Research Article/*Araştırma Makalesi*

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AKDENİZ ÜNİVERSİTESİ
ZİRAAT FAKÜLTESİ DERGİSİ
(2012) 25(2): 117-121

Additive main effects and multiplicative interactions analysis of yield in popcorn (*Zea mays everta* L.) hybrids

Cin mısır (*Zea mays everta* L.) hibritlerinde tane veriminin eklemeli ana etkiler ve çarpımsal interaksiyonlar analizi

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ARTICLE INFO

Received 25 May 2012
Received in revised form 27 November 2012
Accepted 30 November 2012

***Keywords*:**

Popcorn
Hybrid
Genotype by environment interaction
AMMI analysis

ABSTRACT

This study was conducted to investigate the yield performances of 14 popcorn hybrids across four environments representing four different geographical regions of Turkey. The experiment was conducted as a randomized complete block design with three replications. The analysis of variance showed that genotype (G), environment (E) and genotype by environment interactions (GEI) were highly significant and captured 12.9 %, 67.9 % and 19.2 % sum of squares, respectively. For explaining GEI effect on yield and generating knowledge about stability of the hybrids, additive main effects and multiplicative interactions analysis (AMMI) was used. A biplot graph of 14 popcorn hybrids and four environments for yield using genotypic and environmental scores constructed from the first two AMMI terms was a useful picture to see overall genotype and environmental situations According to the results of the biplot graph, some genotypes performed better on some specific environments than others. G1 was selected for its stability across the environments. Besides, G2, G3, G4 and G6 popcorn candidate hybrids can be considered as promising due to their yield performances.

MAKALE BİLGİSİ

Alınış tarihi 25 Mayıs 2012
Düzeltilme tarihi 27 Kasım 2012
Kabul tarihi 30 Kasım 2012

***Anahtar Kelimeler*:**

Cin mısır
Hibrit
Genotip çevre interaksiyonu
AMMI analizi

ÖZ

Bu araştırma, 14 adet cin mısır melezinin dört farklı coğrafik bölgede verim performanslarını belirlemek amacıyla yapılmıştır. Çalışma tesadüf blokları deneme desenine göre 3 tekerrürlü olarak yürütülmüştür. Genotip, çevre ve genotip x çevre interaksiyonları yapılan varyans analizinde önemli olarak bulunmuş ve kareler toplamı değerleri sırasıyla % 12,9, % 67,9 ve % 19,2 şeklinde saptanmıştır. Genotip x çevre interaksiyonunun verim üzerine olan etkisini açıklamak ve hibritlerin stabilite durumları hakkında bilgi elde etmek için eklemeli ana etkiler ve çarpımsal interaksiyonlar analizi (AMMI) kullanılmıştır. İlk iki AMMI öğesinin genotip ve çevresel değerlerinden hesaplanarak oluşturulan biplot grafiği genotip ve çevreler hakkında yararlı bilgiler vermiştir. Analize göre, genotipler arasında G1 aday çeşidi bütün çevreler dikkate alındığında en stabil genotip olarak saptanmıştır. Ayrıca, G2, G3, G4 ve G6 kodlu aday genotipler ümitvar melezler olarak değerlendirilmiştir.

1. Introduction

Popcorn is a specialty-corn type that is increasing importance in the worldwide. A major trait that distinguishes the popcorn from other types of maize is the formation of large flakes after kernel popping as a response to the heat treatment (Pajic 2007). Especially, shape and size of commercially produced popcorn kernels can be visually realized. It can be generally classified into two primary types: pearl or rice. Pearl types have smooth, rounded pearl-like crowns, while rice types are pointed. Popcorn has a hard, flinty endosperm that surrounds a small amount of soft moist starch in the center (Dickerson 2003; Pike 2003).

As it is one of the most favored snack foods in the world as well as in Turkey, the production and consumption of popcorn is getting increase. Grain yield per area is a very economically important trait in the popcorn production. However, it is a quantitative trait that is mostly affected by the environment. Therefore, breeding popcorn hybrids that have good yield potential and able to perform well in different environmental conditions is essential for breeders to meet grower demand.

Crop breeders have been striving to develop genotypes with superior grain yield, quality and other desirable characteristics over a wide range of different environmental conditions. Genotype x environment interaction (GEI) is one of the main complications in the selection of broad adaptation in most breeding programs (Issa 2009). Hence, it is important to know not only average performance of the genotypes but also magnitude of the GEI in the selection. Depending upon the magnitude of the interactions or the differential genotypic responses to environments, the varietal rankings can differ greatly across environments (Kaya et al. 2002).

Several statistical methods have been developed to analyze GEI and yield stability across environments. Additive main effects and multiplicative interactions analysis (AMMI) is considered to be an effective model for explaining GEI, because it accounts large portion of interaction some of squares (SS) (Zobel et al. 1988). Results from the AMMI analysis and the graph usually called biplot (Gabriel 1971) that is generated from genotypic and environmental scores are useful for breeders in the decision of the genotypes either for further evaluation or for cultivar recommendations. Studies on different plant types and environments showed that the AMMI analysis is a good model for evaluation of GEI across environments (Kaya et al. 2002; Ebdon and Gauch 2002; Tarakanovas and Ruzgas 2006; Naveed et al. 2007; Ilker et al. 2009; Anandan et al. 2009; Arulselvi and Selvi 2010; Sadeghi et al. 2011) . Since, type of crop, diversity of the germplasm under evaluation and environmental conditions can affect the degree of the complexity of the GEI and also the best predictive model of the AMMI analysis (Crossa et al. 1990), the present study may help in the understanding of GEI effect on yield of popcorn hybrids developed and grown in Turkey.

The objectives of the study were to (i) analyze GEI by AMMI analysis of yield performances of 14 popcorn hybrids over 4 environments, (ii) determine the hybrids that are stable across environments with high yield performance and (iii) find out the best hybrids under evaluation for each environment.

2. Materials and Methods

In the present study, eleven developed single crosses and three commercial checks (Antcin-98, Elacin and Turkpop) were tested. Crosses obtained in 2010 and single crosses that have sufficient seed were tested in 2011. Genotypic codes, short pedigree and definition of the hybrids were given in Table 1. The locations represent four different geographical regions of Turkey and most of popcorn production is done in these environments (Table 2).

Experiments were conducted in a randomized complete block design with three replications. Plots consisted of four rows, 5 m long and row spacing was 0.7 m. Border rows were also included to eliminate border effects. After emergence, plants were thinned to approximately 0.2 m. Fertilization and plant protection measures were done according to local recommendations. Nitrogenous fertilizer was applied 2 times as 10 kg before sowing and 10 kg at the fifth leaf stage.

A program developed by Hernandez and Crossa (2000) was used to compute the AMMI model and the biplot of multi-environment trials in SAS software (1999). In the program, PROC GLM was performed for quantifying genotype by environment interactions. For each genotype and environment, PROC IML procedures applied to the data in order to obtain genotypic and environmental scores. Once the results of the AMMI are obtained using IML, the information was used for computing the Gollob (1968) F-test and for obtaining the biplot.

Table 1. Genotypic codes, short pedigree/origin numbers and definition of the hybrids used in the study.

Genotypic code	Pedigree/Origin	Definition of the hybrids
G1	AntCin-10971	Experimental hybrid
G2	AntCin-10972	Experimental hybrid
G3	AntCin-10973	Experimental hybrid
G4	AntCin-10974	Experimental hybrid
G5	AntCin-10975	Experimental hybrid
G6	AntCin-10976	Experimental hybrid
G7	AntCin-10977	Experimental hybrid
G8	AntCin-10978	Experimental hybrid
G9	AntCin-10979	Experimental hybrid
G10	AntCin-10980	Experimental hybrid
G11	AntCin-10981	Experimental hybrid
G12	Antcin-98	Commercial Check
G13	Elacin	Commercial Check
G14	Turkpop	Commercial Check

3. Results and Discussion

Mean yield of the genotypes over environments were presented in Table 3. Due to the environmental conditions yield of the genotypes changed in different locations. Therefore, genotype by environment interaction needed to be analyzed.

The AMMI analysis of variance of yield (t ha^{-1}) of the 14 popcorn hybrids tested in 4 different environs showed that mean squares environments, genotypes and genotype x environment interactions were significant (Table 4). Environments captured 67.9 % of the total sum of squares, genotypes 12.9 % and GEI 19.2 %. The high percentage of environment effect indicated that the environments were diverse and caused great variation in yield of the tested genotypes. GEI sum of squares were larger than that of genotypes and showed that there were genotypic responses to the environments.

The AMMI analysis generated four interaction principle component axes (IPCA). The results showed that the first (IPCA 1) AMMI term accounted 65.47 % of the interaction sum of scores, while the second (IPCA 2) accounted 33.86. The mean scores of the first two AMMI terms were significant at $P<0.01$ level and these terms captured nearly the entire sum of squares of genotype x environment interaction. Zobel et al. (1988) determined that the first two interaction principle component axes were the best predictive model for AMMI. Furthermore, similar results from different researchers (Kaya et al. 2002; Tarakanovas and Ruzgas 2006; Ilker et al. 2009; Arulselvi and Selvi 2010) indicated that first two AMMI terms are sufficient models for prediction the AMMI. Further interaction principal component axes captured noise and were not useful for validation of the model. Therefore, interaction of the 14 popcorn hybrids with four diverse environments was predicted using first two AMMI terms.

Principle component axes of 14 popcorn hybrids and four environments for yield using genotypic and environmental scores was constructed using the first two AMMI terms was shown in Figure 1. Genotypic and environmental scores can be

Table 2. Description of the environments.

Environment	Code	Geographical region	Latitude	Longitude	Climatic conditions	Soil properties
Konya	E1	Central Anatolia	37°52'N	32°35'E	Semi dry	Clay, alkaline, low organic matter, high lime, salt free
Sakarya	E2	Marmara	40°48'N	30°25'E	Humid	Clay- loam, slightly alkaline, medium organic matter, medium lime, salt free
Samsun	E3	Black Sea	41°15'N	36°22'E	Semi Humid	Clay- loam, slightly alkaline, low organic matter, medium lime, salt free
Antalya	E4	Mediterranean	36°52'N	30°45'E	Humid	Clay- loam, alkaline, low organic matter, very high lime, salt free

Table 3. Mean yield (t ha^{-1}) of the genotypes over environments.

Genotype	E1**	E2**	E3**	E4**	Mean**
1	2.1 f	5.8 df	2.7 g	4.3 ed	3.7 f
2	2.8 d	7.7 ab	3.8 d	5.8 ab	5.0 ac
3	2.0 f	5.4 ef	2.8 fg	5.6 ac	4.0 ef
4	2.0 f	7.2 ad	2.7 g	4.8 be	4.2 e
5	3.9 b	6.7 be	5.4 a	4.7 be	5.2 ab
6	2.8 d	6.2 cf	3.4 e	6.6 a	4.7 bc
7	4.3 a	7.3 ac	5.6 a	3.7 e	5.2 a
8	2.4 d	6.5 be	3.1 ef	4.0 e	4.0 ef
9	3.3 c	5.4 ef	4.3 b	5.8 ab	4.7 cd
10	2.9 d	4.8 f	3.7 d	3.7 e	3.8 ef
11	3.1 cd	5.5 ef	3.9 cd	4.5 ce	4.3 de
12	4.1 ab	6.7 be	5.5 a	4.1 ed	5.1 ac
13	3.3 c	8.2 a	4.1 bc	5.2 bd	5.2 a
14	3.3 c	7.4 ab	4.3 b	5.7 ab	5.2 a
Mean	3.0	6.5	4.0	4.9	4.6

Means followed by different letter(s) are significantly different at the 1% level of probability.

Table 4. Additive main affects and multiplicative interactions of variance for yield of the hybrids across environments.

Source	DF	SS	MS	Explained (%)
Model	55	406.2039042	7.3855255 **	
Environment (E)	3	275.8273494	91.9424498**	67.9
Genotype (G)	13	52.2876125	4.0221240**	12.9
ExG	39	78.0889423	2.0022806**	19.2
IPCA 1	15	51.1279	3.40853**	65.47
IPCA 2	13	26.4357	2.03352**	33.86
IPCA 3	11	0.5253	0.04775	0.68
IPCA 4	9	0.0000	0.00000	0.0
CV(%)=12.6	R^2=0.915			

** Significant at the 0.01 probability level.

seen on the biplot and the environments took place in four different sections. The genotypes closer to the line that marks the environments have the potential to enhance yield in that specific environment. Within 14 popcorn hybrids it can be concluded that G3 and G6 are the best genotypes for E4 which represents Antalya, a southern site of the country. G13 which is a commercial check is suitable for E2 representing Sakarya location a northwest site of Turkey, which has the best ecological conditions for maize production. G5 has good enhance for E3 representing Samsun which is located in the northeast of Turkey. Moreover, G10 and G11 hybrids can be mentioned as the best genotypes for E1 representing Konya location, which is a Central Anatolian city.

Genotypes located near the plot origin were less responsive than the vertex genotypes (Kaya et al. 2002). In this respect, G4 and G6 seems to be more yielding genotypes among the 14 popcorn hybrids but were not stable across environments due to the fact that they did not give the small PCA 2 scores. On the other hand, G12 a commercial check representing Antcin 98 and G1, an experimental hybrid, were determined as the most stable hybrids over the environments due to their small PCA 2 scores. Although G12 was a stable hybrid, it was not a good yielding genotype because it had large negative PCA 1 score. G1 was a stable (small PCA 2) hybrid and also had a relatively good yield potential in all environments under the test. Moreover, the average yields of genotypes 7, 8, 10 and 11 were under experiment average (PCA 1 <0) and also the genotypes were highly unstable (large PCA 2 scores).

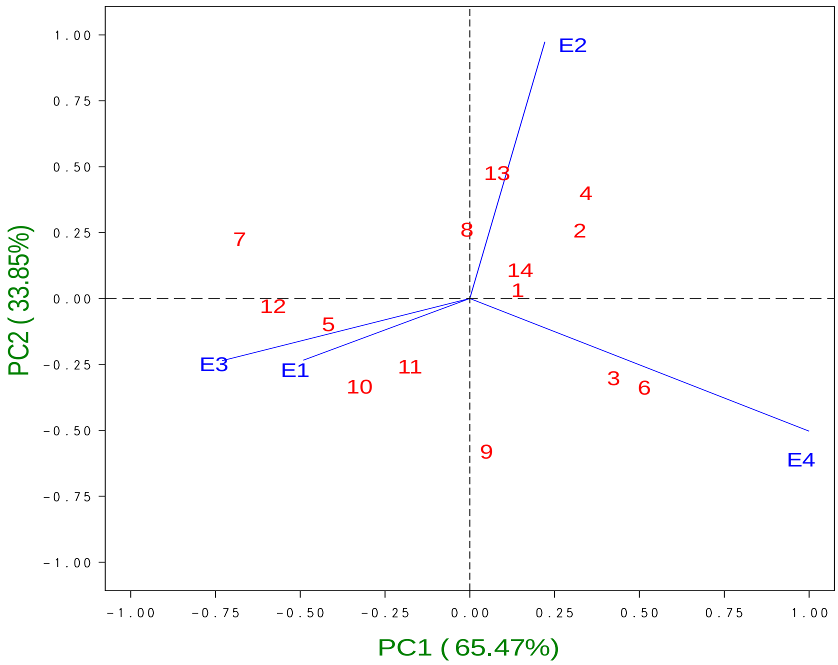

Figure 1. AMMI biplot of 14 popcorn hybrids and four environments for yield using genotypic and environmental scores.

The biplot was also a good informative graph for analyzing test sites. Among the used environments for testing popcorn hybrids, E4 was the most distinctive as it had longest distance between its marker and the origin. Genotype performances at E4 site, however, may not reflect the performances averaged over all sites due to the large PCA 2 scores. Furthermore, genotypic differences at E3 and E1 sites must be more consistent with those averaged at all sites, because they had relatively small PCA 2 scores.

4. Conclusion

The present study showed that there was a significant GEI in popcorn hybrids evaluated in different locations of Turkey. Because of the need for understanding GEI pattern and to generate knowledge about stability situations of the hybrids, additive main effects and multiplicative interactions analysis was used.

The analysis determined that the first two AMMI components captured nearly all interaction sums of squares and these findings were similar with those previous studies with different plant types. A biplot graph of 14 popcorn hybrids and four environments for yield using genotypic and environmental scores constructed using the first two AMMI terms was a good picture to see genotype and environmental situations.

According to the results of the biplot graph, it can be said that some genotypes were determined as best for some specific environments. G1 was selected for its stability across the environments. Besides, G2, G3, G4 and G6 popcorn candidate hybrids can be considered as promising due to their yield performances.

Acknowledgements

The authors thank to General Directorate of Agricultural Research Policy (TAGEM) of Turkey for supporting this breeding program. Also, the authors appreciate the help by Gregrorio Alvarado Beltran and Jose Luis Crossa CIMMYT for analyzing our data.

References

Anandan A, Sabesan T, Eswaran R, Rajiv G, Muthalagan N, Suresh R (2009) Appraisal of environmental interaction on quality traits of rice by additive main effects and multiplicative interaction analysis. Cereal Research Communications 37: 131–140.

Arulselvi B, Selvi B (2010) Grain yield stability of single cross maize (*Zea mays* L.) hybrids over three different environments. Electronic Journal of Plant Breeding 1: 577–584.

Crossa J, Gauch HG and Zobel RW (1990) Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. Crop Science 30: 493–500.

Dickerson GW (2003) Specialty corns. http://aces.nmsu.edu/pubs/_h/h-232.pdf Accessed 12 February 2012.

Ebdon JS and Gauch, JHG (2002) Additive main effect and multiplicative interaction analysis of national turfgrass performance trials: II. Cultivar recommendations. Crop Science 42: 497–506.

Gabriel KR (1971) The biplot graphic display of matrices with application to principal component analysis. Biometrika 453–467.

Gollob HF (1968) A statistical model which combines features of factor analytic and analysis of variance techniques. Psychometrika 33: 73–115.

Hernandez MV and Crossa J (2000) The AMMI analysis and graphing the biplot. Biometrics and Statistics Unit, CIMMYT.

İlker E, Tonk FA, Çaylak Ö, Tosun M, Özmen İ (2009) Assessment of genotype x environment interactions for grain yield in maize hybrids using AMMI and GGE biplot analyses. Turkish Journal of Field Crops 14: 123–135.

Issa AB (2009) Genotype by environment interaction and yield stability of maize hybrids evaluated in Ethiopia. http://etd.uovs.ac.za/ETD-db/.../IssaAB.pdf Accessed 01 February 2012.

Kaya Y, Palta C, Taner S (2002) Additive main effects and multiplicative interactions analysis of yield performance in bread wheat genotypes a cross environments. Turkish Journal of Agricultural and Forestry 26: 275–279.

Naveed M, Nadeem M and Islam N (2007) AMMI analysis of some upland cotton genotypes for yield stability in different milieus. World Journal of Agricultural Sciences 3: 39–44.

Pajic Z (2007) Breeding of maize types with specific traits at the Maize Research Institute, Zemun Polje. Genetika 39: 169–180.

Pike D (2003) Crop profile for corn (pop) in the United States (North Central Region). http://www.ipmcenters.org/cropprofiles/.../us-ncr. Accessed 14 February 2012.

Sadeghi SM, Samizadeh H, Amiri E and Ashouri M (2011) Additive main effects and multiplicative interactions (AMMI) analysis of dry leaf yield in tobacco hybrids across environments. African Journal of Biotechnology 10: 4358–4364.

SAS Institute. (1999) SAS/STAT users guide, second edition. SAS Institute Inc., Cary, NC.

Tarakanovas T, Ruzgas V (2006) Additive main effect and multiplicative interaction analysis of grain yield data of wheat varieties in Lithuania. Agronomy Research 4: 91–98.

Zobel RW, Wright M.J, Gauch JHG (1988) Statistical analysis of a yield trial. Agronomy Journal 80: 388–393.