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Analysis of Genotype × Environment Interaction for Grain Yield in Early and Late Sowing Date on Durum Wheat (*Triticum durum* Desf.) Genotypes

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Abstract

Studying genotype × environment interactions and identifying the morphological traits contribution to the interaction are among the important tasks in crop breeding programs. The present investigation aims to analyze grain yield genotype × environment interaction and partitioning it into genotype × year and genotype × sowing date of 15 durum wheat (*Triticum durum* Desf.) genotypes. Trials were conducted during three consecutive cropping seasons, 2012/13, 2013/14 and 2014/15 and at two seeding dates (early vs late). The results indicate that genotype × year interaction was more significant than that of genotype x sowing date. Correlations of IPCA1 genotypic scores with several morphological plant traits indicated that 1000-kernel weight, number of spikes/m² and spikes weight/m² contributed significantly to grain yield interaction. Bousselam and Massara genotypes exhibited a general adaptation, with a grain yield mean above the overall average. Furthermore, the results suggested that the number of the testing years should be greater than the number of the seeding dates per year in studying genotype × environment interaction. Selection of stress tolerant genotypes should be based on 1000-kernel weight, number of spikes and spikes weight/m² to minimize grain yield interaction.

Keywords Triticum durum, G×E interaction, Sowing date, Grain yield, Regression, SSIndex.

1. Introduction

Wheat varieties react differently to a number of factors such as moisture stress, high temperature, weed infestation, soil fertility, disease pressure and sowing date, expressing a yield ranking change across environments, termed Genotype × Environment Interaction (GEI) (Bouzerzour and Refoufi, 1992; Basford and Cooper, 1998; Anwar et al., 2007, Subedi et al., 2007). Late planted crop, usually, suffers a yield decline due to the exposure to water deficit and high temperature at critical growth stages. These abiotic stresses hasten crop maturity, affect spikes number/m², pollen fertility, seeds set and seed weight (Chaudhry et al., 1995; Iqbal et al., 2001; Silva et al., 2014). Comparatively, optimum sowing date enhances the yield, as a result of relatively favorable weather conditions during the vegetative growth stage, and as such, this environment is relatively more suitable to discriminate between genotypes through their yielding abilities. Planting date management aimed generally to avoid or to minimize stress effects on crop performance (Tapley et al., 2013; Silva et al., 2014). GEI attenuates the relationship between phenotype and genotype, thereby reduces genetic progress.

Targeting high performing and stable genotypes is based on a better understanding of GEI pattern. Selection for specific or general adaptation is suggested and practiced as a way to increase genetic gain. Nouar et al. (2012) used AMMI model to study the GEI in durum wheat; they identified three sub-regions and concluded that selection for specific adaptation generated 10.5% genetic gain over selection for large adaptation. Furthermore, understanding the environmental and the genotypic

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causes leading to genotype × environment interaction is an important issue in a plant breeding program while selecting parental material for crossing, and ideal test conditions.

Van Eeuwijk and Elgersma (1993) mentioned that regression of AMMI IPCA environmental scores against environmental covariates allows identifying environmental variables which contributed to the expression of the interaction. Van Oosterom et al. (1996) reported that the 10-day post flowering mean maximum temperature and changes in water satisfaction index during grain filling contributed to GEI in pearl millet. Similarly, genotype scores can be utilized to identify cultivar covariates which cause GEI. Annicchiarico and Iannucci (2008) correlated AMMI genotypic IPCA scores to mean values of various morphological traits to identify GEI causes. The objectives of the present study were to determine the magnitude of grain yield GEI and the traits contributing to the manifestation of the GEI under different sowing dates and to identify high-yielding and stable genotypes among 15 durum wheat genotypes..

2. Materials and Methods

2.1. Field Trials, Plant Material and Experimental Data

Field experiments were conducted during three successive growing seasons (2012/13 to 2014/15) at the Field Crop Station of the Agricultural Research Institute of Setif (ITGC-ARS, 05°24′E, 36°12′ N, 1081 masl), Algeria. A set of 15 durum wheat (Triticum durum Desf) genotypes (Table 1) was sown at two planting dates, early November and late December, in a complete randomized block design with three replications. Experimental plots had 6 rows of 5 m length and 0.2 m inter-row spacing. Plants were scored for Plant Height (PHT, cm), measured just before harvest, on three positions, taken at random along the diagonal of the elementary plot; Days to Heading (DHE), counted as the number of calendar days from January1st to the date when 50% of the spikes were half-way out of the flag leaf sheath. At maturity a 1 m long row-segment was harvested and used to measure the above ground biomass (BIO, g/m²), the number of spikes/m² (SN), and the Harvest Index (HI). Grain Yield (GY, g/m²) and a Thousand-Kernel Weight (TKW, g) were determined from the harvested plots. The Number of Kernels per Spike (NKS) was derived as the ratio of the number kernels/m² divided by the number of spikes/m². These traits were used as genotypic covariables.

Table1. Name and Pedigree of the genotypes tested during three successive years and two seeding dates at the ITGC-AES experimental site (Setif, Algeria).

Name	Pedigree
Bousselam	Heider/Martes//Huevos de Oro
Boutaleb	Hedba3/Ofanto
Cyprus$_2$	Gdo vz$_{512}$/Cit//Ruff/Fg/3/Ggo vz$_{449}$
Gta *durum*	Crane/4/Polonicum PI$_{185309}$//T.glutin enano/2* Tc60/3/Gll
Mansoura	Chinese spring/Mbb
Massara	Mrb$_3$/4/Bye*2/Tc/2/Zb/W/3/Cit
Massinissa	Ofanto/3/ Heider/Martes//Huevos de Oro's
Mbb	Local variety
Megress	Ofanto/Waha//Mbb
Moustakbel	Gta durum/Ofanto
Setif$_{2013}$	Unknown
Setifis	Heider/Martes//Huevos de Oro/3/Ofanto
Tajdid	Ofanto/3/ Heider/Martes//Huevos de Oro
Vitron	Turkey77/3/Jori/ Anhinga//Flamingo
Waha	Plc/Ruff//Gta's/3/Rolette

2.2. Data Analysis

Grain yield data were subjected to one factor analysis of variance per seeding date, to test genotype effect; then subjected to a combined analysis of variance over seeding dates to test seeding date, genotype and genotype x seeding date effects and combined over seeding dates and years to test year, seeding date, genotype main effects and their interactions. The genotype × year interactions within seeding date and over all environments, taking the combination year × seeding date as environment, were analyzed by the AMMI model. In order to achieve a better understanding of genotype × environment interaction, values of the pheno-morphological measured traits served as covariates and were correlated to the AMMI IPCA1 genotypic scores (Van Eeuwijk and Elgersma, 1993). Significant correlations suggested that any separation of the genotypes on the AMMI1 biplot was attributed to the relevant genotypic covariate, highlighting the importance of that covariate to the G × E interactions and suggesting biological interpretations of the factors causing G × E interactions. All statistical analyses were performed using Cropstat software (Cropstat, 2007).

3. Results and Discussion

3.1. Yield variability between years and sowing dates

Grain yield means of early seeding were 511.0, 93.7, and 227.5 g/m^2 in 2013, 2014, and 2015, respectively. Those of late seeding were 469.9, 62.0, and 158.1 g/m^2, respectively. Relative yield reduction, measured under late planting, was 8.0, 33.8, and 30.5% of early sown grain yield, in 2013, 2014, and 2015, respectively. These results suggested the potential of optimum planting date and corroborated results of several research studies (Bassu et al., 2009; Tapley et al., 2013; Silva et al., 2014). Correlation coefficients between years for early (rGY13/GY14= -0.213ns, rGY13/GY15= -0.049ns, rGY14/GY15= -0.024ns) and lately planted trials were insignificant (rGY13/GY14= -0.057ns, rGY13/GY15= 0.122ns, rGY14/GY15= 0.460ns). The correlations between sowing dates within year were insignificant for two seasons 2013 and 2015 (rGYS113/GYS213 = 0.270ns, rGYS115/GYS215 = -0.057ns), and significant for the 2014 trial (rGYS114/GYS214 = 0.604*). These results suggested the significant effect of both genotype × year and genotype × seeding date interactions.

The combined analysis of variance indicated that the differences among environments (combination of year × sowing date) explained 86.0% of the total grain yield variation. The partitioning of these differences, among years and among sowing dates, explained 84.3 and 1.6%, respectively (Table 2). Differences among genotypes explained 2.4%, while genotype x environment interaction (G×E) explained 11.6% of grain yield treatment sum square. The G×E portioning indicated that genotype x year (G×Y), genotype x sowing (G×S) and genotype x sowing date × year (G×S×Y) components accounted for 53.1, 18.3, and 28.6%, respectively. Year main effect, G×Y and G×S×Y interactions accounted for a large proportion of treatment sum square and total G×E variance, respectively (Table 2). The assessment of the relative importance of these sources of variations is justified to take advantage of the GEI. Zhang et al. (2006) reported that contributions of the location, year, and sowing dates are proportionally greater than the main effect of the genotype and interactions. AMMI analysis of variance of grain yield of the three years per sowing date indicated that early sowing was more discriminating between genotypes than late seeding environment. In fact genotype sum square represented 5.27 and 3.81% of the treatment sum square (TSS) for early and late seeding, respectively. G×Y sum square was slightly higher under early than under late sowing (Table 3), suggesting more reactive conditions under early sowing.

High proportion of the G×Y interaction sum square (G×Y SS) was explained by the first AMMI Interaction Principal Component (IPCA1), under both growing conditions of early (77.06%) and late sowing (95.54%). This indicated that biplot AMMI1 sufficiently described the behavior of the tested genotypes (Table 3). Biplot of grain yield measured under early sowing indicated that years were clearly separated with 2014 being the less favorable (93.7 g/m^2) and 2013 the most favorable (511.0 g/m^2) to grain yield expression (Figure 1).

Table 2. Combined analysis of grain yield for 15 genotypes tested during three successive years and two seeding dates at the ITGC-AES experimental site (Setif, Algeria).

Source	Df	SS	MS	%SS
Treatment	89	9681034.8	108775.7**	100.0
Environment (E)	5	8328550.0	1665710.0**	86.0
Year (Y)	2	8159450.0	4079720.0**	84.3
Sowing (S)	1	151815.0	151815.0**	1.6
Y × S	2	17294.0	8647.0**	0.2
Repetition / E	12	2113.9	176.1^{ns}	
Genotype (G)	14	229352.0	16382.3**	2.4
G × E	70	1123110.0	16044.5**	11.6
G × Y	28	596493.0	21303.3**	53.1
G × S	14	205495.0	14678.2**	18.3
G×Y×S	28	321125.0	11468.7**	28.6
Residual	168	33675.6	193.5	

Table 3. AMMI analysis of variance for grain yield of 15 genotypes tested during three successive years and two seeding dates at the ITGC-AES experimental site (Setif, Algeria).

		Early sowing			Late sowing		
Source	Df	SS	MS	%SS	SS	MS	%SS
Treatment	44	4920520.00	111830.00**	100.00	4608690.00	104743.00**	100.00
Year (Y)	2	4085010.00	2042505.00**	83.02	4091730.00	2045865.00**	88.78
Rep / Y	6	1470.08	245.01^{ns}	--	1825.02	304.17^{ns}	--
Genotype (G)	14	259410.60	18529.33^{ns}	5.27	175436.40	12531.17^{ns}	3.81
G × Y	28	576111.00	20575.39**	11.71	341508.00	12196.71**	7.41
IPCA$_1$	15	443973.00	29598.20**	77.06	326289.00	21752.60**	95.54
Deviation	13	132136.80	10164.37**	22.94	15218.61	1170.66^{ns}	4.46
Residual	83	33098.40	398.80		69878.70	841.91	

Year 2013 (IPCA1 score of -15.62), and 2015 (IPCA1 score of 10.87) were the most interactive environments, classifying differently the tested genotypes. Cyprus2 and MBB were low yielding and Setifis and Setif2013 were high performing, in 2013; while in 2015, Mansoura and Moustakbel were low yielding and Waha and Cyprus2 were high yielding varieties (data not shown). Based on the genotype main effect, Mansoura showed a low yielding ability while Setifis and Setif2013 expressed a high yielding capacity under early sowing (Figure 1). Genotypes, with a grain yield mean above average, were Waha, Bousselam, Boutaleb, Massara, Setif2013, and Setifis. Having a below-average grain yield mean, Tajdid, Vitron, Gaviota and Massinissa expressed a relatively high stability, their IPCA1 score varied from -1.29 to 0.74. The most unstable entries were Bousselam, Setifis, with an IPCA1 score below -5.00, and Waha and Cyprus2, with an IPCA1 score above 7.00 (Figure 1).

Biplot of late planting indicated that years were clearly separated with 2015 being the less favorable (62.1 g/m^2) and 2013 the most favorable (469.9 g/m^2) to grain yield expression (Figure 2).

2013 with an IPCA1 score of 14.79, and 2014, with an IPCA1 score of -8.29 were the most interactive environments.

In 2013, Tajdid and Waha were the lowest yielding entries while Mansoura and Bousselam were the best yielding varieties. In 2014, Bousselam and Mansoura were the least performing, while Megress and Massara were top yielding (data not shown). Based on the genotype main effect, Tajdid, Waha, Cyprus2 and MBB exhibited low yielding ability.

Vitron, Bousselam and Megress expressed a high yielding capacity (Figure 2). Entries with a grain yield mean above average were Vitron, Bousselam, Megress, Moustakbel, Massara, and Setifis. Only Bousselam, Setifis and Massara expressed above average grain yield under both growth conditions of early and late seeding (Figures 1, 2). Boutaleb, MBB and Gaviota were relatively more stable, with an IPCA1 score varying from -1.17 to 1.31. Among these three entries Gaviota had above average grain yield. Unstable entries were Tajdid, Waha and Cyprus2, with an IPCA1 score below -4.00, and Bousselam and Mansoura with an IPCA1 score above 7.00 (Figure 2). As the focus of the present study was genotype × year interaction within seeding date treatments, the biplot analysis confirmed that grain yield was more affected by genotype × year than by genotype × seeding date interactions. Several previous studies also showed that differences among consecutive years are larger than differences among locations and among seeding dates within a region (Coventry et al., 2011; Benin et al., 2014). The genotype × year interaction was greater in the early seeded treatment than in late seeded treatment. Year effect on grain yield variation in both sowing dates was the largest. These results suggested that increased number of testing years is justified more than the number of seeding dates per year. Studying the effects of years, locations and sowing dates on the performance of wheat genotypes, Benin et al. (2014) reported that years and locations contributed more to G×E interaction, explaining 24.3% and 12.5%, respectively; while seeding date contributed less, explaining 7.0% only.

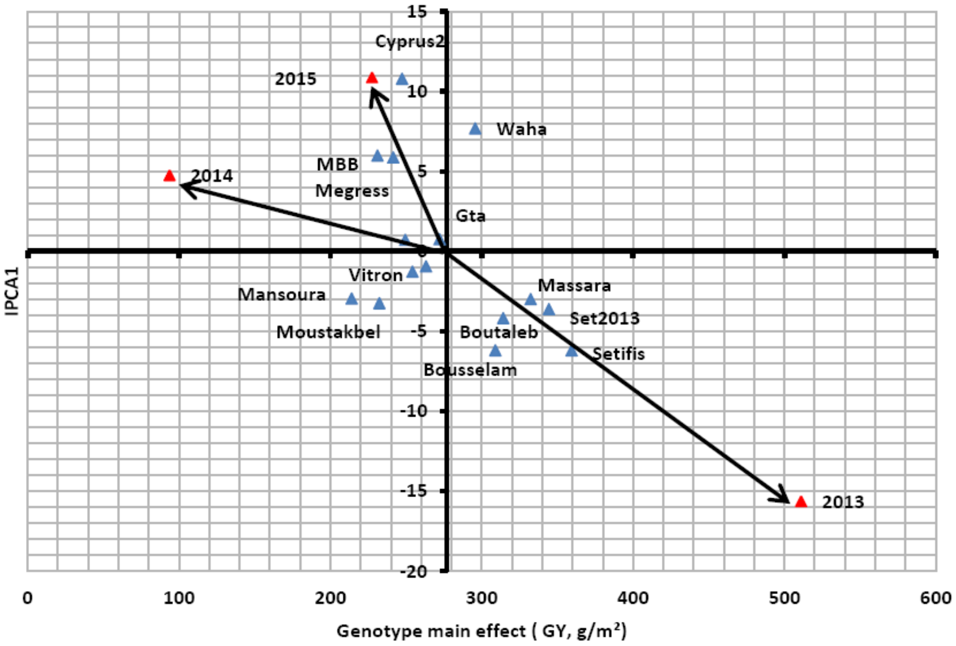

Figure 1. AMMI$_1$ biplot of grain yield for 15 durum wheat genotypes grown under early planting at the ITGC-AES experimental site (Setif, Algeria).

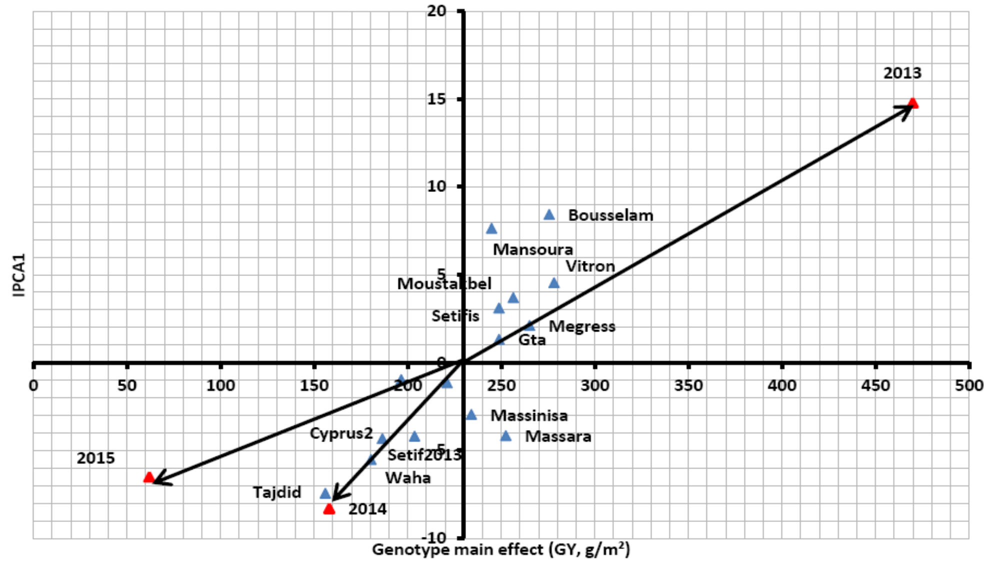

Figure 2. AMMI$_1$ biplot of grain yield for 15 durum wheat genotypes grown under late planting at the ITGC-AES experimental site (Setif, Algeria).

Taking year × seeding date combination as environment, AMMI analysis indicated that G×E interaction is modeled on more than one dimension; with the first three IPCA significant, contributing 56.5%, 35.6% and 5.9 %, respectively (Table 4).

Table 4. AMMI analysis of variance for grain yield of 15 durum wheat genotypes tested in six environments.

Source of variation	df	SS	MS	%SS
Treatment	89	9681034.8	108775.7**	100
Environment (E)	5	8328570.0	1665714.0**	86
Rep/E	12	2113.9	176.2	--
Genotype (G)	14	229351.8	16382.3ns	2.4
G × E	70	1123113.0	16044.5**	11.6
IPCA$_1$	18	634371.0	35242.8**	56.5
IPCA$_2$	16	399735.0	24983.4**	35.6
IPCA$_3$	14	66135.3	4724.0*	5.9
Deviation	22	22872.8	1039.6*	--
Pooled residual	168	34730.3	206.7	--
Total	269	9716090.0		

AMMI2, which explained 92.1% of the sum square of the interaction, indicated that the tested environments classified differently the evaluated genotypes (Figure 3).

Environment E5 was opposed to environment E2, and environment E1 was opposed to E4, E3 and E6 which formed a homogeneous group of environments, classifying similarly the tested genotypes. Based on their high scores, on the IPCA1 and IPCA2, E5, E1 and E2 were the most reactive environments generating interaction. Environment E6 was the least discriminating as indicated by its low score value, also, genotype classification in this environment is similar to the average classification over all environments. Gta durum and Massinissa were the most stable due to their position near the origin (Figure 3). Massara, Setifis, Sétif2013, Bousselam and Boutaleb were best expressed in E1; Waha, Cyprus2 and Tajdid in E5; MBB and Megress in E4 and E3; while Vitron, Mansoura and Moustakbel had high grain yield in E2 (Figure 3). Based on the AMMI2 biplot analysis, most of the tested genotypes expressed specific adaptation. Nominal yield, which helps to apprehend the general adaptability of each cultivar and to identify genotypes that yielded best at specific location IPCA1, classified the tested environment into two recommendation domains. The first recommendation domain is constituted by five environments (E1, E2, E3, E4 and E6) where Setifis was the leading genotype. Environment E5 constituted a separate recommendation domain where cultivar Waha was the winner (Figure 4).

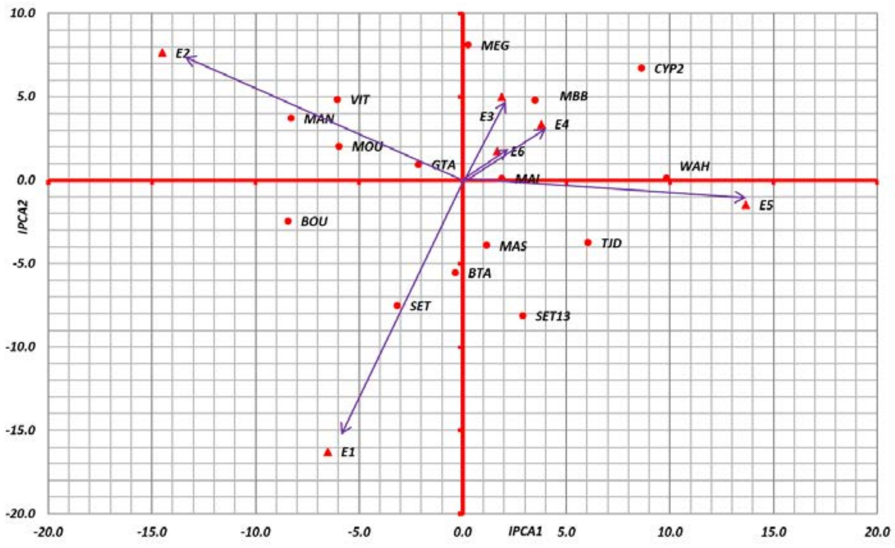

Figure 3. AMMI$_2$-biplot of grain yield for 15 durum wheat evaluated in six environments (Mas= Massara, Set13= Sétif2013 ,Cyp2= Cyprus2, MBB= Mohammed Ben Bachir, WAH= Waha, GTA= Gaviota durum, VIT= Vitron, MEG = Megress, SET= Setifis, BOU= Bousselam, MAN= Mansoura, MAI= Massinissa, TJD= Tajdid, MOU= Moustakbel, BTA= Boutaleb, E1 = early seeding 2013, E2 = late seeding 2013, E3= early seeding 2014, E4 = late seeding 2015, E5= early seeding 2015, E6 = late seeding 2015).

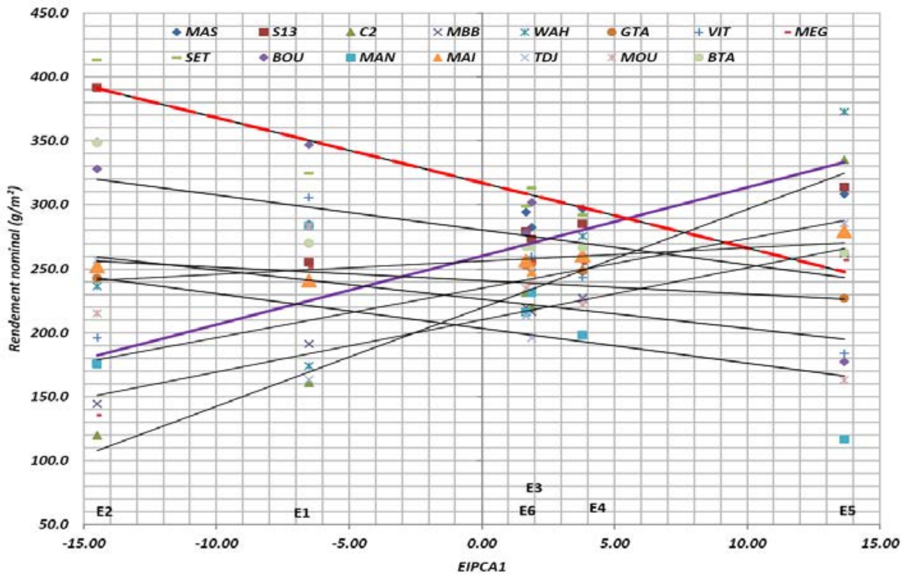

Figure 4. Nominal grain yield variation for 15 durum wheat genotypes evaluated in six environments (Mas= Massara, Set13= Sétif2013 ,Cyp2= Cyprus2, MBB= Mohammed Ben Bachir, WAH= Waha, GTA= Gaviota durum, VIT= Vitron, MEG = Megress, SET= Setifis, BOU= Bousselam, MAN= Mansoura, MAI= Massinissa, TJD= Tajdid, MOU= Moustakbel, BTA= Boutaleb, E1 = early seeding 2013, E2 = late seeding 2013, E3= early seeding 2014, E4 = late seeding 2015, E5= early seeding 2015, E6 = late seeding 2015).

3.2. Traits Implicated in GEI Expression

As genotypic IPCA1 scores summarize a sizeable part of the GEI expressed, any morphological traits significantly correlated with the PC1 scores are causative of GEI. IPCA1 showed negative correlations with 1000-kernelweight ($P < 0.01$) and plant height ($P < 0.05$) indicating that lower height and lower grain weight tended to contribute to GE interaction. Significant correlations existed between IPCA1 scores and thousand-kernel weight (rIPCA1/TKW = -0.452*), between IPCA1 and number of spikes/m² (rIPCA1/SN = -0.500*) and between IPCA1 scores and spikes weight/m² (rIPCA1/SW = -0.479*). These correlations indicated that variation in the expression of these plant traits led some genotypes to achieve a high grain yield in some environments but less so in others. These traits explained 21%, 25% and 23% of grain yield GEI, respectively. These results corroborated findings of Nachit et al. (1992) who mentioned that plant height and fertile tillers explained up to 59% of the manifestation of grain yield GEI in rainfed durum wheat. Mohammadi and

Amri (2013) noted that plant height contributed most to GEI in rainfed durum wheat yield. Van Ginkel et al. (1998) showed the importance of number of spikes/m² in situations in which wheat plants experienced late-season drought stress during grain filling, as this is the case under delayed sowing. Van Eeuwijk et al. (1996) reported that differences in diseases resistance are implicated in the expression GEI in wheat. Yan and Hunt (2001) mentioned that differences in plant height and cycle duration are contributors to grain yield GEI. Consequently, thousand kernel weight, spike number and spike weight could be used as the basis for selecting high yielding genotypes less sensitive to variable environments.

4. Conclusion

The results of the present study show the potential of the optimum planting of durum wheat under semi-arid conditions and the presence of both genotype × year and genotype × seeding date interactions. The combination of year x sowing date, with 86.0%, was the most important source of grain yield variation. Differences among genotypes explained 2.4%, and genotype × environment interaction (G×E) explained 11.6%. Early sowing was more discriminating between genotypes than late seeding environment. High proportion of the G×Y interaction sum square was explained by the IPCA1, under early (77.06%) and late sowing (95.54%) conditions. In general, genotypes with a grain yield mean above average were less stable than those with a grain yield mean below yield average, under early and late sowings. Bousselam and Massara genotypes expressed above average grain yield under both growth conditions of early and late plantings. As year effect on grain yield variation in both sowing dates was the largest, the results suggested that increased number of testing years is justified more than the number of seeding dates per year. IPCA1 scores were negatively correlated with 1000-kernel weight, number of spikes/m² and spikes weight/m², suggesting that variation in the expression of these plant traits led some genotypes to achieve a high grain yield in some environments and low in others. Consequently, thousand kernel weight, spike number and spike weight could be used as the basis for selecting high yielding genotypes less sensitive to environmental variations.

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