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ADDITIVE MAIN EFFECT AND MULTIPLICATIVE ANALYSIS OF SYNTHETIC-DERIVED BREAD WHEAT UNDER VARYING MOISTURE REGIMES

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Abstract

Synthetic-derived bread wheat populations are used as sources of resistance genes for biotic and abiotic stresses. This study used direct field evaluation of synthetic-derived wheat lines to assess grain yield and its associated traits under varying moisture regimes during 2005-06 and 2006-07 at Tel Hadya and Breda, the main research stations of the International Center for Agricultural Research in Dry Areas (ICARDA), Syria. Forty synthetic-derived wheat lines and eight check cultivars were tested in 5 experiments using alpha-lattice design with three replicates at Tel Hadya and Breda, Syria. Additive main effects and multiplicative interactions analysis (AMMI) indicated that the yield of genotypes was under high genotype by environmental interaction. The first two principal component axes (PCA1 and PCA2) were significant ($p \leq 0.01$) and in total contributed 87.6% of the total genotype by environment interaction. We identified some lines bearing *T. tauschii* germplasm with yields equal and superior in some of the yield components to that of the high-yielding cultivars used as checks, thus providing useful material to wheat breeders.

Introduction

The mandate of the bread wheat breeding program at the International Center for Agricultural Research in Dry Areas (ICARDA) is to develop broad-based and high yielding bread wheat germplasm for the developing countries to enhance wheat production worldwide. Erratic environmental stresses are major constraints, responsible for low wheat production. Wild relatives of wheat are useful sources of various biotic and abiotic stresses for bread wheat improvement. The production of synthetic-derived lines through inter-specific hybridization of the original donors of wheat genome is one of the strategies employed at CIMMYT for capturing the desirable characteristics of the *A. tauchii* (Trethowan, 2004). Synthetic-derived lines had higher grain yield than recurrent parents (Del Blanco *et al*., 2001; and Ogbonnaya *et al*., 2007), suggesting that it may result in the transgressive segregation. Some quantitative traits of economic importance were improved through transfer of alleles from synthetic hexaploids into wheat (Del Blanco *et al*., 2001; Van Ginkel & Ogbonnaya 2007).

Analysis of environmental and genotypic factors is always important in plant breeding (Inamullah *et al*., 2006; Jackson *et al*., 1996; Yan & Hunt, 1998). Significance of clustering based on the shifted multiplicative model (SHMM) to field data has proven to overcome the problem of cross over genotype by environment (GE) interactions and to enhance the effectiveness of selection (Abdalla *et al*., 1997). The SHMM method is based on correlation or regression analysis that relates the genotypic and environmental scores derived from principal component analysis of the GE interaction. The GE biplot method for studying the causes of GE interaction is one of the effective techniques (Van Eeuwijk, 1996). The knowledge of GE interaction is needed to ascertain responsiveness and stability of genotypes across environments. The bread wheat breeding program at ICARDA is studying extensively some synthetic-derived wheat lines for identifying high yielding populations.

Although, synthetic hexaploids have been a source of mono-genic and oligo-genic traits, limited data supports their use as a source of quantitative traits for quantitative trait improvement. The specific objectives of this research were to i) interpret GEI obtained by AMMI analysis of yield performance of 48 bread wheat genotypes over five environments, ii) assess yield performance across environments based on the biplot, and iii) determine genotypes with high yield, based on the genotypic responses to environments.

Materials and Methods

Forty synthetic-derived bread wheat lines and eight check cultivars (Table 1) were tested under different levels of moisture in alpha lattice design with three replicates during 2005-06 and 2006-07. Experiments 1 and 2 were grown on March 23, 2006 and February 02, 2006 at Tel Hadya under irrigated and rainfed conditions, respectively. Experiments 3 and 4 were grown on December 3 at Tel Hadya under irrigated and rain-fed conditions, respectively. Experiment 5 was planted on November 14, 2006 at Breda under rain-fed conditions. Hereafter 2005-06 will appear as year-1 and 2006-07 as year-2. Seedling rate was equal to 130 kg ha^{-1}. The soil type at Tel Hadya and Breda are low in organic matter, clays with a pH of 7.8 and 8.2 respectively. Upon severe dryness, it gets cracked. Plots consisted of 8 rows, 2.5 m long and 20 cm between rows. The plots were pre-plant fertilized with 45 kg ha^{-1} N and side dressed with another 45 kg ha^{-1} N. Other nutrients were determined to be sufficient for crop production based on soil test. Weedex, broad-leaf herbicide was applied to effectively control the weeds. Tel Hadya is 284 meter above sea level and between 36°01'N and 36°56'E whereas Breda is 300 meter above sea level and between 35°56'N and 37°10'E. The climate of these regions is semiarid with an average rain shower of 254 mm distributed mainly during winter season. Rainfall in spring is very erratic and usually no rain during summer months.

The SAS software (SAS, 1996) was used to carry out analysis of AMMI on the data of grain yield obtained per plot across environments. PROC GLM of SAS was run to determine genotype by environment interactions. Principal component axes (PCAs) were calculated and statistically tested by F-test procedure (Vargas and Crossa, 2000). These components were used to obtain a biplot, using SAS software.

Results and Discussion

The AMMI analysis of variance for grain yield of 40 synthetic lines and 8 check cultivars in the five environments indicated that 65.4% of the total sum of squares was due to environmental effects, only 12.3% to genotypic effects, and 18.7% to genotype by interaction (GEI) effects (Table 2). It can be inferred from a large sum of squares for environment that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. The value of the GEI sum of squares was 1.5 times larger than that for genotypes, showing that there were significant differences in genotypic response over environments (Inamullah *et al.*, 2006; Nachit *et al.*, 1992).

Table 1. Synthetic-derived wheat populations and check cultivars across five environments during 2005-06 and 2006-07.

Code	Populations/check cultivar
1.	ALTAR 84/AEGILOPS SQUARROSA (TAUS)//OPATA
2.	DVERD-2/AE.SQUARROSA (214)//2*ESDA
3.	CROC-1/AE.SQUARROSA (224)//OPATA
4.	CROC-1/AE.SQUARROSA (205)//2*BCN
5.	CROC-1/AE.SQUARROSA (205)//2*BCN
6.	**HUBARA-9**
7.	REBWAH-3
8.	REBWAH-7
9.	REBWAH-11
10.	REBWAH-13
11.	REBWAH-17
12.	**ATTILA-7**
13.	REBWAH-21
14.	QIMMA-2
15.	QIMMA-3
16.	QIMMA-4
17.	QIMMA-6
18.	**CHAM-6**
19.	QIMMA-8
20.	QIMMA-12
21.	CHEN/AEGILOPS SQUARROSA (TAUS)//FCT/3/STAR
22.	QAFZAH-8
23.	QAFZAH-11
24.	**DEBEIRA**
25.	QAFZAH-13
26.	QAFZAH-18
27.	QAFZAH-23
28.	QAFZAH-26
29.	QAFZAH-32
30.	**GIRWILL-7**
31.	QAFZAH-33
32.	QAFZAH-35
33.	CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ
34.	CROC-1/AE.SQUARROSA (205)//KAUZ/3/SASIA
35.	CROC-1/AE.SQUARROSA (205)//KAUZ/3/SASIA
36.	GIRWILL-9
37.	CROC-1/AE.SQUARROSA (205)//KAUZ/3/ATTILA
38.	CROC-1/AE.SQUARROSA (205)//KAUZ/3/ATTILA
39.	PASTOR/KAUZ/3/CROC-1/AE.SQUARROSA (224)//OPATA
40.	MUNIA/CHTO/3/PFAU/BOW//VEE#9/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN
41.	CROC-1/AE.SQUARROSA (224)//OPATA/3/PASTOR
42.	**KATILA-13**
43.	CROC-1/AE.SQUARROSA (224)//OPATA/3/PASTOR
44.	CROC-1/AE.SQUARROSA (224)//OPATA/3/PASTOR
45.	SKAUZ/BAV92/3/CROC-1/AE.SQUARROSA (224)//OPATA
46.	MILAN/KAUZ/3/URES/JUN//KAUZ/4/CROC-1/AE.SQUARROSA (224)//OPATA
47.	TAM200/TUI//MILAN/KAUZ/3/CROC-1/AE.SQUARROSA (224)//OPATA
48.	**HUBARA-5**

Table 2. Additive main effects and multiplicative interactions analysis of variance for grain yield of 48 genotypes across five environments during 2005-06 and 2006-07.

Source	D.F.	Sum of square	Mean square	Explained (%)
Model	241	469899846.3	1949791.89	
Environments	4	307271596.7	76817899.18	65.391
Genotypes	47	57843292.8	1230708.36	12.310
EXG	188	87777971.7	466904.10	18.680
PCA1	50	56127253.86	1122545.08	63.942
PCA2	48	20734608.32	431971.01	23.622
PCA3	46	7615429.56	165552.82	8.676
PCA4	44	3300679.98	75015.45	3.760
PCA5	42	0	0	
Pool Error	478	145690501.5	304791.8	

The AMMI analysis showed that the first principal component axis (PCA1) of the interaction captured 63.9% of the interaction sum of squares in 26.6% of the interaction degrees of freedom (Table 2). The second principal component axis (PCA2) explained 23.6% of the GEI sum of squares. The sum of squares for genotypes was less than the sums of squares product of PCA1 and PCA2. Mean squares for PCA1 and PCA2 were significant and collectively contributed to 87.6% of the total GEI. The higher PCA's were non-significant. Thus, the first two principal components were helpful to predict the interaction of 48 genotypes in 5 environments and this confirmed the previous findings of Gauch & Zobel, 1996.

In a biplot presentation like Fig. 1, when a genotype or an environment has similar sign on the PCA axis, their interaction is positive; if different, their interaction is negative. If a genotype or an environment has a PCA score of nearly 0, it has small interaction effects, fits well by an additive model. Fig. 1 displays both main effects and interaction. For example, synthetic-derived lines 46 and 37 differ in main effects but not in interaction, whereas synthetic-derived line 46 differs from synthetic-derived line 3 only in interaction since the PCA score differs but mean yields do not. It can easily be seen that synthetic-derived lines 46 and 4 differ both in main and interaction effects. Three of the five environments differ in main effects but not in interaction effects whereas their interaction with other two environments is negative. Both years, there was positive interaction between irrigated and rain-fed experiments whereas the experiment in year-1 had negative interaction with year-2 experiments. Mean grain yield of irrigated experiments across two years at Tel Hadya was 1881 kg ha^{-1} while mean grain yield of experiments under drought conditions was 1871 kg ha^{-1}. It can be extracted from the non-significant differences between mean grain yields of irrigated versus rain-fed environments across two years at Tel Hadya that supplemental irrigation did not cause any significant increase in grain yield or synthetic-derived lines tended to realize similar genetic potential in favorable and unfavorable environments.

A biplot is generated using genotypic and environmental scores of the first two PCAs (Vargas and Crossa, 2000). A biplot has four sections, depending on signs of the genotypic and environmental scores. The genotypes that fell on the vertexes were high yielding in their respective environment/s. In Fig. 2, the best synthetic-derived lines with respect to environment E1 were 20 and 4. Synthetic-derived lines 19 and 14 were best for environment E2. For environments E3 and E4 best synthetic-derived lines were 11, 43 and 26. Synthetic-derived lines 17 and 20 were best for environment 5. Synthetic-derived lines 21, 32, 44 and two check cultivars ('KATILLA-13' and 'HUBARA-5') appeared stable genotypes as these genotypes were close to origin.

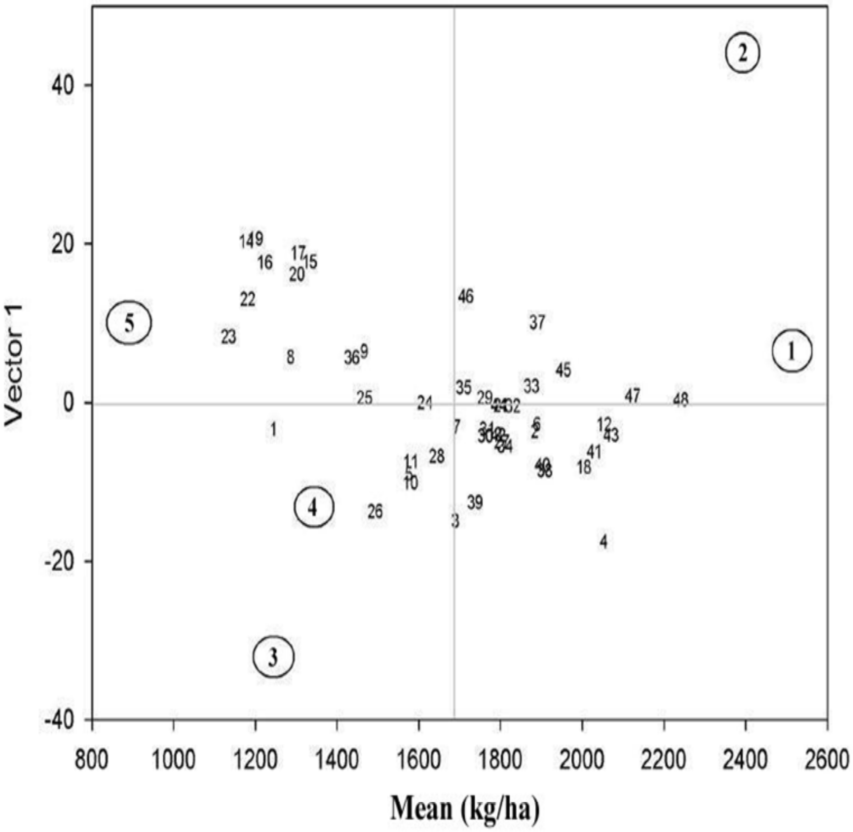

Fig. 1. Biplot of the AMMI model for grain yield (kg ha^{-1}) of 48 genotypes across five environments during 2005-06 and 2006-07. (Genotype and environment codes are given in Materials and Methods).

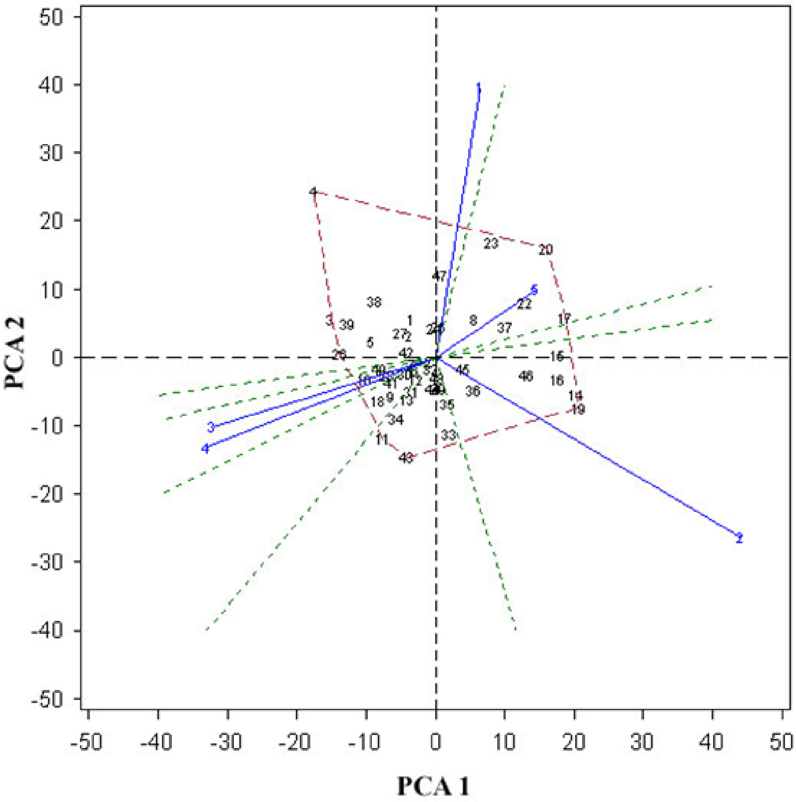

Fig. 2. Biplot of 48 genotypes and five environments for grain yield using genotypic and environmental scores during 2005-06 and 2006-07.

Conclusion

AMMI clearly indicated genotypes with narrow adaptability while others with superior performance in all environments. The interaction of the 48 genotypes was best predicted by the first two principal components of genotypes and environments. Thus, biplots generated using genotypic and environmental scores of the first two AMMI components can help breeders to understand behavior of the genotypes, environments and their interactions. We identified some lines bearing *T. tauschii* germplasm with stable performance and yields equal to that of the high-yielding cultivars used as checks, thus providing useful material to wheat breeders.

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