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Additive Main Effects and Multiplicative Interactions (AMMI) Analysis of Grain Yield in Barley Genotypes Across Environments

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ABSTRACT

The study was carried out to analyze grain yield performances of nine varieties and sixteen advanced barley genotypes across eight environments of Southeastern Anatolia, Turkey, between 2003-2007 growing seasons. The experimental layout was randomized complete block design with four replications. Additive main effects and multiplicative interactions analysis (AMMI) revealed that the yield performances of genotypes were under the main environmental effects of genotype by environmental interactions. The first two principal component axes (IPCA 1 and IPCA 2) were significant ($P < 0.01$) and cumulatively contributed to 61.07% of the total genotype by environmental interaction. According to the AMMI biplot analysis, genotype G17 and G21 had the desirable characteristics of high or moderate stability with high grain yield and were thus recommended for commercial release in Turkey and genotypes G7, G9 and the G8 proved to be valuable sources for yield stability in barley breeding programs.

Keywords: AMMI analysis; Barley; Biplot analysis; Grain yield; Stability

Arpa Genotiplerinde Çevreler Üzerinden Tane Verimlerinin Eklemeli Ana Etkiler ve Çarpımsal İnteraksiyonlar Analizi

ESER BİLGİSİ

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ÖZET

Bu çalışma, 16 ileri hat ve 9 arpa çeşidinin 8 çevrede verim performanslarını belirlemek amacıyla 2003-2007 yılları arasında yürütülmüştür. Denemeler, tesadüf blokları deneme deseninde 4 tekerrürlü olarak kurulmuştur. Eklemeli ana etkiler ve çarpımsal interaksiyonlar analizi (AMMI), genotip \times çevre interaksiyonunda genotiplerin verim performansları üzerine çevresel etkilerin baskın olduğunu göstermiştir. İlk iki ana bileşen eksenini (PCA 1 ve PCA 2), istatistiksel olarak önemli ($P < 0.01$) bulunmuş ve genotip \times çevre interaksiyonunun % 61.07'sini açıklamıştır. AMMI modeli esas alınarak yapılan biplot analizlerinden elde edilen bulgular: (1) orta veya yüksek stabilite ile birlikte yüksek tane verimine sahip olmaları sebebiyle G17 ve G21 genotipleri Türkiye'de tescile teklif edilmiştir; (2) G7, G9 ve G8 genotiplerinin verim stabilitesi bakımından arpa ıslah programları için önemli bir kaynak oldukları tespit edilmiştir.

Anahtar Kelimeler: AMMI analizi; Arpa; Biplot analizi; Tane verimi; Stabilite

1. Introduction

Barley (*Hordeum vulgare* L.) is the second important cereal crop of Turkey and accounts for about 25% of the total cereal production (SAP 2010). In South-Eastern Anatolia, barley has been cultivated for many years and has a significant role. It is also grown mainly on rainfall conditions, but genotype \times environment interaction (GEI) restricts the progress in yield improvement under rainfed and unpredictable climatic conditions. Thus, experimental research needs to be carried out over multiple environment trials in order to identify and analyse the major factors that are responsible for genotype adaptation and final selection (DeLacy et al 1996; Öktem et al 2004; Özcan et al 2005; Akcura et al 2006). GEI is an important for plant breeders and agronomists and the stability is mostly used to characterize a genotype, which specified a comparatively stable yield and not affected to changing environmental conditions. In barley improvement activities and in many aspects of barley research, the analysis of GEI is of primary importance, as it is also for other crops (Ceccarelli 1996; Annicchiarico 2002; Voltas et al 2002). The stability methods can be divided into two major groups: parametric (univariate and multivariate) and non parametric stability measures. The main problem with univariate and nonparametric stability statistics is that they do not provide an accurate picture of the complete response pattern, because of the multivariate nature of the genotype's response to varying environments (Lin et al 1986). Therefore, using multivariate statistics such as the AMMI model is more useful than univariate stability methods for explanation GEI. The AMMI model ensures a multivariate analytical parameter for interpreting GEI (Crossa et al 1990; Ebdon & Gauch 2002).

When main effects and interaction are both important, AMMI is the model of first choice to improve accuracy of yield estimates (Zobel et al 1988). AMMI method combines ANOVA and principal component analysis (PCA) into a united approach. The most important feature of this analysis is that adjustment is carried out using information from other locations to refine the estimates within

a given location (Sadeghi et al 2011). It removes residual or noise variation from GEI (Crossa et al 1990). It has no specific experimental design requirements, except for a two-way data structure (Zobel et al 1988). The effectiveness of AMMI procedure has been widely applied by many authors (Zobel et al 1988; Yan & Rajcan 2002; Yan et al 2001; Kaya et al 2002; Muhe & Assefa 2010; Wieslaw et al 2011; Mahalingam et al 2006; Ilker et al 2009; Banik et al 2010; Bantayehu 2009; Rodriguez et al 2007). Therefore, the objectives of the study were to (i) explicate GEI obtained by AMMI analysis of yield performances of twenty five barley genotypes over eight environments, (ii) visually evaluate variation of yield performances across environments based on the biplot and (iii) determine genotypes with high grain yield stability.

2. Material and Methods

The study was carried out to determine the yield performances of twenty five barley genotypes across eight environments, including five rain-fed environments and three irrigated environments. The agro-ecological characteristics of the locations are shown in Table 2. Sixteen of the twenty five genotypes were advanced genotypes that were obtained from the ICARDA (International Center for Agricultural Research in the Dry Areas), and nine were modern varieties that were chosen from those evaluated in national variety trials and recommended for the south eastern Anatolia, except for Beecher, Assala-04, W12291 and Moroc 9 - 75, which have never been commercialized in Turkey. The name and code of genotypes are given in Table I.

The experiment was conducted using randomized completely block design (RCBD) with four replicates. The experimental plots consisted of six rows, each five m in length with twenty cm row spacing. The seeding density was four hundred seeds m^{-2} . All test plots were sown in the fall (November), which is the optimal sowing time for barley in the trial areas. The growing seasons, soil properties, amount of rainfall together with supplementary irrigation and details of fertilizer application at each

Table 1- Name or pedigree, code number and mean grain yield in 8 environment of barley genotypes used for AMMI analysis

Çizelge 1- AMMI analizine esas kullanılan arpa genotiplerinin isim, pedigrisi, kod numaraları ve sekiz çevreye ait tane verim ortalamaları

Code	Pedigree and selection history	Origin	Yield (t ha ⁻¹)
G1	Hml02/Arabi Abiad//ER/Apm/3/Belford Barley/Carben//Ms237 ICB89-0014-5LAB-1AP-0TR-0AP-5AP-0AP-4AP-8AP-0AP	IBYT-MRA	5.929
G2	Lignee527/Chn-01//Lignee527/As45 ICB93-0813-0AP-5AP-0AP	IBYT-MRA	5.562
G3	Hma-02//11012- 2/CM67/3/Arar/PI386540//Giza121/Pue ICB93-0247-0AP-9AP-0AP	IBYT-MRA	5.514
G4	<i>Beecher</i>	USA	5.209
G5	<i>Şahin-91</i>	TURKEY	4.938
G6	<i>Assala-04</i>	ICARDA	4.990
G7	SLB15-05/4/H.spont.96-3/3/Roho//Alger/Ceres362-1-1 ICB93-0700-0AP-10AP-0AP	IBYT-MRA	5.989
G8	<i>WI2291</i>	USA	6.024
G9	Alanda/4/Arar/3/Mari/Aths*2//M-Att-73-337-1 ICB94-0512-14AP-0AP	IBYT-MRA	6.085
G10	<i>Sur-93</i>	TURKEY	5.170
G11	F2cc33ms/Ci07555//Alanda ICB93-0436-0AP-2AP-0AP	IBYT-MRA	6.105
G12	Rhn/Lignee527/3/Hma-02//11012-2/CM67 ICB93-0251-0AP-10AP-0AP	IBYT-MRA	5.135
G13	Hm02//110122/CM67/6/CI01021/4/CM67/U.Sask.1800//Pro/C ICB94-0564-40AP-0AP	IBYT-MRA	5.880
G14	Unknown	-	5.382
G15	<i>Tokak - 157/37</i>	TURKEY	4.465
G16	Arar/PI386540//Giza121/Pue/3/Lignee527//Chn-01ICB93-0394-0AP 3AP-0AP	IBYT-MRA	5.524
G17	Arta/4/Arta/3/Hml-02//Esp/1808-4L ICB96-0601-0AP-10AP-0AP (Altikat)	IBYT-LRA-M	6.075
G18	Erdorado/4/ROD586/Nopal's'3/PmB/Aths//Bc ICB93-0932-0AP-1AP-0AP	IBYT-LRA-M	5.703
G19	Hml-02//WI2291/Bgs ICB83-1554-1AP-1AP-6AP-0AP-6AP-0AP	IBYT-LRA-M	5.443
G20	<i>Vamikhoca - 98</i>	TURKEY	5.753
G21	Hml-02//WI2291/Bgs (Samyeli) ICB83-1554-1AP-1AP-6AP-0AP-22AP-0AP	IBYT-LRA-M	6.076
G22	805145/Hma01/6/805132/4/Bera's'/Cel//Oksam/3/Ore's'/5/Glori ICB93-0209-0AP-5AP-0AP	IBYT-LRA-M	5.179
G23	<i>Moroc9 - 75</i>	ICARDA	6.716
G24	Moroc9-75/WI2291/WI2269 ICB93-1132-0AP-32AP-0AP	IBYT-LRA-M	5.467
G25	<i>Akhisar -98</i>	TURKEY	5.711
	Mean		5.601
	LSD _(0.05)		0.326

IBYT-MRA, international barley yield trials Moderate Rainfall Areas (ICARDA); IBYT-LRA-M, low rain fall areas (mild winter) (ICARDA), genotypes name in italics and bolds are variety; Means followed by same letter (or no letter) do not differ significantly at $P < 0.05$ using LSD

Table 2- Data on experiment, soil properties and climate for environments where the experiments were conducted*Çizelge 2- Denemelerin yürütüldüğü çevrelere ait toprak ve iklim özellikleri*

Code	Growing seasons	Environments	Soil properties	Fertilization (kg ha ⁻¹)		Rain-fall (mm)	Irrigation (mm)	Yield (t ha ⁻¹)
				N	P ₂ O ₅			
E1	2003 - 04	Diyarbakır (rainfed)	pH = 7.58 clay-silt	50 ^a +30 ^b	50 ^a	539.9	-	6.03
E2	2004 - 05	Diyarbakır (rainfed)	pH = 7.43 clay-silt	50 + 30	50	389.4	-	6.11
E3	2004 - 05	Diyarbakır (irrigated)	pH = 7.61 clay-silt	60 + 40	60	389.4	50	6.40
E4	2005 - 06	Diyarbakır (rainfed)	pH = 7.50 clay-silt	50 + 30	50	540.5	-	6.09
E5	2005 - 06	Diyarbakır (irrigated)	pH = 7.69 clay-silt	60 + 40	60	540.5	50	6.30
E6	2006 - 07	Diyarbakır (rainfed)	pH = 7.30 clay-silt	50 + 30	50	534.2	-	4.73
E7	2006 - 07	Diyarbakır (irrigated)	pH = 7.43 clay-silt	60 + 40	60	534.2	50	4.72
E8	2006 - 07	Mardin (rainfed)	pH = 7.58 clay-silt	40 + 30	40	319.0	-	4.45

^a, seed bed; ^b, stem elongation

location during the growing period are given in Table II. All agronomic application such as weed control and fertilization were practiced uniformly except irrigation which was only applied to experiment conducted under irrigated conditions.

Combined analysis of variance was carried out for all the tested environments and then genotype × environment interaction was partitioned according to AMMI model in accordance to Gauch & Zobel (1996). The larger the PCA scores, either negative or positive, the more specifically adapted a genotype is to certain environments; the smaller the PCA scores, the more stable the genotype is over all environments studied (Bantayehu 2009). AMMI analysis combines ANOVA and principal component analysis (PCA) into a single model with additive and multiplicative parameters. All statistical analysis was carried out using the SAS (Statistical Analysis Systems) program (SAS Institute 1999).

3. Results and Discussion

The AMMI analysis of variance of grain yield (t ha⁻¹) of the twenty five genotypes tested in eight environments demonstrated that 56.76% of the total sum of squares was attributable to environmental effects, only 22.19% to genotypic effects and 21.05% to GEI effects (Table III). Results from AMMI analysis (Table III) also

indicated that the IPCA 1 of the interaction captured 40.42% of the interaction sum of squares in 17.85% of the interaction degrees of freedom. Moreover, IPCA 2 explained a further 20.66% of the GEI sum of squares. The mean squares for the IPCA 1 and IPCA 2 were significant at $P < 0.01$ and cumulatively contributed to 61.07% of the total GEI. The model was adequate enough to explain the total genotype × environment interaction component. Besides, Yan & Rajcan (2002) reported that the GT (genotype-by-trait biplot) for each of the six years explained 52 to 63% the total variation of the standardized data. Also, the prediction assessment showed that AMMI with only two interaction principal component axes was the best predictive model (Zobel et al 1988) and had 58 degrees of freedom. Further interaction principal component axes captured mostly noise and therefore, did not help to predict validation observations (Mekonnen & Mohammed 2010). Thus, the interaction of the twenty five genotypes with eight environments in this study was predicted by the first two principal components of genotypes and environments.

The IPCA scores of a genotype provide indicators of the stability of a genotype across environments (Purchase 1997). The inferences drawn from biplots will be valid only when the IPCA or the first two

Table 3- AMMI analysis for grain yield (t ha⁻¹) of 25 genotypes evaluated in 8 environments

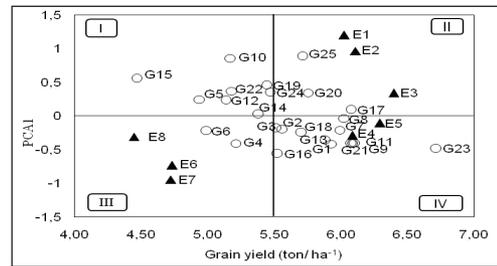
Çizelge 3- Tane verimi açısından 25 adet genotipin değerlendirildiği 8 çevreye ait AMMI analizi

Source	DF	Sum of square	Mean of squares	F Ratio	Explained (%)
Model	202	821.459363	4.066631	8.62	
Environment	7	465.4137839	66.4876834	141.01 **	56.76
Genotype	24	181.9141563	7.579756	16.08 **	22.19
G × E	168	172.6322317	1.0275728	2.18 **	21.05
Interaction PCA 1	30	69.7826	2.32609	4.93327 **	40.4227
Interaction PCA 2	28	35.6583	1.27351	2.70092 **	20.6556
Interaction PCA 3	26	29.0459	1.11715	2.36930**	16.8253
Interaction PCA 4	24	16.3707	0.68211	1.44665	9.4830
Interaction PCA 5	22	13.9706	0.63503	1.34679	8.0927
Interaction PCA 6	20	4.3102	0.21551	0.45707	2.4968
Interaction PCA 7	18	3.4940	0.19411	0.41168	2.0240
Interaction PCA 8	16	0.0000	0.00000	0.00000	0.0000
Pooled Error	597	281.491634	0.471510		
C. Total	799	1102.950997			
	CV (%): 12.25		R ² : 74.4		

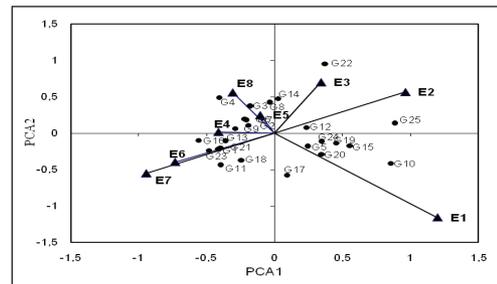
** , P < 0.01 probability level; DF, degree of freedom; F, tabulated frequency; CV, coefficient of variation; R², correlation coefficient of multiple determination

IPCA1 explain maximum interaction variation. Also, biplots are commonly used to explain AMMI results considering one or two PCAs at a time. Plant breeders would like to identify varieties which are stable and high yielding when more than two PCA axes are retained in the AMMI model which cannot be explained with the help of biplots (Hanamaratti et al 2009), in general, factors like type of crop, diversity of the germplasm, and range of environmental conditions will affect the degree of complexity of the best predictive model (Crossa et al 1990).

In Figure 1, the IPCA1 scores for both the genotypes and environments were plotted against the grain yield for the genotypes and the environments and in Figure 2, the IPCA1 scores for both the genotypes and environments were plotted against the IPCA2 scores for the genotypes and the environments. In the biplot, the broken vertical line passing through the center of the biplot was the grand mean (5.601 tone ha⁻¹) of the experiment, and the solid horizontal line passed through at the IPCA1 axis score = 0. The IPCA1 was highly significant and explained the interaction pattern better than other interaction axes. The mean genotypes or environments in AMMI model 1 biplot located on the same parallel line, relative to the ordinate, have similar yield, while those located on the right side of

**Figure 1- Biplot analysis of GEI based on AMMI 1 model for the PCA1 scores and grain yield**

Şekil 1- Tane verimi ve PCA 1 skoru için AMMI 1 modeli esaslı GEI biplot analizi

**Figure 2- Biplot analysis of GEI based on AMMI 2 model for the first two interactions principal component scores**

Şekil 2- İlk iki ana bileşen interaksiyonlarına ait AMMI 2 modeli esaslı GEI biplot analizi

the center of the axis has higher yields than those on the left hand side (Banik et al 2010).

The AMMI model 1 biplot of the barley genotypes was demonstrated in Figure 1. The environments demonstrated much variability in both main effects and interactions. In the biplot, nine barley genotypes (G7, G8, G9, G11, G13, G17, G18, G20, G21, G23 and G25) and five environments (E1, E2, E3, E4 and E5) located at the right side of the grand mean were considered as high yielding genotypes and environments while their corresponding low yielding counterparts were located at the left side of the grand mean (Figure 1). In addition, the high potential environments were distributed evenly in quadrant II (E3) and IV (E4 and E5) with minimum interaction effects, while the high potential environments were sparsely distributed in quadrants II (E1 and E2) with high IPCA1 values. The lowest yielding environments, E6 and E7 demonstrated the high IPCA1 scores. This biplot also indicated E3 as the highest yielding environment.

The relative contributions of barley genotypes to GEI sum square were represented by the magnitude of the respective IPCA score, which in turn determined their position in the biplot. Barley genotypes (G10, G15, G16, G19 and G25) located far from the IPCA axis contributed more to the GEI sum square than other genotypes that were located either on or closer to IPCA1 axis = 0 (Figure 1). Barley genotypes (G2, G3, G7, G8, G14 and G17) had IPCA score value closer to zero, and were classified as highly stable whereas the IPCA scores of cultivars (G1, G4, G5, G6, G9, G11, G12, G18, G20, G21, G22, and G24) were moderately large, and these group of barley genotypes could be classified as less stable. Consequently, AMMI 1 model analysis of barley genotypes produced three categories of responses: (1) most stable and high yielding genotypes G17, G8 and G7, (2) less stable and high yielding genotypes, G21, G23, G11 and G9, and (3) most stable and low yielding genotypes, G2, G3, G14, G12 and G5 (Figure 1).

However, for the AMMI 2 model, PCA2 scores was considered in interpreting GEI that captured

20.07% of the interaction sum of squares as suggested by Gauch & Zobel (1996). The AMMI model 2 biplot of the genotype trials was demonstrated in Figure 2. A biplot is generated using genotypic and environmental scores of the first two AMMI components (Vargas & Crossa 2000). As IPCA2 scores also have a significant role in explaining the GEI, the IPCA1 scores were plotted against the IPCA2 scores for further explore adaptation (Figure 2). Moreover, when IPCA1 was plotted against IPCA2, Purchase (1997) explained that the closer the genotypes score to the center of the biplot, the more stable they are. According to this figure, G2, G7, G6, G9, G3, G8, G14, G12 and G5 were close to the center and were considered to have high grain yield stability. A little further from the origin were the genotypes G24, G19, G20, G17, G18, G1, G21 G13 and G23 which may be considered to have medium stability. On the other hand, the genotypes G15, G11, G4, G22, G25 and G10 are unstable due to their dispersed position. Also, biplot analysis (Figure 2) displayed that genotype G10, G25 and G22 and environment E1, E2 and E7 have the greatest effect in the GE interaction. Genotype number G25 has specific adaptation with environment E2, while genotype number G10 has specific adaptability with environment E1 and genotype G22 has specific adaptation with environment E3. The accessions G1; G2, G14, G16, G23, G11 and G18 have positive interaction with environment E6 and E7. Genotype G6, G7, G3, G8, G14 and G4 have positive interaction with environment E8, but as the length of the vector for genotype 4 is more on the environment E8, hence it has specific adaptability with environment E8. The genotype G5, G20, G24, G19, G15 and G10 have positive interaction with environment E1. The underlying causes of the interaction observed can therefore be based on both the genetic differences between these genotypes and the different in environments (Wallace et al 1995).

4. Conclusions

The analysis of variance for the AMMI model of grain yield showed that genotypes, environments, genotype x environments interaction and AMMI

components 1 and 2 were significant. Thus, both yield and PCA1 and PCA2 scores should be taken into account simultaneously to utilize the useful effect of GEI and to make recommendation of the genotypes more accurate. It showed that the GEI was an important source of barley yield variation and its biplots were powerful enough for visualizing the response patterns of genotypes and environments. The variety G23 (Moroc9-75) ranked first in grain yield but tended to be unstable. Genotype G7, G9, G8, and G17, namely Altıkat, the best yielding among the studied genotypes showed high yield stability, while G2 and G3 were moderately yielding and high stable genotypes. Genotypes G17, G1, G21 and G13 were high yielding and moderate stable genotypes. Genotype G18 and G20 were moderately yielding and moderate stable genotypes. E5 (Diyarbakır irrigation) environment was the best for testing barley genotypes.

As a result, advanced line G17 and G21 were ideal candidates in this regard as they had high or moderate stability with high grain yield and desirable quality with acceptable morphological traits. These genotypes, namely Altıkat and Samyeli cultivar respectively, proposed for registration were approved for spring coast regions of Turkey. Also, genotypes G7, G9 and variety G8 (W12291) identified to be a valuable source for yield stability in barley breeding programs.

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Abbreviations and Symbols

AMMI	additive main effects and multiplicative interactions
PCA	principal component analysis (axes)
E	environment
G	genotype
GEI	genotype environment interaction

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