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Effect of genotype by environment interactions on quality parameters and grain yield of durum wheat

FAWZIA BOUCHETAT[1,♥], RAFIKA GHANAI[1], SARA HIMOUR[2], SARA BOUAROUDJ[2], LEILA ALLAL BENFKIH[1]

[1]Department of Biotechnology, Laboratory of Aromatic and Medicinal Plants, Faculty of Nature and Life Sciences, Saad Dahlab University. Blida 1, 270 P.O.BOX, Soumaa Road, Blida, Algeria. Tel./fax.: +21-379-0637132. ♥email: bouchetatfouzia@yahoo.fr

[2]Laboratory of Natural Sciences and Materials (LSNM), Abdelhafid Boussouf University Center. BP N°26 RP Mila 43000 Algeria

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Abstract. *Bouchetat F, Ghana R, Himour S, Bouaroudj S, Benfikh LA. 2023. Effect of genotype by environment interactions on quality parameters and grain yield of durum wheat. Biodiversitas 24: 5565-5571.* Two experimental trials were conducted at different bioclimatic levels, with the aim to investigate the effect of genotype x environment (Gx E) interaction on grain yield and technological parameters of eight durum wheat (*Triticum durum* Desf.) varieties. The experiment was set up in a randomized complete block with three replications. The results showed a high Gx E effect on the expression of all evaluated traits. Varieties V4 and V1 with respectively, (24.95 q/ha and 24.73 q/ha) exhibited the highest average yield values across targeted environments. Averaged over the variety main effect, a significant difference of 42 q/ha, in favor of a humid environment, came out for yield. Varieties V3 (84.1 kg/hl) and V6 (83.36 kg/hl) demonstrated the best average specific weight values per hectolitre. Similarly, V2; V3; V5 and V7 had the highest rates of black point, while V2 shawled resistance to vitreous kernels (4.33%). The V3 variety was strongly resistant to grain scalding (2.16%). The highest levels of protein content were obtained in V6 and V4 (13.38 %; 13.3%). Varieties: V3; V6 and V1 expressed the best wet gluten content (27.7%; 26.15% and 26.13%). Indeed, the results obtained indicate that each variety is expressed by a particular behavior in relation to environmental diversity.

Keywords: Behavior, durum wheat, genotype × environment interaction, technological parameters, yield

INTRODUCTION

Durum wheat, (*Triticum turgidum* var. durum) is the most widely cultivated form of allotetraroid wheat (2n = 4x = 28, AABB). Durum wheat is a highly valued food, it represents one of the most important food resources in the Mediterranean regions, Central and Western Asia and mainly in North Africa (Beres et al. 2020). Durum wheat contributes about 10% to global cereal production; in recent years its production has been estimated at around 30 Mt (Faostat 2022). The European Union, Canada and the United States represent almost 60% of this production (Mohammadi et al. 2015). Worldwide, its cereals are mainly used in the food industry, as a raw material, in the production of bread, couscous and pasta. (Agezew et al. 2022).

Technological traits and grain yield determine the commercial value of durum wheat. Protein content, specific weight of kernels, falling number and yellowness index, black point, scalding and vitreous of kernels are the most important technological parameters and that have a direct impact on durum wheat marketing (Melash et al. 2019). Wheat cultivation is most often affected by environmental constraints, which affects its technological quality and its quantity produced. Therefore, bad distribution of rains, precipitation in large quantities at the time of physiological ripening, most often causes mediocre grain quality (Khoa et al. 2020). In addition, important rainfall decreases protein content of the grains, slows down the drying of the grains, promotes the germination of the grains and reduces the falling index (Wan et al. 2022). Very heavy rains can also influence the color of the grain while causing black point, the speckling of the grains that will appear in the semolina and in the products made from this semolina (Kondhare et al. 2015; Yadav and Ellis 2017). On the other hand, in areas characterized by water stress, the protein content is frequently increased because there will be an increase in the accumulation of nitrogen in the grain and consequently decrease in the concentration of carbohydrates. Indeed, under water stress conditions, starch deposition in the grain is reduced while exerting a positive effect on protein concentration (Huanhui et al. 2021). It has been noted that late irrigation, at the grain filling stage leads to a potential increase in grain protein (Torrion 2017). On the other hand, this method is not always guaranteed because the grain protein content is closely associated with nitrogen fertilizer inputs, irrigation, environment and cultivar (Bicego et al. 2019). In addition, the yield potential of each cultivar also determines the protein content. Varieties that contain higher protein content are characterized by low grain yield potential, while varieties that have high grain yield have low protein contents (Visioli et al. 2018; Jones and Olson-Rutz 2020; Lijalem et al. 2021).

Therefore, when selecting durum wheat varieties, it is essential to consider both grain protein content and grain yield (Melash 2019). Visioli et al. (2018) suggested that high productivity of durum wheat could be combined with good quality traits through an appropriate breeding approach (Bapela et al. 2022). Indeed, in modern agricultural systems, the main concern of farmers is the simultaneous improvement of grain yield and technological characteristics of gains, and this across the different cropping areas (Bicego et al. 2019).

This research focuses on the study effect of genotype × environment interaction on the technological traits and yield of eight varieties of durum wheat. The study aims to target the genetic potential of the genotypes tested (local and introduced) in order to select the best cultivars that best express their technological and agronomic qualities while adapting to the humid and semi-arid environments of Eastern Algeria.

MATERIALS AND METHODS

Experimental protocol

Trials were conducted by the Technical Institute for Field Crops (ITGC) in the framework of the national participatory breeding program during the agricultural campaign (2020-2021) at two different localities situated respectively, in a humid region (Ferdoua) and a semi-arid region (Oued Seguen) in eastern Algeria. The humid zone (environment 1) is characterized by a relatively mild climate but with a hot summer. The average rainfall in this region varies between (300 mm and 860 mm) with high temperatures and hot winds which coincide with the end of the durum wheat cultivation cycle causing water deficits that influence the grain filling phase. On the other hand, the semi-arid zone (environment 2) is characterized by a relatively dry climate with low precipitation varying between (200 mm and 300 mm). Environment 1 has a silty-clay type texture with a surface layer very rich in organic matter. However, environment 2 is characterized by shallow and infertile soils due to the lack of restitution of organic matter.

The plant material studied is composed of eight pure varieties of durum wheat (local and introduced) (Table 1). Average plowing was carried out regularly with the burying of the basic fertilizers at the rate of 1 q of Monoammonium Phosphate (MAP) followed by surface plowing in order to prepare an adequate seedbed for the setting instead of culture. The sowing was carried out according to an experimental device in complete random blocks with total randomization. The cultivars were sown on the same date for both localities, after the calculation of the seeding rate this is estimated at 1.5 q/ha. Weeding and cover fertilizer were done at the right time.

Traits studied

A total of nine parameters were evaluated, including yield and technological parameters that allow the assessment of the quality of durum wheat grain and that of semolina.

Yield

After the harvest, at the level of the two environments, the recovered grains are cleaned and weighed. The harvested quantity is expressed in kg per plot, then it is converted into quintal per hectare (q/ha).

Grain technology analysis

The technological analyses were carried out at the laboratory of genetics, biochemistry and plant biotechnology at the University of Constantine 1 and at the laboratory of the Agro-industry group of mill Beni Haroune Grarem-Gouga, Mila.

Physical grain analysis

The weight per hectolitre (Phl) is determined by measuring the mass of grains of durum wheat in a volume of one liter by free flow of a sample through a hopper into a container using a liter Niléma (ISO 7971-3:2019). The mass of a thousand whole grains freed from impurities is determined by counting using a grain counter (Numigal) (ISO 520:2010). The black point rate is determined on 20 grams of clean wheat by visual assessment. The results are expressed in grams of speckled grains per 100 grams of samples (BIPEA). The determination of the vitreous kernel rate is made on 300 grains by counting the vitreous grains after having cut them transversely using the Pohl grain cutter (ISO 5532:1987). In scalding kernels (Shrunken), light and fine, the accumulation of nutrients is determined due to physiological and pathological influences. Scalding kernels pass through a sieve with long rounded openings 1.90 mm in width (ISO 11051:1994).

Table 1. Type, pedigree and origin of the studied durum wheat cultivars

No./variety type	Name/pedigree	Origin
V1/ Pure variety	AIN LAHMA/ baltagy3Bcr/gro1//mgnl1lcd97-0396-t-1ap-0ap-5ap-0ap-16ap-0ap	ICARDA Sery
V2/ Pure variety	BOUSSELAM/heider/marte//huevo de oro icd86-0414-abl-otr-4ap-otr-14ap-otr	ICARDA-CIMMYT
V3/ Pure variety	GTA DUR/gaviota/durum	CIMMYT Mexico
V4/ Pure variety	OUED ELBARED/ gta dur/ofanto-dz-itgc-set-008-2004/2005-1s-3s-0s	ITGC Algeria
V5/ Pure variety	SAOURA/belikh//gediz/bitAcs-d-7284-22iz-9iz-2iz-0iz	ACSAD Sery
V6/ Pure variety	SIMETO/capeiti//valvona	Italy
V7/ Pure variety	VITRON/jo“s“/aa“s“//fg“s“-cm9799	Spain
V8/ Pure variety	WAHBI/ bidi17/Waha//bidi17	ITGC Algeria

Note: ICARDA: The International Center for Agricultural Research in the Dry Areas; CIMMYT: The International Center for Maize and Wheat Crop Improvement; ITGC: the Technical Institute for Field Crops of Algeria

Biochemical and technological analysis

The protein content is determined by the Kjeldahl method (ISO 20483: 2013), and also measured indirectly on whole (or ground) grains by near-infrared spectrometry. This device makes it possible to obtain the protein content of a wheat sample. The moisture content is measured using the same infrared device (NIRS) and under the same measurement conditions. The results are expressed as a percentage of moisture relative to dry matter. Gluten extraction is obtained by mechanical mixing of a flour paste and washing with a buffered NaCl solution, then by draining and weighing the residue (AACC International. 38.12-02/2000).

Statistical analysis and interpretation approach

The data collected was analyzed by IBM-SPSS Statistics Software, version 24 (Statistics Package for the Social Science). The analysis of variance makes it possible to compare the means of several supposedly normal populations and of the same variance from simple random samples independent of each other, this preliminary and essential global test is estimated by the following additive model:

$$Yij = U + Gi + Bj + \varepsilon ij \quad \text{(1)}$$

Where:

Yij : the observed value of genotype i at the level of block j,

U : the general mean of the population considered, Gi is the effect of genotype i,

Bj : the effect of block j and εij is the effect that is due to experimental error.

In order to predict the performance of genotypes in the different environments considered, the option of taking the genotypes as fixed and the environments as random is adopted in the processing of our data. Denis et al. (1997) argued this model indeed, these authors justify this choice by the fact that it is a question of studying a finite number of genotypes, hence the fixed genotype effect. However, the environments are not considered for themselves, but as samples from a larger population of possible environments for which the varieties are intended. This mixed linear model generally based on the averages per genotype and per environment is expressed by the following formula:

$$Yij = m + gi + Ej + (gE)ij + eij \quad \text{(2)}$$

Where:

Yij : the response of genotype i from environment j,

m : the grand mean, and

gi : the fixed effect of genotype i.

The effect Ej of environment j, the interaction (gE)ij and the error term eij are assumed random. The comparison of the different means shows us the number of homogeneous groups existing for the studied parameter. This comparison is made using the Newman and Keuls test. If the statistical analysis shows a significant effect in the interaction of the two studied factors (genotype × environment interaction), this indicates that there is a dependence of the expression of the two factors. If, on the contrary, the statistical analysis does not show any significance of the genotype × environment interaction, we just interpret the factors that show a significance (genotype or environment) without going to the Newman and Keuls test (or the PLSD test) for the G × E interaction factor.

RESULTS AND DISCUSSION

The genotype factor variance statistical analysis shows that the observed F test is much less important than the theoretical F test. This implies that there is a non-significant effect of the genotype on all the traits studied (Table 2). The environment factor variance analysis indicates a non-significant difference between the two environments with a probability greater than (0.05) concerning characters: rate of vitreous kernels, rate of speckling, protein content, moisture content and gluten. On the other hand, the difference between the two environments is highly significant to very highly significant for, respectively, thousand kernel weight, specific weight, scalding rate and yield. The genotype x environment interaction factor variance analysis indicates a very highly significant difference between the genotypes in the two environments for all the evaluated traits, with a probability of (0.0001), (Table 2). Indeed, the expression of all characters is dependent on the genotype x environment interaction; therefore, the interpretation of the results will focus on the combined effect of the genotype x environment interaction factor only.

Grain yield

Within the same environment, the genotypes present the same performances to express yields whose deviations are not significantly different. The comparison of means between the two environments reveals highly significant differences whose best performance is obtained in environment 1. The test of the smallest significant amplitude reveals several homogeneous groups. The average yield values oscillate between 24.95 q/ha and 20.67 q/ha (Figure 1).

Table 2. Analysis of variance (mean squares) of different traits measured in durum wheat varieties

Studied parameters	Mean of squares		
	Genotypes	Environments	Interaction
GYD	018.933^{ns}	14338.945***	025.145***
GTW	007.867^{ns}	00091.025***	030.385***
WTG	016.374^{ns}	00514.175**	039.777***
VIT	481.131^{ns}	00075.000^{ns}	741.190***
BLP	085.131^{ns}	00243.000^{ns}	087.190***
SCR	026.095^{ns}	01386.750***	021.512***
MCG	000.253^{ns}	00003.101^{ns}	001.403***
PC	002.218^{ns}	00000.992^{ns}	004.267***
WGC	064.747^{ns}	00000.403^{ns}	060.005***

Note: GYD: Yield; GTW: Test Weight; WTG: Thousand Kernel Weight; VIT: Vitreous Kernels Rate; BLP: Black Point Rate; SCR: Scald Rate; MCG: Moisture Rate; PC: Protein Content; WGC: Wet Gluten Content. **: highly significant at P≤0.01; ***: very highly significant at P≤0.001; ns: not significantly different at P>0.05

According to the results of this analysis, there is a difference in behavior between the two environments. This difference could be explained by the influence of the environment exerted on the genotypes. Indeed, under favorable conditions, average temperature and sufficient rainfall (humid environment), the genotypes express better yields (environment 1). The same genotypes take care of giving very low yields in environment 2 (semi-arid environment), the cultivars are affected by the environment: the rainfall deficit would be the main factor limiting yields at the beginning and at the end of the cycle. Grain yield is a parameter linked to the genetic potential of each cultivar and to the climatic conditions characterizing each environment. That is confirmed by the very highly significant effect of the genotype × environment interaction factor (Figure 1), these results are in agreement with those of (Popović et al. 2020; Chairi et al. 2020), they confirmed that yield is a complex trait that largely depends on genetic potential and varies considerably, mainly due to the environmental conditions during the growing season.

The physical parameters of the grain

Within the same environment, the genotypes present the same performances to express the specific weight and the thousand-grain weight, which the deviations are not significantly different. The comparison of the means between the two environments reveals very highly significant differences, the best performance of each is obtained in environment 1 (Figures 2A and 2B). Indeed, the weight of a thousand grains is a parameter linked to the genetic potential of each cultivar and to the climatic conditions characterizing every environment, the same for the specific weight of the grains. This is confirmed by the highly significant effect of the genotype × environment interaction factor. The Newman and Keuls test shows the presence of several homogeneous groups, these fluctuations in the weight of the same variety imply that the genotypes are not expressed in the same way from one environment to another. Gate et al. (1996), observed very strong reductions in the weight of 1000 grains in wheat and barley sown in France and Algeria and which go up to 35 g/1000 grains, caused by high temperatures. (Baillot et al. 2018) show that the grain filling rate explains the genotypic differences in thousand-kernel weight better than the duration of the grain filling phase.

At the level of the same environment, the cultivars present the same performances to express the rate of vitreous kernels, the rate of black point and the rate of scalding. On the other hand, the genotypes react differently in the two environments passing reciprocally from susceptibility to resistance (Figures 3A, 3B and 3C). Varieties: V1; V6; V8 and V4 represent a rate of kernels vitreous of less than 20%. On the other hand, the varieties: V2; V3; V5 and V7 record rates exceeding 20%, which is too high and consequently, the semolina yield drops. If during the filling of the grain, the protein material is in sufficient quantity, the album will take on a glassy appearance, on the other hand, in the case of a protein deficiency this would lead to the formation of numerous air vacuoles within albumen, giving it an opaque or floury appearance, which would lead to a reduction in semolina yield by increasing flour production (Mastanjević et al. 2023). Resistance to vitreousness is a trait that depends on genetic factors (Lullien-Pellerin 2020). It is directly related to protein content (Sieber et al. 2015). 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 others, nitrogen fertilization (Brankovic et al. 2014). Indeed, this phenomenon could only be explained by the close dependence of the genotype x environment interaction, which would involve resistance genes that would be inhibited or activated depending on the environmental conditions, which joins the results of Lullien-Pellerin (2020).

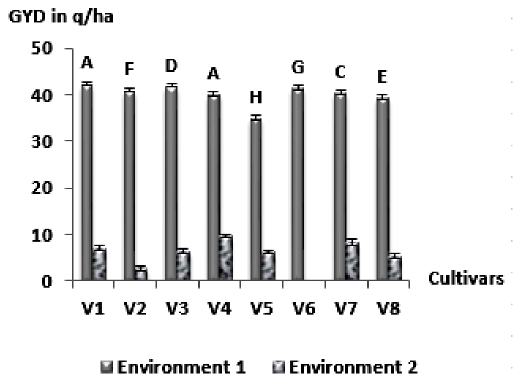
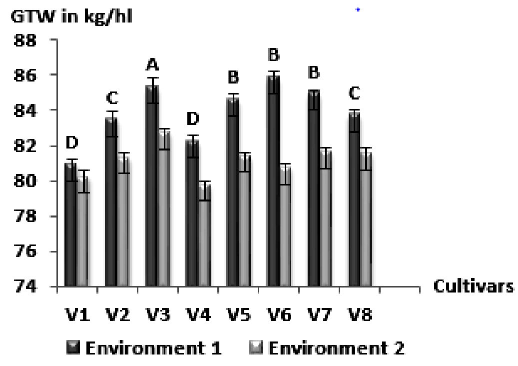
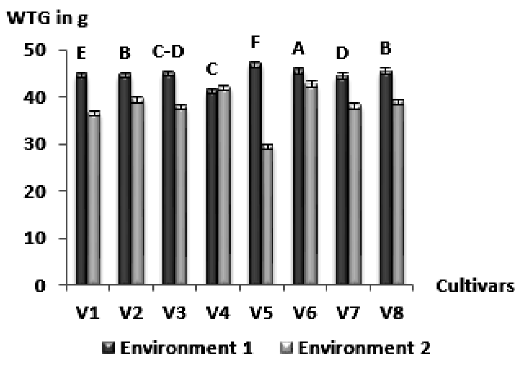


Figure 1. Effect of genotype x environment interaction on yield (GYD)



A



B

Figure 2. A. Effect of genotype x environment interaction on test weight (GTW). B. Effect of genotype x environment interaction on thousand kernel weight (WTG)

The black point rate varies between 2% and 20%, including the V2, V4, V5 and V6 genotypes that are the most resistant with rates below 10% (Figure 3B). Brown or black patches of color on ripe grains are penalized because when they are found in semolina and pasta, they depreciate their commercial value. These results would be linked to the combined effect of the genetic and environmental factor, which would explain the significance of the genotype x environment interaction factor. The research of Husenov et al. (2021), confirmed that black point is caused by three agents: abiotic conditions, insects and fungi. Pre-harvest environmental conditions such as rain, humidity and temperature have been observed to lead to discoloration symptoms such as black point (Khani et al. 2018). Previous studies have suggested that cereal black point tolerance is inherited. It has been reported that barley and wheat varieties show quantitative genetic variation in tolerance to this trait (Bretträger et al. 2023)

The highest rates of scalding kernels are recorded at the level of environment 2, of which the V3 and V5 varieties are the most resistant (Figure 3C). The variation in grain size greatly affects the semolina yield and the commercial value of the grain. According to Agezew et al. (2022), this parameter is closely linked to climatic conditions, end-of-cycle rainfall, sowing date and nitrogen fertilizers.

Within the same environment, the genotypes record the same grain water content. On the other hand, the analysis of the variance of the genotype x environment factor reveals a very highly significant difference. This translates the impact of the two factors genotype and environment in interaction on the moisture of the grains. The test of Newman and Keuls shows the presence of two homogeneous groups whose values do not exceed 15%. The balance is between 16 and 13% depending on the ambient temperature and humidity. Common grain moisture values are around 14%. For longer wheat storage, the maximum moisture level should be 12.5% or less (Ahmad et al. 2022), (Figure 3D).

The genotype x environment interaction variance analysis is also very highly significant, thus confirming the simultaneous impact of the two factors genotype and environment on the protein content. Grain protein values fluctuate between 11% and 15% (Figure 4A). The magnitude of this protein variation implies that the performance of genotypes differs from one environment to another. These results corroborate what is reported by many authors, including Melash et al. (2019), stating that the protein content of durum wheat is controlled by fertilization, environment and heredity. According to them, it is a hereditary trait that varies with the environment. Similarly, according to Mefleh et al. (2019), the protein content is a genetically transmissible trait, but the variations linked to heredity are of the order of 5%. Cultivation conditions, especially soil fertility, strongly influence grain protein content as well as grain yield. De Santis et al. (2017), agree with these authors by mentioning that the protein content of the grain varies greatly depending on the agro-climatic conditions (previous crop, nitrogen fertilizer, scalding) and to a lesser extent, depending on the variety (Krishnappa et al. 2019).

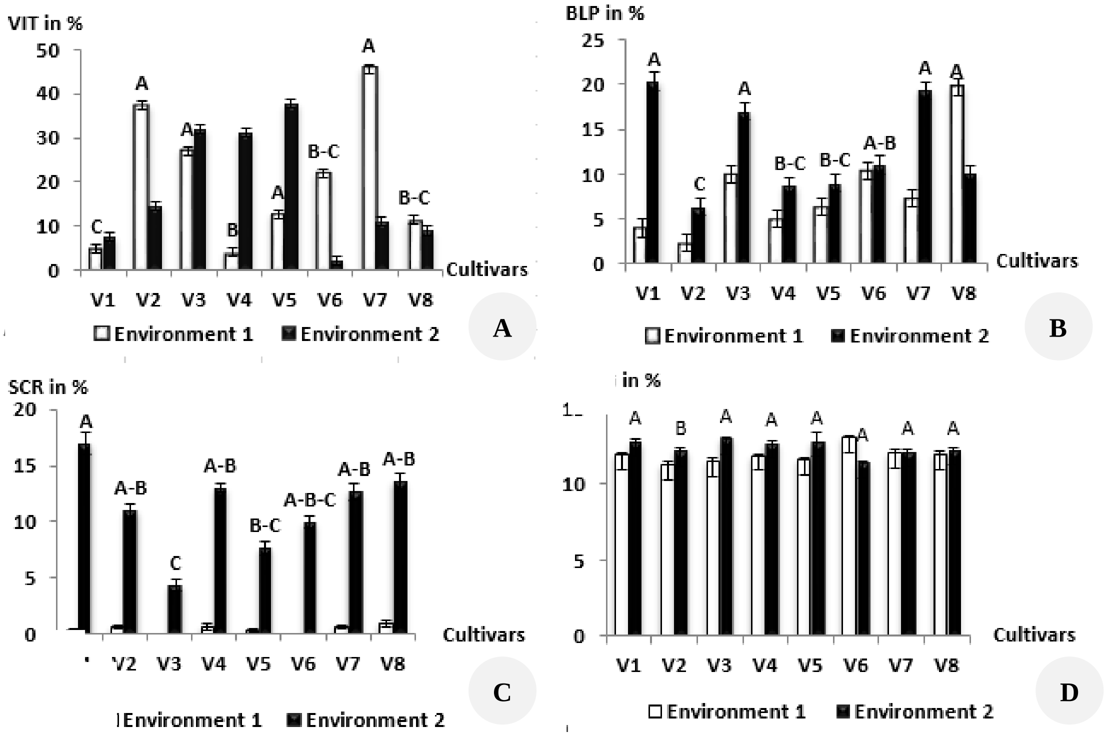


Figure 3. A. Effect of genotype x environment interaction on vitreous kernels rate (VIT). B. Effect of genotype × environment interaction on black point of grains rate (BLP). C. Effect of genotype x environment interaction on rate scalding (SCR). D. Effect of genotype x environment interaction on grain moisture content (MCG)

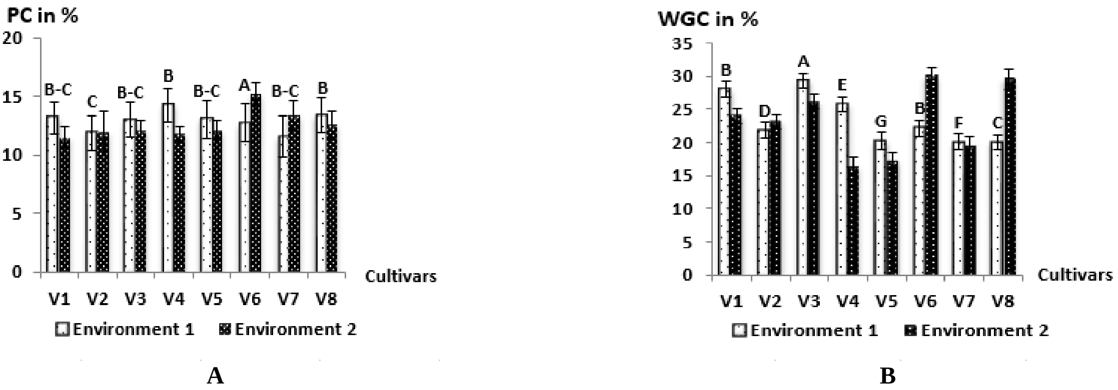


Figure 4. A. Effect of genotype × environment interaction on grain protein content (PC). B. Effect of genotype x environment interaction on grain gluten content (WGC)

The genotype x environment interaction factor variance analysis therefore reflects a very highly significant difference for the gluten content. These results reveal the definite effect of the two factors genotype and environment on semolina gluten. The examination of the minimum and maximum values of gluten, shows a large difference between certain genotypes. The minimum gluten value is 16.30% and the maximum value is 30.13%. All the varieties express values greater than 15%, which agrees with the results of Brankovic et al. (2018) (Figure 4B). The wheat is very strong and the semolina obtained is suitable for making couscous and pasta (Hammami et al. 2022). These results show that gluten varies according to the genotype × environment interaction and are in agreement with those of Kariithi et al. (2016) who claim that gluten content represents an environmentally influenced phenotypic factor.

In conclusion, the expression of all the characters evaluated is dependent on the genotype x environment interaction. Within environment 1 (humid environment), the best average values were obtained by the genotypes for most of the studied parameters: yield (42.35 q/h), specific weight per hectolitre (85.93 kg/hl), thousand grain weight (47 g), grain scald resistance (0%) and grain black point resistance (2.33%). In contrast, at environment 2 level (semi-arid environment), the genotypes expressed the best vitreous kernel resistance approximately (4%), the best protein content (15.33%) and the best gluten content (>30%). According to this study, the cultivars do not express themselves in the same way, each variety has its own strategy to adapt to different environmental conditions, the V4 and V1 varieties are the most productive in both environments, on the other hand, the V6, V3 and V4 varieties are the best for the technological parameters, indeed, the V4 is retained as the best cultivar in terms of production and technological quality. The choice of the variety is a major adaptation of the technical itineraries towards environmental diversity. Indeed, in a breeding program, a good understanding of the environment and the extent of genotype x environment interaction is essential to improve grain yield and quality traits of wheat.

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