude 36° 17 and longitude 6° 37' in Eastern Algeria, rainfall amount vary from 500 to 600 mm per year. Littoral region, favorable area for cereal production, fertile deep soils and suitable for cereal seed production. Main constraints: diseases (mainly yellow rust and septoria leaf blotch) and terminal drought.
(ii) Tiaret: Western high plateaus, soils are clay loam to shallow in almost all the area. Rainfall is irregular and averages from 350 to 450 mm. One main cereal growing areas of Algeria where cereal production suffers from early drought and terminal heat stress.
(iii) Setif: Expands over three natural landscapes, the Northern Atlas tell, the central high plains and Hodna highlands in the south where the majority of arable area is situated. Altitude is comprised between 800 to 1300 m above sea level. Cereals constitute the first farmers crop. Climate is of continental type to semi-arid with cold winters (minima -8°C) and hot summer (maxima 41°C). Mean rainfall fluctuates from 200 to 500 mm from South to North. Drought is mainly associated with frost all over winter season.

Material

Four durum wheat genotypes were used in this study, including two local commercial varieties (Waha, Boussellem) and two advanced lines (Gta/Dur69., and Lahn/Ch1.2003) from the CIMMYT–ICARDA durum wheat breeding program.

Traits analyzed

Several commercial and technological quality parameters were determined. Grain-protein content (PROT) was determined by means of a Near Infra Red device. Yellow berry (MITA) was evaluated using a farinotome (grain splitter) by the average of three samples of visual inspection of 100 grains. A grain was considered defective if it was completely or partially starchy (yellow berry) or affected by fungal infections showing black spots (MOUCH) mainly around the embryo area (Autran, 1984). Thousand kernel weight named PMG was calculated as mean weight of three sets of 1000 grains per plot. Grain yield (RDT) is weighed from the total grains harvested from each plot unit. The seed rate was adjusted for a density of 300 viable seedsm^2 in Setif and Tiaret and 350 seeds m^2 in Guelma. Plot size was 12 m^2 (six rows of 10 m long and 20 cm apart).

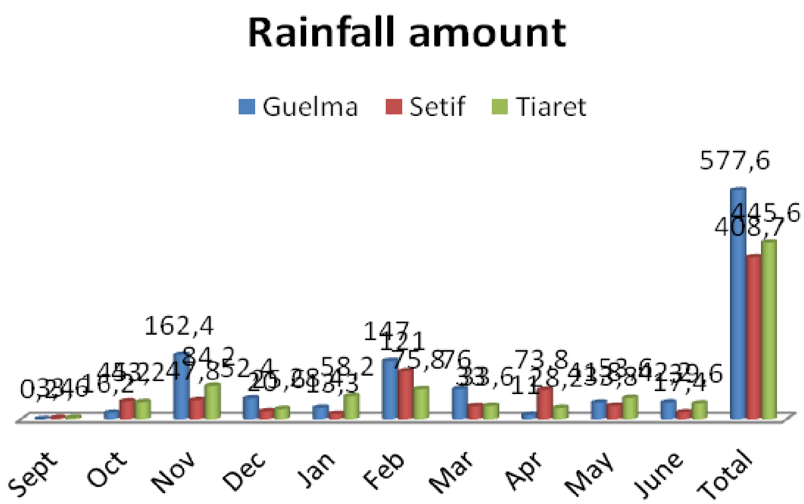

Figure 1. Rainfall amount (Guelma, Setif and Tiaret) in 2010/2011 growing season.

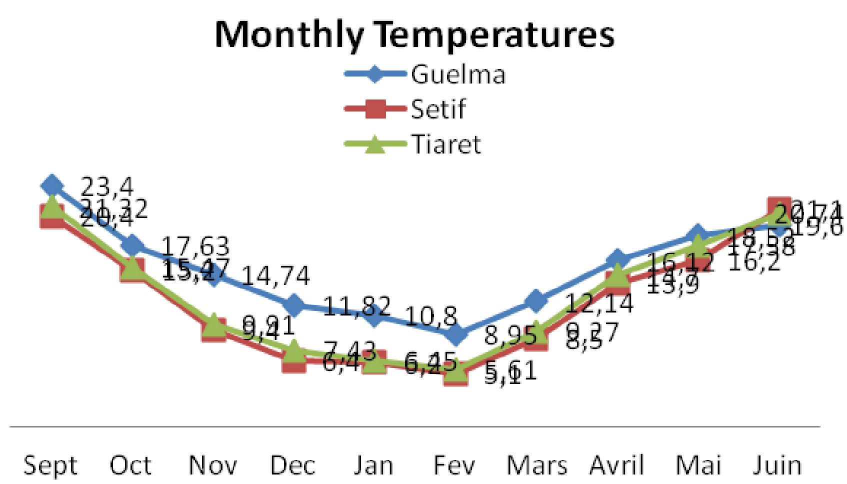

Figure 2. Monthly temperatures in 2010/2011 growing season at the 3 sites.

Statistical methods

In each trial, genotypes were sown in a randomized complete-block design with four replications. A one-way analysis of variance was done to compare more than two means from random independent samples (Dagnelie, 2003). This test was used to compare the different traits among varieties and sites. Mean comparisons between trials for each quality characteristic and a one way ANOVA were performed and least significant difference (LSD) values were calculated at the 5% probability level, groups were classified by the Tukey's test.

RESULTS AND DISCUSSION

Analysis of the climatic conditions

Even though rainfall distribution was not stable, rainfall was normal at Guelma (577.6 mm) in the 2010/2011 growing season; it was above yearly average at Setif and Tiaret sites (445.6 and 408.7 mm) where normal average rainfall is 395 and 382 mm respectively (Figure 1). Most of the precipitations fell in November and February. Temperatures were normal for all sites (Figure 2); they were colder with a high frequency of frosty days exceeding 40 days in the high plateaus during fall and winter and hotter in summer season.

Analysis of variance by site

a) Guelma: Anova results show highly significant differences in all varieties for all traits except for grain yield (Table 1). Grain moisture (12.7%) , protein content

Table 1. Quality traits and grain yield results at Guelma, Setif and Tiaret sites during 2010/2011 season.

Varieties	GUELMA	SETIF	TIARET	General Mean
Grain Moisture	12.7***	12.95***	12.94**	12.86
Prot leyel	11.8***	13***	16.93***	13.91
Black Points	22.22***	11.87***	9.14***	14.4
TKW	42.77***	55.87***	51.2***	49.95
Yellow Berry	26.57***	1.46***	0.29*	9.44
Yld	3.545NS	4.508NS	2.528***	3.527

P>0.05 NS. P≤0.05*. P≤0.01**. P≤0.001***.

Table 2. Response of the four varieties to the different quality and grain yield traits during 2010/2011 season.

Varieties	WAHA	BOUSSELAM	LAHN/CH1 2003	GTA/DUR69	General Mean
Grain Moisture	12.79***	13.1***	12.51***	12.6***	12.86
Prot leyel	14.3***	13.52***	13.79***	13.99***	13.91
Black Points	7.08***	11.32***	9.41***	24.38***	13.05
TKW	47.45***	53.83***	50.36***	48.36***	49.94
Yellow Berry	9.51***	7.31***	9.12***	11.96***	9.37
Yld	3.303**	3.429***	3.971**	3.576***	3.527

P>0.05 NS. P≤0.05*. P≤0.01**. P≤0.001***.

(11.8%), and thousand kernel weight (42.77g) were relatively lower than average mean over sites (12.86, 13.91 and 49.95%). Yellow berry level and black spots on the grain level were high in this site (26.57 and 22.2% respectively) implying a low vitrousness of the grain.

b) Setif: Differences are highly significant in all traits except grain yield. Proteins (13%) look better than in Guelma site, it is on average a little bit lower than the overall mean and much lower than in Tiaret site. Yellow berry had a low level (1.46%) showing a good vitreousness of the grain in this semi arid high plateau site. All other parameters studied are higher than in the other sites or even than the overall average.

(c) Tiaret: In contrast to the other two sites, differences were significant to highly significant in all varieties for all studied quality parameters. In this semi arid site grain yield that was lowest (2.53 t/ha) due mainly to low rainfall frequency and other abiotic stresses (cold in winter and early spring), than elsewhere while excellent results appeared for protein content (16.93%) that was highest with almost no yellow berry in the grain (0.29%), PMG is also high (51.2 g) and black spots level was lower than overall average (9.14 Vs 14.74%). It looks clearly that rainfed conditions in the semi arid sites offer the best opportunity for production of good quality durum wheat.

Genotypes analysis

It is noticed that variations are very important in all varieties for all the traits. Differences are highly very high significant in all parameters for all varieties. Waha showed a lower grain yield (3.3 t/ha), thousand kernel weight and black point or spot level (5.08%) than the other varieties Bousselam, Lahn/Ch12003 and Gta/Dur 69 (Table 2 and Figure 3).

In Bousselam, we also found very highly significant differences for all parameters. Grain yield (3.429 t/ha) was a little higher than in Waha (3.3 t/ha) but still lower than the overall average (3.53 t/ha). Thousand kernel weight (PMG) was highest in this variety released in the setif high plateau (53.83 g) while it ranged from 47.45 to 50.36 g for the other varieties. Yellow berry (MITA) had the lowest level (7.31%) but protein content (PROT) showed the lowest amount (13.52%). The variety Gta/Dur69 one of the newly released genotypes shows also highly significant differences among sites. The homogenous groups are represented in Table 4. The other new variety in the pipeline Lahn/Ch12003 exhibits also same conclusive results as Gta/Dur69. These results conclude that there is in general a spatial variation for all traits in the different sites of study.

G x E interaction analysis

The greatest proportion of variation (Table 3) for protein content was attributed to the site effect which took more than 95% (p<0.001) of the total variation. Under rainfed conditions, the year effect on wheat yield and quality parameters have been reported by different authors in Mediterranean environments who showed that this effect

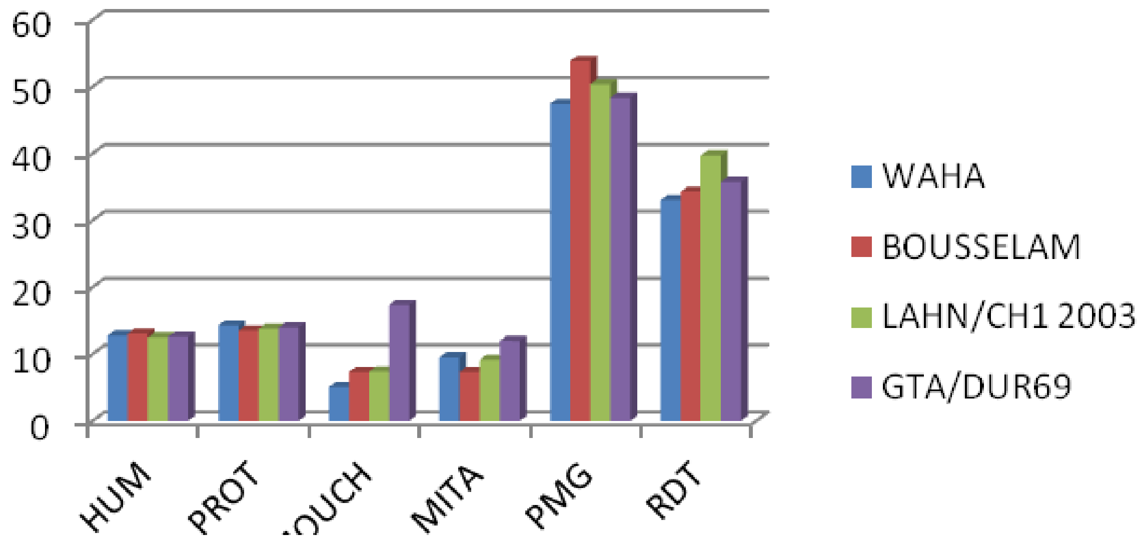

Figure 3. Quality traits and grain yield over sites for the different varieties studied in 2010/2011 season.

is almost the consequence of weather conditions during grain filling and accumulation of assimilates from the stem to the grain (Garrido-Lestache et al., 2005; Elhani et al., 2007; Bahlouli et al., 2008). Efficient water use in highland areas might have promoted plant nutrient uptake and translocation and, consequently, produced better-quality grain (Diacono et al., 2012). This can explain results observed for Tiaret and setif where protein content was higher. When comparing different sites, Tiaret faced drought conditions, while Guelma received the biggest amount of reproductive rainfall during winter season. Setif had the better yields during the studied growing season than Guelma or Tiaret (4.5, 3.5 and 2.5 t/ha, respectively). Drought period in Tiaret resulted in a reduced yield of 2.5 t/ha due to water stress during grain filling (Annicchiarico and Mariani, 1995; Monneveux et al., 2006; Villegas et al., 2010; Rizza et al., 2012). As it is known, yield reduction observed at Tiaret is mainly due to water stress but was associated with highest protein content (Oweis et al., 1999; Rharrabti et al., 2003b; Flagella et al., 2010; Diacono et al., 2012; Hussain et al., 2012). Mean squares were not significant among varieties and on variety by site interaction.

DISCUSSION

Growing conditions were different in each site; they were more favorable in the littoral area rather in the high plateau sites where it is more continental. According to Basso et al. (2012) the growing season vegetative rainfall occurs from December to February and the growing season reproductive rainfall occurs from March to May. Tiaret faced drought conditions with a total of 28.6 mm during booting stage, the most critical stage for spike constitution and early grain filling in this area; this drought period resulted in a reduced average yield (2.52 t/ha) due to water stress. Guelma received the largest amount of reproductive rainfall with a total of 406.6 mm; from boot stage to physiological maturity it received 128.8 mm that made a quite good average grain yield (3.5 t/ha) superior to Tiaret site by one ton on average (Dagnelie, 2003; Basso et al., 2012; Juan-Aracil et al., 1995; Rizza, 2012). Rainfed conditions affected thus wheat yield and quality parameters; this has been reported by different authors in Mediterranean environments who showed that this effect is mainly due to weather conditions during grain filling and assimilates accumulation in the grain (Baenziger, 1985; Bahlouli et al, 2008; Diacono et al., 2012). The spatial variability of durum wheat varieties observed in all sites is probably mainly influenced by soil types (texture, bulk density and organic matter) (Mariani, 1995). During our trials, a similar relationship was expressed between rainfall with grain yield (RDT) and thousand kernel weight (PMG) at Setif, meaning that conditions favored the expression of those parameters simultaneously. As it is known, yield reduction observed at Tiaret was likely due to water stress but on the other hand it was associated with highest protein content measured by the near infra red (Rharrabti et al, 2003; Flagella, 2010; Akman et al, 2013; Mariani, 1995).

Yellow berry level was excellent (very low) in the high plateau sites. High yellow berry percent in the most humid areas on newly released genotypes was probably the result of the reduced uptake of water which has limited the N use efficiency of wheat varieties (Rharrabti, et al 2003; Desclaux, 2000). Yellow berry is generally related to low protein content (Fernandez and Conner, 2011), this was not the case in our study at Tiaret where this trait was lowest for yellow berry but highest for

Table 3. Effect of variety, sites and interaction (% of total meansquare) on durum wheat grain.

Prameters	Site	var	Site*var
Humidity	22.45***	38.59***	38.95***
Proteins	95.79***	0.10***	4.09***
Mouch (Black points)	75.60***	14.68***	9.70***
PMG(TKW)	83.44***	11.32***	5.23***
Mit (Yellow Berry)	97.17***	1.18***	1.63***
RDT (Yield)	96.74***	1.76NS	1.49NS

Table 4. Anova comparison among sites and homogenous groups (Genotype/environment) for all quality traits during 2010/2011 season.

Varietis/location	Yld	TKW	Prot leyel	Yellow Berry	Black Points	Grain Moisture
Waha/Guelma	26.80^{b}	44.627^{b}	12.867^{b}	25.604^{a}	0.983^{b}	12.800^{ns}
Waha/Setif	45.850^{a}	51.887^{a}	12.867^{b}	2.583^{b}	7.050^{a}	12.767^{ns}
Waha/Tiaret	26.440^{b}	45.853^{b}	17.267^{a}	0.354^{c}	7.200^{a}	12.800^{ns}
Boussellem/Guelma	35.53^{a}	43.187^{a}	12.167^{a}	20.875^{a}	0.833^{a}	12.800^{b}
Boussellem/Setif	43.610^{a}	61.553^{b}	11.533^{b}	0.8125^{b}	10.067^{b}	13.500^{a}
Boussellem/Tiaret	23.750^{b}	56.757^{c}	16.867^{c}	0.250^{b}	11.067^{c}	13.00^{b}
GTA-Dur69/Guelma	37.06^{a}	43.057^{a}	10.533^{a}	35.542^{a}	2.066^{a}	12.833^{a}
GTA-Dur69/Setif	43.970^{a}	52.820^{b}	14.533^{b}	0.229^{b}	20.700^{b}	12.067^{b}
GTA-Dur69/Tiaret	26.271^{b}	49.207^{c}	16.933^{c}	0.104^{b}	10.750^{c}	12.90^{a}
Lahn -Ch1 2003/Guelma	42.53^{a}	40.193^{b}	11.633^{b}	24.667^{b}	5.017^{b}	12.267^{b}
Lahn -Ch1 2003/Setif	46.900^{a}	57.760^{a}	13.067^{b}	2.229^{b}	9.660^{a}	12.200^{b}
Lahn -Ch1 2003/Tiaret	29.687^{b}	53.020^{b}	16.667^{a}	0.479^{a}	7.567^{a}	13.067^{a}

protein content. High percent of black point disease observed occurred as expected in wettest environment like in Guelma (Desclaux, 2000; Rharrabti et al., 2003; Fernandez and Conner, 2011; Akman et al., 2013).

Conclusion

Results deriving from different analysis (mean, anova, tukey test) show the high spatial variation existing between the different varieties for all quality parameters considered in this study. The differences were highly significant in all varieties for all traits except for grain yield at Guelma and Setif. This latter trait was lowest at Tiaret (2.5 Vs 4.5 t/ha at Setif). The newly released variety Beni Mestina (Lahn/Ch1 2003) out yielded all the other varieties in all sites. Humidity was in a good range at all sites averaging 12.8%. Protein content reached a high level (16.93%) at Tiaret site; the best overall level was on average in Waha with 14.3%.

It is important to notice that the best yielders did not have the best protein level meaning that the quantity of the product did not match with its quality. Our results showed the excellent results that appeared for protein content with almost no yellow berry in the grain and a high PMG in the high plateau semi arid sites implying clearly that rainfed conditions in the semi arid sites offer the best opportunity for production of good quality durum wheat.

Under rainfed conditions, durum wheat cropping system in Algeria show sensitivity to spatial and climatic variability. Therefore, crops should be managed specifically according to the site where they are cultivated, especially by the use of techniques that improve protein content in their wheat varieties. Spatial analysis of yield and quality parameters allowed for the identification of Tiaret as the best site for grain quality because of its stable rainfall during grain filling period during our experiments. Varieties with shorter cycle and a good water use efficiency or drought tolerance released recently are better in littoral areas whereas varieties with long cycle are suitable in the high plateau sites. Our results suggest that, it is necessary to focus on each specific region with different environment types and select performing genotypes with the expression of best quality parameters for each variety in each site.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Abecassis J, Autran JC, Adda J (1990). La qualité technologique des blés. Le blé à l'INRA : Recherches et innovations. Revue mensuelle INRA. N°4:6-9.

Akman H, Tamkoc, Topal A (2013). Effects on Yield, Yellow berry and Black Point Disease of Fertilization Applications in Hungarian Vetch and Durum Wheat Intercropping System. Digital Proceeding Of THE ICOEST'2013-, Cappadocia. Ozdemir C., Şahinkaya S., Kalıpcı E., Oden M.K. (editors). Nevsehir, Turkey, June 18-21, 2013.

Annicchiarico P, Mariani G (1995). Prediction of adaptability and yield stability of durum wheat genotypes from yield response in normal and artificially drought-stressed conditions. Field Crops Res. 46:71–80. http://dx.doi.org/10.1016/0378-4290(95)00087-9

Annicchiarico P, Bellah F, Chiari T (2006). Repeatable genotype x location interaction and its exploitation by conventional and GIS-based cultivar recommendation for durum wheat in Algeria. Europ. J. Agron. 24:70–81 http://dx.doi.org/10.1016/j.eja.2005.05.003

AUTRAN JC (1984). Identification varietals à partir des constituants protéiques. Guide pratique d'analyses dans les industries des céréales. Coll. Sc. Tech. Agr. Alim. Lavoisier

Baenziger PS, Clements RL, McIntosh MS, Yamazaki WT, Starling TM, Sammons DJ, Johnson JW (1985). Effect of cultivar, environment, and their interaction and stability analysis on milling and baking quality of soft red winter wheat. Crop Sci. 25:5–8. http://dx.doi.org/10.2135/cropsci1985.0011183X002500010002x

Bahlouli F, Bouzerzour H, Benmahammed A (2008). Effets de la vitesse et de la durée du remplissage du grain ainsique de l'accumulation des assimilats de la tigedansl'élaboration du rendement du blédur (*Triticum durum* Desf.) dans les conditions de culture des hautes plaines orientales d'Algérie. Biotechnol. Agron. Soc. Environ 12(1):1–39.

Bahlouli F, Bouzerzour H, Benmahammed A (2008). Effets de la vitesse et de la durée du remplissage du grain ainsi que de l'accumulation des assimilats de la tige dans l'élaboration du rendement du blé dur (*Triticum durum* Desf.) dans les conditions de culture des hautes plaines orientales d'Algérie. Biotechnol. Agron. Soc. Environ. 12(1):31-39.

Basso B, Fiorentino C, Cammarano D, Cafiero G, Dardanelli J, 2012. Analysis of rainfall distribution on spatial and temporal patterns of wheat yield in Mediterranean environment. Europ. J. Agron. 41:52-65http://dx.doi.org/10.1016/j.eja.2012.03.007

Benbelkacem A (1996). Adaptation of cereal cultivars to extreme agroecologic environments of North Africa. Field Crops Res. 45:49-55.http://dx.doi.org/10.1016/0378-4290(95)00058-5

Boggini G, Doust MA, Annicchiarico P, Pecetti L (1997). Yielding ability, yield stability, and quality of exotic durum wheat germplasm in Sicily. Plant Breed. 116:541–545.

Dagnelie P (2003). Principes d'expérimentation. Panification des expériences et analyse de leurs résultats. Les Presses Agronomiques de Gembloux, Belgique, P. 397.PMCid:PMC1773566

Desclaux D (2000). Environmental conditions inducing black-point symptoms in durum wheat. In: Royo C. (ed.), Nachit M. (ed.), Di Fonzo N. (ed.), Araus J.L. (ed.). Durum wheat improvement in the Mediterranean region: New challenges. Zaragoza: CIHEAM, (Options Méditerranéennes: Série A. Séminaires Méditerranéens; 40:501-503.

Desclaux D (2005). Amélioration de la valeur technologique et commerciale du blé dur : vers une réduction des taux de moucheture et de mitadin. Rapport du projet de recherche. INRA. Montpellier. France, P. 120.PMid:15698076

Diacono M, Castrignanò A, Troccoli A, De Benedetto D, Basso B, Rubino P (2012). Spatial and temporal variability of wheat grain yield and quality in a Mediterranean environment: A multivariate geostatistical approach. Field Crops Res. 131:49–62. http://dx.doi.org/10.1016/j.fcr.2012.03.004

Djermoun A (2009). La production céréalière en Algérie : les principales caractéristiques. Revue Nature et Technologie, 01:45-53

Elhani S, Martos V, Rharrabti Y, Royo C, Garcia del Moral LF (2007). Contribution of main stem and tillers to durum wheat (*Triticum turgidum* L. var. durum) grain yield and its components grown in Mediterranean environments. Field Crops Res. 103:25–35. http://dx.doi.org/10.1016/j.fcr.2007.05.008

Fernandez MR, Conner RL (2011). Black point and smudge in wheat. Prairie Soils. Crops J. 4:158-164.

Flagella Z, Giuliani MM, Giuzio L, Volpi C Masci S (2010). Influence of water deficit on durum wheat storage protein composition and technological quality. Eur. J. Agron. 33:197–207. http://dx.doi.org/10.1016/j.eja.2010.05.006

Garrido-Lestache E, Lopez-Bellido RJ, Lopez-Bellido L (2005). Durum wheat quality under Mediterranean conditions as affected by N rate, timing and splitting, N form and S fertilization. Eur. J. Agron. 23:265–278. http://dx.doi.org/10.1016/j.eja.2004.12.001

Hussain M, Khan AS, Khaliq I, Maqsood M (2012). Correlation studies of some qualitative and quantitative traits with grain yield in spring wheat across two environments. Pak. J. Agric. Sci. 49(1):1-4.

Juan-Aracil J, Michelena A (1995). Durum wheat in Spain. In: diFonzo, N, Kaan, F, Nachit, M. (Eds.), Proceedings of the Seminar on Durum Wheat Quality in the Mediterranean Region. Options Me'diterrane'ennes 22:129–121.

Kezih R, Bekhouche F, Merazka A (2013). Some traditional Algerian products from durum wheat. Afr. J. Food Sci. 8(1):30-34.

Mariani BM, D'Egidio MG, Novaro P, (1995). Durum wheat quality evaluation: influence of genotype and environment. Cereal Chem. 72:194–197.

Michelena A, Romagosa I, Martin JA, Lopez A (1995). Influencia ambiental y varietal en diferentes para'metros de calidad y rendimiento en trigo duro. Invest. Agric. 10:192–201.

Monneveux P, Rekika D, Acevedo E, Merah O (2006). Effect of drought on leaf gas exchange, carbon isotope discrimination, transpiration efficiency and productivity in field grown durum wheat genotypes. Plant Sci. 170:867–872. doi:10.1016/j.plantsci.2005.12.008 http://dx.doi.org/10.1016/j.plantsci.2005.12.008

Oweis T, Pala M, Ryan J (1999). Management alternatives for improved durum wheat production under supplemental irrigation in Syria. Eur. J. Agron. 11:255–266. http://dx.doi.org/10.1016/S1161-0301(99)00036-2

Nachit MM, Baum M, Impiglia A, Ketata H (1995). Studies on some grain quality traits in durum wheat grown in Mediterranean region. In: di Fonzo N, Kaan F, Nachit M. (Eds.), Proceedings of the Seminar on Durum Wheat Quality in the Mediterranean Region. Options Mediterraneennes 22:181–187.

Novaro P, D'Egidio MG, Bacci L, Mariani BM, (1997). Genotype and environment: their effect on some durum wheat quality characteristic. J. Genet. Breed. 51:247–252.

Peterson CJ, Graybosch PS, Baenziger PS, Grombacher AW (1992). Genotype and environment effects on quality characteristics of hard red winter wheat. Crop Sci. 32:98–103. http://dx.doi.org/10.2135/cropsci1992.0011183X003200010022x

Rharrabti YC, Royo D, Villegas N, Aparicio LF, Garcia Del Moral (2003). Durum wheat quality in Mediterranean environments II. Influence of climatic variables and relationships between quality parameters. Field Crops Res. 80:133-140. http://dx.doi.org/10.1016/S0378-4290(02)00177-6

Rharrabti Y, Villegas D, Royo C, Martos-Nunez V, García del Moral LF, (2003b). Durum quality in Mediterranean environments II. Influence of climatic variables and relationships between quality parameters. Field Crop Res. 80:133–140. http://dx.doi.org/10.1016/S0378-4290(02)00177-6

Rizza F, Ghashghaie J, Meyer S, Matteu L, Mastrangelo AM, Badeck F-W, (2012). Constitutive differences in water use efficiency between two durum wheat cultivars. Field Crops Res. 125:49–60. http://dx.doi.org/10.1016/j.fcr.2011.09.001

Villegas D, Casadesus J, Atienza SG, Martos V, Martos F, Karam F, Aranjuelo I, Nogués S (2010). Tritordeum, wheat and triticale yield components under multi-local mediterranean drought conditions. Field Crops Res. 116:68–74. http://dx.doi.org/10.1016/j.fcr.2009.11.012