

AMMI Model to Assess Durum Wheat Genotypes in Multi-Environment Trials

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ABSTRACT

The goal of this research was to assess the stability and yield performance of 150 durum wheat genotypes in multi-environment trials in two locations (Diyarbakir and Kiziltepe), in 2011-2012, and 2012-2013 growing seasons. The trials were designed by Lattice Experimental Design with two replications (incomplete block design). The AMMI (Additive Main Effects and Multiplicative Interaction) and GEI (Genotype×Environment Interaction) analysis were used in the study to estimate GEI effects on grain yield, because of plant breeders' great interest in these models for breeding programs. AMMI evaluation indicated that genotypes made the most important contributions to treatments Sum of Squares (59.8%), environments (3.5%), and GEI (36.7%), respectively, suggesting that grain yield had been affected by environment. IPCA 1 and IPCA 2 axes (Principal Component) were significant as $P < 0.01$ and explained 63.8 and 36.2%, respectively. Results showed that Kiziltepe 2013 was more stable and high yielding, meanwhile Diyarbakir 2012 and Diyarbakir 2013 environments were unstable and low yielding. According to stability variance, usually the province lines were more productive and stable than some old cultivars and many landraces/genotypes. Moreover, genotype G24 was more effective in all environments. The GEI model according to AMMI analysis suggested that this genotype can be considered as a candidate, due to extensive adaptability and high performances in all environments.

Keywords: AMMI, GGE biplot, Rain fed wheat, Stability.

INTRODUCTION

Durum wheat (*Triticum durum* Desf.) is produced in all agro-ecological zones of Southeastern Anatolia Region. This region is referred to as ideal for the durum wheat genes due to the conditions of Karacadağ basin (Kendal *et al.*, 2012). The durum wheat production is nearly 4 million tons per year in Turkey, and half of which is produced in Southeastern Anatolia Region (Anonymous 1, 2012; Anonymous 2, 2015; Kendal, 2015). Therefore, durum wheat has been well adapted and the yields are high, consistent with average yield

(kg ha⁻¹) of this region, when compared with other areas. Durum wheat is grown under both rainfed and irrigated conditions, but GEI restricts the progress in yield improvement under rainfed and unpredictable climatic conditions (Kilic, 2014). As a result, GEI is of principal significance because it offers some information on the effect of check environments on genotype overall performance and plays a vital key role in evaluation of the overall yield performance balance of the breeding genotype (Mohammadi *et al.*, 2013). Increasing genetic gain in yield

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performance is possible in part from narrowing the adaptation of genotypes and so maximizing yield in particular environments are described by GEI (Sabaghnia *et al.*, 2012b). On the other hand, durum wheat landraces are still cultivated to take advantage of their excellent grain and straw quality, adaptation to abiotic stresses, and extremely wide variety of uses (Amallah *et al.*, 2014).

Additive Main Effects and Multiplicative Interaction Models (AMMI) are important to analyze multi-environment trials data and it interprets the effect of the Genotype (G) and Environments (E) as additive effects and the G×E as a multiplicative component (which are sources of variation) and submits it to principal component analysis. AMMI is widely used to analyze main effects and Genotype by Environment (GEN, ENV) interactions in multilocation variety trials. Furthermore, this function generates biplot, triplot graphs and analysis. The AMMI procedure has been shown to increase estimation accuracy since it fits additive main effects for genotypes and environments by an ordinary ANOVA procedure and then applies PCA to the matrix of residuals of that remain after fitting of the main effects (Gauch, 1988). In AMMI model, the interaction (GE_{ij}) and the residual (ε_{ij}) can be decomposed into several Interaction Principal Component Axes (IPCA) using PCA.

Many factors, genetic as well as environmental fluctuations are relatively affecting the yield, due to the fact it is a complicated marker that depends on fairly other markers (Rharrabti *et al.*, 2003; Akter *et al.*, 2014). However, the GEI (Genotype Environment Interaction) is significant for breeding program and interaction of genotypes (McLaren *et al.*, 1994). The version of AMMI is a complicated version including both two way data structure and additive multiplicative additives which enable a

breeder to get specific prediction on genotypic potentiality and environmental impacts on it. The impact of AMMI approach has been clearly shown by different researchers using multi-environment. This approach could be very powerful for reading GEI (Tarakanovas and Ruzgas, 2006), provide the correlative size and significant effects of GEI and its interaction (Asfaw *et al.*, 2009), show huge distinction within the addition predominant effects for environments and genotypes (Kadi *et al.*, 2010), and display greater information in different genotype response over environments. Also, it describes specific and non-particular resistance of genotypes, figuring out most discriminating environments (Mukherjee *et al.*, 2013), reveals the two PCA axes account for the major diversity of GEI (Bantayehu *et al.*, 2013), demonstrates the presence of GEI, and shows highly significant differences for environment, genotype and their interactions (Nouri Rad *et al.*, 2013). Additionally, it envisions the average outstanding performance, adaptability of genotypes across environments (Fantie *et al.*, 2013), is important for testing promising lines under across environments to estimate stability and performance (Hagos *et al.*, 2013), could be a great tool to select the most suitable and stable high yielding genotype for special and diverse environments (Akter *et al.*, 2014), shows the mean performance, stability of genotypes over the environments (Islam *et al.*, 2014), reveals the efficiency performances of genotypes under the different effect of conditions and effects of GEI (Kilic, 2014), provides more useful information for achieving definitive results and definite mega-environments (Mohammadi *et al.*, 2013), reveals significant difference for genotype in environments under study, and GEI (Mehari *et al.*, 2014), enables better understanding of genotypes performance over several environments, and selection of stable and high yielding genotypes (Mirosavlievic *et al.*, 2014),

and thus, it is useful for breeders and supporting breeding program decisions.

The principal objective of the present study was to examine display adaptation of durum wheat genotypes using AMMI analysis to estimate the importance of GEI on yield, outline mega-environments, identify the nice appearing genotype for each mega-environment, and discuss the inclusion of the GEI in durum wheat breeding.

MATERIALS AND METHODS

One hundred and fifty durum wheat genotypes (50 cultivars, 25 landraces, 75 advanced lines) were evaluated during two growing seasons in two locations of Southeastern Anatolia Region of Turkey. All informations about genotypes are shown in Table 1. The cultivars were collected from around provinces, and races were collected from Southeastern Anatolia Region of Turkey and advanced lines from Turkey, CMMYT and ICARDA breeding program.

The durum wheat multi-environmental trials were conducted at two environment (Diyarbakir, normal conditions, and Kiziltepe, heat stress conditions) and different years (2012 and 2013). The environments had different growing seasons and growing regions characterized by differences in climatic conditions. The Diyarbakir (GAP International Agricultural Research and Training Center) location was chosen as a normal condition, Kiziltepe (farmers' fields) location was chosen as heat stress condition (Table 2). So, Kiziltepe location was irrigated two times per season. In this location, a total of 250 mm of water was given by sprinkler irrigation system every year at the sowing time and during the growing period. Because of heat stress and low rainfall, rainfed production of durum wheat is impossible in Kiziltepe condition. Also, there were different climatic conditions in the two study years.

The study was designed as Lattice experimental design (Incomplete Block Design) with two replications. The plot size was 3.6 m² (1.2×3 m) at sowing and 2.4 m² (1.2×2 m) at harvest time. Totally, 450 seeds were used per m². Sowing was done by Wintersteiger drill. The fertilization rates for all plots were 60 kg N ha⁻¹ and 80 kg P ha⁻¹ at sowing time and 60 kg N ha⁻¹ was applied to plots at the early stem elongation.

The grain yields of 150 genotypes in four environments (2 year×2 location) were evaluated by AMMI analysis (Gauch, 1988; Kendal and Tekdal, 2016). The AMMI1 and AMMI2 biplots were used to identify the mega-environments and superior genotypes. All statistical analyses were performed using GenStat Release 14.1 (Copyright 2011, VSN International Ltd.).

AMMI Model Analysis

The grain yield data were subjected to AMMI analysis which combines Analysis Of Variance (ANOVA) with additive and multiplicative parameters into a single model (Gauch, 1988). After removing the replicate effect when combining the data, the genotypes and environments observations are portioned in two sources: Additive main effects for genotypes and environments and non-additive effects due to genotype by environment interaction. The AMMI model is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^n \lambda_k \alpha_{ik} \gamma_{jk} + \theta_{ij} \quad (1)$$

Where, $i = 1, 2, \dots, 13$ genotype, $j = 1, 2, \dots, 4$, environment, Y_{ij} is the observed mean yield of i th genotype in the j th environment; μ is the grand mean, G_i is the i th genotypic effect, E_j is the j th environment effect, λ_k is the Eigen value of the Principal Component Analysis (PCA) axis k , α_{ik} and γ_{jk} are the i th genotype j th environment PCA scores for the PCA axis k , θ_{ij} is the residual, n is the number of PCA axes retained in the model. Ordinarily, the number n is judged on the basis of empirical consideration of F -test of significance (Baraki *et al.*, 2014).

**Table 1-** The information about genotypes used in the experiment.

| Code | Genotype | Cultivars owner, origin of landraces and pedigree of advanced lines | Genotypes Mean (kg ha ⁻¹) | Interaction PCA (1) | Interaction PCA (2) |
|------|-----------|---|---------------------------------------|---------------------|---------------------|
| G1 | Cultivar | GAP TAEM/Şanlıurfa | 8494 | 2.09913 | -5.90179 |
| G2 | Cultivar | TARM / Ankara | 8264 | -5.82605 | -6.92784 |
| G3 | Cultivar | GAP TAEM/Şanlıurfa | 6235 | -21.76386 | 5.13355 |
| G4 | Cultivar | GKTAEM/Eskişehir | 6396 | -11.81715 | -8.68337 |
| G5 | Cultivar | GAP IARTC/Diyarbakır | 7583 | 8.60704 | -5.21898 |
| G6 | Cultivar | DATAEM/Adana | 8289 | 1.95414 | 0.04903 |
| G7 | Cultivar | TARM / Ankara | 6570 | -17.08673 | -6.07337 |
| G8 | Cultivar | GAP UTAEM/Diyarbakır | 8028 | 5.81343 | -0.05065 |
| G9 | Cultivar | GAP UTAEM/Diyarbakır | 7928 | -10.60966 | -3.20575 |
| G10 | Cultivar | DATAEM / Adana | 6984 | 8.25076 | 14.44232 |
| G11 | Cultivar | MARO Tarım | 8116 | 3.14376 | 1.87913 |
| G12 | Cultivar | GAP UTAEM/Diyarbakır | 7088 | 1.25853 | 20.42909 |
| G13 | Cultivar | GKTAEM/Eskişehir | 5886 | -19.22490 | 16.77824 |
| G14 | Cultivar | TARM/Ankara | 7013 | -23.43630 | 4.33951 |
| G15 | Cultivar | GKTAEM/Eskişehir | 5302 | -21.73872 | 7.13060 |
| G16 | Cultivar | GAP UTAEM/Diyarbakır | 7107 | -5.77097 | 4.74150 |
| G17 | Cultivar | GAP UTAEM/Diyarbakır | 7271 | -0.79008 | 20.03610 |
| G18 | Cultivar | ETAEM/İzmir | 8618 | 4.37612 | -1.09331 |
| G19 | Cultivar | TARM/Ankara | 6808 | -13.24989 | 7.59530 |
| G20 | Cultivar | GAP UTAEM/Diyarbakır | 8642 | 6.98899 | -2.22757 |
| G21 | Cultivar | GAP UTAEM/Diyarbakır | 8308 | 2.34439 | -10.00819 |
| G22 | Cultivar | DATAEM/Adana | 8768 | 8.26563 | -2.63659 |
| G23 | Cultivar | ETAEM/İzmir | 8296 | 9.73463 | -2.41257 |
| G24 | Cultivar | ETAEM/İzmir | 8760 | -1.01418 | -4.79286 |
| G25 | Cultivar | GAP IARTC/Diyarbakır | 8066 | -3.32225 | -4.26699 |
| G26 | Cultivar | GAP UTAEM/Diyarbakır | 7274 | 1.89639 | 5.44394 |
| G27 | Cultivar | TARM/Ankara | 7174 | -21.12944 | 5.36854 |
| G28 | Cultivar | TARM/Ankara | 6332 | -23.94365 | 3.81600 |
| G29 | Cultivar | GKTAEM/Eskişehir | 5186 | -20.06735 | 4.19693 |
| G30 | Cultivar | GKTAEM/Eskişehir | 7082 | -22.62039 | 3.10097 |
| G31 | Cultivar | TASACO Tarım | 8156 | 8.29255 | -0.83878 |
| G32 | Cultivar | TARM/Ankara | 6345 | -21.24961 | 3.69462 |
| G33 | Cultivar | HARRAN Univ./Şanlıurfa | 8280 | -3.69139 | -1.32295 |
| G34 | Cultivar | ULUDAĞ Üniv./Bursa | 7755 | -1.41675 | 8.70745 |
| G35 | Cultivar | MARO Tarım | 7674 | -10.71672 | 12.73736 |
| G36 | Cultivar | ETAEM/İzmir | 7319 | 13.12605 | 3.26091 |
| G37 | Cultivar | TASACO Tarım | 8113 | 12.04809 | 14.85005 |
| G38 | Cultivar | GAP IARTC/Diyarbakır | 8864 | -0.23882 | 7.74971 |
| G39 | Cultivar | BDUTAEM/Konya | 6184 | -26.94965 | 5.07282 |
| G40 | Cultivar | DATAEM/Adana | 7656 | -10.11215 | 8.57733 |
| G41 | Cultivar | TASACO Tarım | 8057 | -3.44659 | 5.27843 |
| G42 | Cultivar | GAP UTAEM/Diyarbakır | 7724 | -0.70265 | -2.53442 |
| G43 | Cultivar | ETAEM/İzmir | 7171 | 4.60673 | 1.11488 |
| G44 | Cultivar | ETAEM/İzmir | 7920 | 0.26867 | -10.41626 |
| G45 | Cultivar | ETAEM/İzmir | 7944 | -2.15414 | -7.18147 |
| G46 | Cultivar | HARRAN Univ./Şanlıurfa | 7022 | -0.89881 | -11.48911 |
| G47 | Cultivar | GKTAEM/Eskişehir | 6933 | -16.56132 | 2.98245 |
| G48 | Cultivar | TARM/Ankara | 7306 | -16.73397 | 4.14367 |
| G49 | Cultivar | TASACO Tarım | 7262 | -1.38521 | -0.70731 |
| G50 | Cultivar | GAP UTAEM/Diyarbakır | 8908 | 2.78757 | -3.12091 |
| G51 | Landraces | Bagacak | 4429 | -18.76037 | -19.97861 |
| G52 | Landraces | Beyaziye | 5339 | -18.44421 | -14.27165 |
| G53 | Landraces | Menceki | 4372 | -14.32073 | -12.48930 |
| G54 | Landraces | İskenderi | 4798 | -27.42473 | -10.10902 |
| G55 | Landraces | Sorgul-Y | 4084 | -16.88060 | -12.20192 |

Table1 continued...

Continued of Table1.

| Code | Genotype | Cultivars owner, origin of landraces and pedigree of advanced lines | Genotypes Mean (kg ha ⁻¹) | Interaction PCA (1) | Interaction PCA (2) |
|------|-----------|---|---------------------------------------|---------------------|---------------------|
| G56 | Landraces | Akbugday/Hevedi | 5948 | -13.64658 | 1.07025 |
| G57 | Landraces | Hav 27 | 6263 | -11.28366 | 11.70333 |
| G58 | Landraces | Minaret | 6718 | 3.38499 | 1.02861 |
| G59 | Landraces | Devedisi | 5090 | -13.33152 | 1.50487 |
| G60 | Landraces | Sorgul | 5920 | -4.27246 | 7.39858 |
| G61 | Landraces | Karakılıçık | 5421 | -2.64863 | -0.93751 |
| G62 | Landraces | Havrani | 4510 | -11.74073 | -0.58347 |
| G63 | Landraces | Kunduru-Malatya | 4517 | -15.26333 | -8.13606 |
| G64 | Landraces | Giberunda (Kibriz) | 6459 | -3.61960 | 5.52955 |
| G65 | Landraces | Hacihalil | 6754 | -5.01051 | 20.40183 |
| G66 | Landraces | Siverek | 4667 | -2.06076 | -5.75687 |
| G67 | Landraces | Kurtalan | 4292 | -20.60133 | 2.94052 |
| G68 | Landraces | Sırnak Akkaya | 4645 | -17.77768 | -14.74060 |
| G69 | Landraces | Sogol Acırlı | 4999 | -17.31112 | -11.78274 |
| G70 | Landraces | Sarıbaş isa | 6294 | 4.14370 | -13.23470 |
| G71 | Landraces | Morhamam | 4089 | -13.46472 | -11.18182 |
| G72 | Landraces | A-97 | 5626 | -17.57879 | 11.30499 |
| G73 | Landraces | Sırnak | 7834 | -5.13637 | 6.37408 |
| G74 | Landraces | Selçuklu-97 | 4836 | -14.11170 | -5.84868 |
| G75 | Landraces | Siraslan | 5160 | -9.65814 | -13.23470 |
| G76 | Adv. Line | BOOMER_18/LOTUS_4 | 7395 | 18.47280 | 0.79246 |
| G77 | Adv. Line | GRVAND-16 | 8312 | 10.72667 | -0.17598 |
| G78 | Adv. Line | EMU//CHEN/ALTAR84/3/MTTE/CARC//RU | 8626 | 7.25989 | -12.06777 |
| G79 | Adv. Line | USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI | 8530 | 17.90618 | -2.63581 |
| G80 | Adv. Line | MX102-03 DS C36 IDYN 32 /ÇTAE | 8300 | 2.77351 | 2.34507 |
| G81 | Adv. Line | MX102-03 DS C36 IDYN 49 /ÇTAE | 8802 | 5.96506 | 11.90746 |
| G82 | Adv. Line | AJAIA_12/F3LOCAL(CELETHIO.135.85) | 8620 | 6.75079 | 3.53352 |
| G83 | Adv. Line | AVILLO_1/SNITAN | 8676 | 8.00913 | -2.33760 |
| G84 | Adv. Line | D86135/ACO89//PORRON_1/4/3/SNITAN | 8482 | 6.31504 | 12.10740 |
| G85 | Adv. Line | USDA595/3/B67.3/RABI//CRA/4/ALO/5/HUI | 8040 | 7.26604 | 19.65178 |
| G86 | Adv. Line | SOMAT_4/I CDSS01B00481S | 8143 | 18.98289 | 6.15611 |
| G87 | Adv. Line | PLATA_6/G CDSS02Y00369S | 7579 | 5.81518 | 7.56314 |
| G88 | Adv. Line | Icajihani ICD01-0251-T-4AP-TR-1AP... | 7847 | 7.54348 | 7.81011 |
| G89 | Adv. Line | SILVER_3/RISSA//SOOTY_9/RASCON_37 | 8766 | -7.97132 | 7.76806 |
| G90 | Adv. Line | GAUNT-10/SNITAN | 8626 | 4.44616 | 7.98386 |
| G91 | Adv. Line | SHAG-23/LAPDY-25 | 8582 | 0.29777 | 4.11478 |
| G92 | Adv. Line | SN TURK MI83-84 375/NIGRIS-5//TANT.. | 7947 | 12.23811 | 7.19513 |
| G93 | Adv. Line | PLATA_8/4/GARZA/AFN//CRA/3/GTA/5/R. | 7343 | 17.47926 | -10.89050 |
| G94 | Adv. Line | PLATA-7/ILBOR-1//HAI-OU-17 | 8296 | 2.21795 | -6.12946 |
| G95 | Adv. Line | FOCHA/3/HUI//CLT71/CII/4/CHN/ALTAR . | 7456 | 12.00941 | -10.24598 |
| G96 | Adv. Line | MXI06-07\C40IDSN\182,221 | 7150 | 6.27741 | -17.25764 |
| G97 | Adv. Line | MXI06-07\C40IDSN\182,227 | 8226 | 7.76412 | 9.09918 |
| G98 | Adv. Line | MXI06-07\C40IDSN\182,241 | 7704 | 8.40184 | -6.32364 |
| G99 | Adv. Line | MXI06-07\C40IDSN\182,260 | 7914 | 2.18166 | -5.51287 |
| G100 | Adv. Line | MXI06-07\C40IDSN\182,268 | 9532 | 7.45027 | 0.71201 |
| G101 | Adv. Line | MXI06-07\C40IDSN\182,270 | 9346 | 0.80179 | -8.04892 |
| G102 | Adv. Line | MXI06-07\C40IDSN\182,295 | 8986 | 11.17975 | -6.76649 |
| G103 | Adv. Line | MXI06-07\C40IDYN\180,031 | 8469 | 5.20200 | 2.68701 |
| G104 | Adv. Line | MXI06-07\C40IDYN\180,078 | 8284 | 4.56395 | -4.98387 |
| G105 | Adv. Line | MXI06-07\C40IDSN\182,083 | 8619 | 11.06330 | -9.08479 |
| G106 | Adv. Line | AVILLO-1/SNITAN | 8724 | 5.28703 | -5.67085 |
| G107 | Adv. Line | SULA/AAZ-5//CHEN/ALTAR84/3/AJAIA-- | 8730 | 7.17979 | 4.23421 |
| G108 | Adv. Line | GS/4/D.BUCK//TME/2*TC/3/LACK/... | 7540 | 10.64873 | -12.50974 |
| G109 | Adv. Line | FG/ATO//HUI/3/ROK/5/EGE88/5/SHAW/.. | 8697 | 1.01442 | 2.03369 |
| G110 | Adv. Line | HYDRANASSA30/SILVER_5/4/STN/ALT.. | 7039 | 8.61769 | 7.20710 |

Table1 continued...



Continued of Table1.

| Code | Genotype | Cultivars owner, origin of landraces and pedigree of advanced lines | Genotypes Mean (kg ha ⁻¹) | Interaction PCA (1) | Interaction PCA (2) |
|------|-----------|---|---------------------------------------|---------------------|---------------------|
| G111 | Adv. Line | Diyarbakir-81/Chen Allepo | 7476 | 7.28469 | 1.88795 |
| G112 | Adv. Line | SU-ORDEGI3/6/CTA/3/FG/DOM//KIF/4/ST. | 8584 | 0.93032 | 15.53786 |
| G113 | Adv. Line | Marsyr3/3/Gcn//Stj/Mrb3. OSD | 8013 | 6.34015 | 2.41563 |
| G114 | Adv. Line | Mck2/Tilo2//Bcrch1/Kund1149..OSD | 8420 | 7.58288 | -16.62000 |
| G115 | Adv. Line | Marsyr3//Sadi 1989/Chan..OSD | 7876 | 3.16133 | 9.82049 |
| G116 | Adv. Line | Mrb 3/Mna-IICD91-0760- | 7700 | 10.53494 | -10.42913 |
| G117 | Adv. Line | DA-6 Black Aqns/3/Bcr//Memo/Gool | 7652 | 3.27506 | 8.78541 |
| G118 | Adv. Line | E90040/MFOML_13//LOTAIL_6 | 8926 | 6.43664 | -14.21594 |
| G119 | Adv. Line | AUK/GUIL//GREN | 8860 | 5.44060 | -15.61798 |
| G120 | Adv. Line | KUCUK CD91B2620 | 8990 | 8.56635 | -8.60188 |
| G121 | Adv. Line | PLATA_16/UNI | 9204 | 10.81070 | -2.49464 |
| G122 | Adv. Line | Azeghar-1/6/Zna-1/5/Awl-/4/Ruff//Jo/Cr/3/ . | 8773 | 5.97336 | -5.18394 |
| G123 | Adv. Line | Sabil.21/Altintoprak-98 | 8808 | -2.70382 | -6.68681 |
| G124 | Adv. Line | SN TURKM183-84 375/Nigris-5//Tantlo-1 | 9382 | 4.77150 | -5.34634 |
| G125 | Adv. Line | Ter-1/3/Stj3//Bcr/Lks41 | 8024 | 18.22859 | -3.26822 |
| G126 | Adv. Line | MXI06-07\C40 | 7620 | 10.45288 | -5.49137 |
| G127 | Adv. Line | MXI06-07\C40IDSN\182,202 | 8448 | 11.75103 | -4.64093 |
| G128 | Adv. Line | MXI06-07\C40IDSN\182,222 | 7771 | 1.53914 | -1.76824 |
| G129 | Adv. Line | MXI06-07\C40IDSN\182,224 | 8129 | 13.17394 | 5.35932 |
| G130 | Adv. Line | MXI06-07\C40IDSN\182,256 | 7843 | 18.77694 | 8.94106 |
| G131 | Adv. Line | MXI06-07\C40IDSN\182,321 | 7866 | 10.81822 | 11.54550 |
| G132 | Adv. Line | MXI06-07\PMDW\2 | 8454 | 1.39032 | -4.85901 |
| G133 | Adv. Line | MXI06-07\C40IDYN\180,047 | 7512 | 16.63487 | 0.03946 |
| G134 | Adv. Line | 13307/Azn1/6/Zna-1/5/Aw11/4/Ruff / jo/Cr/3 . | 7112 | 11.08906 | 10.51990 |
| G135 | Adv. Line | ALTAR84/BCDSS99B1265T | 7274 | 6.04173 | 18.04405 |
| G136 | Adv. Line | Miki2... | 7104 | 12.03303 | 7.19109 |
| G137 | Adv. Line | Gcn/4/D68-1-93A-1A//Ruff/Fg/3/Mtl-5 | 8064 | 4.53569 | 12.04600 |
| G138 | Adv. Line | Aghrass-1/3/Mrb16/Ru | 8296 | 1.47696 | 9.63533 |
| G139 | Adv. Line | COMBA2//AAZ/MORUS 1 | 7546 | 4.54150 | 11.28222 |
| G140 | Adv. Line | DIPPER/PLATA_3/4/FG/ATO//HUI/3/ROK | 7692 | 0.48053 | 4.07268 |
| G141 | Adv. Line | GAN/DIYARBAKIR 81 | 7789 | 1.81772 | 2.55657 |
| G142 | Adv. Line | BUSHEN-6/SKARV | 6433 | 2.02987 | 9.46095 |
| G143 | Adv. Line | Quarmal/Gbch2/3/Mrf2/Normal Hamri/. | 7564 | 10.75447 | -13.57255 |
| G144 | Adv. Line | Bcrch1/3/Mrf2//Bcr/Gro1 OSD | 8104 | -1.38571 | -13.24740 |
| G145 | Adv. Line | Ter1//Mrf1/Stj2. OSD | 7104 | 5.78795 | -17.99230 |
| G146 | Adv. Line | MXI06-07\C40IDSN\182,247 | 7962 | 17.48722 | -6.74187 |
| G147 | Adv. Line | MXI06-07\C40IDSN\182,330 | 8165 | 6.56080 | 16.60211 |
| G148 | Adv. Line | MXI06-07\C40IDSN\182,146 | 8174 | 1.81772 | -6.61108 |
| G149 | Adv. Line | Mgn13/Ainzen-II | 6902 | 3.10586 | -16.04153 |
| G150 | Adv. Line | Sarıçanak-98/Omrabi-5 | 7726 | 5.71914 | -13.57255 |

Table 2. Years, sites, codes, coordinate status and precipitation of the test environments.

| Years | Sites | Altitude (m) | Latitude | Longitude | Annual rainfall (mm) | Long term Rainfall (mm) |
|---------|------------|--------------|-----------|-----------|----------------------|-------------------------|
| 2011-12 | Diyarbakir | 611 | 37° 55' N | 40°14' E | 405.1 | 483.0 |
| 2012-13 | Diyarbakir | 618 | 37° 55' N | 40°14' E | 680.6 | |
| 2011-12 | Kiziltepe | 484 | 37° 19' N | 40° 58' E | 217.0+250* | 305.6 |
| 2012-13 | Kiziltepe | 486 | 37° 19' N | 40° 58' E | 397.8+250* | |

*supplement irrigation

RESULTS AND DISCUSSION

The variance analysis of AMMI showed that all factors, genotypes, environments and GEI, PC1 and PC2 had significant effect ($P < 0.01$) on durum wheat grain yields of 150 genotypes tested in four environments and total sum of squares explained 59.8% for genotypic effects, only 3.5% for environmental effects, and 36.7% GEI effects (Table 3).

The high addition of genotypes consequences showed that there were important differences among genotypes in terms of grain yield. On the other hand, the GEI effect was higher than E effect. Moreover, Beleggia *et al.* (2013), reported that a small impact of genotype and large effects of both year and genotype-by-environment interaction on the metabolite composition and quality of the durum wheat grain. Farshadfar and Sutka (2006) reported that the same source E, G and G×E explained 86.0%, 2.0%, and 12.0%; Bantayehu (2013) reported 75.24, 9.32, and 15.44%; Rezene (2014), reported 89.6%, 1.8% and 8.6%; Mirosavlievic *et al.* (2014), explained 50-84, 5.3-13.6, 6.7-36.3% of treatments variations. The results of environment, genotype, and GEI effects obtained from this study illustrated different results of the studies described above and the effect of G > E > GEI. The results showed

that the effect of variation sources changes depending on the number of genotypes and environments. The effects of AMMI evaluation showed that genotypic effect was more crucial in the study, because of the genetic variability of genotypes (cultivars, lines, and landraces).

The GEI of durum wheat multi-environment trials were further analyzed with the AMMI2 model, including principal component axis (IPCA1 and IPCA2), which accounted for 79.92% of the GE variation. (Table 3). The data obtained from the AMMI model confirm adequacy (Yan and Hut, 2001). This status of AMMI calculated the effects of genotype and environment. The results of mean square of the PC1 and PC2 interaction axis showed that it was significant ($P < 0.01$). Results of AMMI analysis also indicated that the PC1 axis accounted for 65.11%, and the second accounted for 14.81%. The total of IPCA1 and IPCA2 accounted for 79.92% (Figures 2, 3, and 4). AMMI model showed existence of GEI, so it was portioned between the first and second IPCA (Interaction Principal Component Axes). The durum wheat grain yield variation is relying on genotypic and environment factors as shown Tables 1 and 2.

AMMI 1 Model

In the AMMI model 1, X axis represents the genotypes and environment main effect and Y axis represents the effects of interaction (Figure 1). The environment and genotypes

Table 3. The variance of AMMI analysis on grain yield of durum wheat genotypes.

| Resource of Variance | DF ^a | SS ^b | MS ^c | F value | G ^d + E ^e + GE SS Explained (%) | GE SS Explained (%) |
|----------------------|-----------------|-----------------|-----------------|---------|---|---------------------|
| Total | 1199 | 3777930782 | 3150901 | | | |
| Treatments | 599 | 3200591684 | 5343225 | 5.81** | | |
| Genotypes | 149 | 1915523834 | 12855865 | 13.99** | 59.8 | |
| Environments | 3 | 112446289 | 37482096 | 5.05** | 3.5 | |
| Block | 4 | 29676399 | 7419100 | 8.07 | | |
| Interactions | 447 | 1172621560 | 2623314 | 2.85** | 36.7 | |
| IPCA1 | 151 | 664284240 | 918897 | 1.48** | | 63.8 |
| IPCA2 | 149 | 308042830 | 2067402 | 2.25** | | 36.2 |
| Residuals | 147 | 200294490 | 1362548 | 4.79 | | |
| Error | 596 | 547662699 | 4399233 | | | |

^a Degrees of freedom; ^b sum of squares; ^c mean square. ^d Genotypes; ^e Environments. **, $p < 0.01$

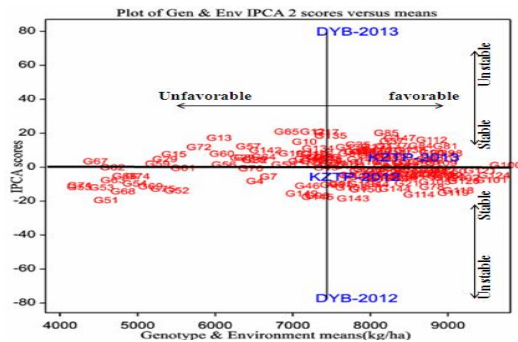


Figure 1. The AMMI 1 model showing grain yield (kg ha^{-1}) of 150 durum wheat genotypes in four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

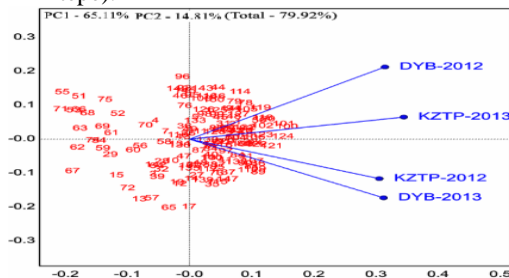


Figure 2. The AMMI 2 biplot graph showing interaction of PCA1 to PCA2 scores of 150 durum wheat genotypes in four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

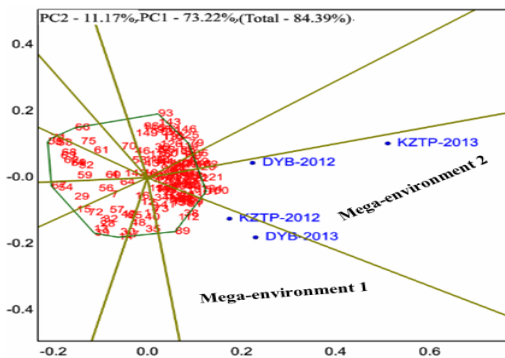


Figure 3. AMMI model showing "which-won-where" and sectors of 150 durum wheat genotypes in four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

indicated much more variability in both main effect and interaction. According to AMMI1, Kiziltepe 2012, Kiziltepe 2013 and majority of cultivars (G1-50) and promising line (G75-150), showed good performance, because they are placed above the axis (mean yield). It is

believed that these genotypes and environments were high yielding. On the other hand, Diyarbakir 2012, Diyarbakir 2012 and the majority of landraces (G51-75) demonstrated low performance, since they are positioned under the axis (mean yield). The genotype and environments that were located under the axis (mean yield) were low yielding. Moreover, Kiziltepe 2013 had both high potential and stable environment; more promising lines had broad adaptability to the four test environments. Also, G100, G101, G121 and G124 could be recommended for the four test environments with high potential and IPCA values (Table 1), while G13, G51, and G67 were unstable. According to Miroslavievic *et al.* (2014), the genotypes with small IPCA1 values are more stable, Becker and Leon (1988), the fundamental static idea of stability suggests minimum variance of stable genotype throughout one of the environments. However, Becker (1981) stated that static concept has little value for plant breeders and agronomists, because they typically opt for genotypes with excessive mean yields in favorable environments. Genotype with a steady excessive yield is referred to as dynamic stability idea is the preferred choice in commercial plant breeding (Flores *et al.*, 1998). G100 and Kiziltepe 2013 had high mean yield, but they had low IPCA 1 values. Similar outputs were recorded by Mohhamadi *et al.* (2013), in barley, Sabaghnia *et al.* (2010) in durum wheat, Kendal and Tekdal (2016), the AMMI analysis provides more useful information for acquiring certain results, and the identity of mega-environments and winning genotypes are inevitable.

AMMI 2 Model

The AMMI 2 biplot (IPCA1 versus IPCA2 scores) provides good explanation of the pattern, regarding the first two IPCA (Figure 2). This model includes the first two interaction axes of genotype and environment scores (Vargas and Crossa, 2000). The AMMI-axes can establish the GEI, in terms of differential sensitivities of the genotypes to the most discriminating environmental variables. Also, AMMI 2 clearly demonstrates "which-

won-where” pattern and also reveals the sensitivity degree of genotypes to environment (Li *et al.*, 2006). Purchase (1997) explained that the genotypes positioned to the center of the biplot are more stable than the others which are far from the center of the biplot. The landraces (G51 and G75) indicated low IPCA scores with mean yield. Moreover, these genotypes could not be encouraged for the test environments with slim adaptability. The cultivar (G1-G50) indicated both low and moderate mean yield and stability, and so some of these genotypes can be proposed for special environments. The majority of promising lines (G75-G150) indicated best performance of IPCA scores and mean yield. Therefore, a few of promising lines can be recommended for the test environments. In addition, ten sectors are seen in biplot graph, which are known as mega-environments along with all environment with wining promising lines (G75-150) and some cultivars (G1-50). On the other hand, all of the landraces (G51-75) and the majority of cultivars (7, 14, 15, 29, 30, 35, 39 and 48) and some promising lines (149, 143) could not associate with any environment (Figure 2). On the other hand, the results showed that totally mega-environments were present among the test environments, but these mega-environments can not be separated from each other (Figure 6). Sayar and Han (2016) reported that the two growing seasons were found to be significantly different, because they were located in different mega-environments. The results of Islam *et al.* (2014) indicated that interaction is positive when genotypes and environments are in the same sectors. Whereas interaction is negative, when they are in opposite sectors. If they fall into contiguous area, interaction is really more complex. On the other hand, According to Akter *et al.* (2014), the genotypes are close to each other at the plot, they may be looking nearly efficient throughout the environments, even as genotypes are away from each other, which display distinct reaction over the environments. This analysis makes possible developed comprehension of GEI by using the first two principal component axes (Kendal and Tekdal, 2016).

The polygon view of “which-wins-where” models shows grain yield in multi-

environmental trial data analysis (Figures 3 and 4). The Figures divided on mega environments with ten sectors which apart from center graph. The G89 is positioned on top of polygon of sector 1 and displays favorable to Kiziltepe 2012 and Diyarbakir 2013 environments, with G38 (Cultivar) and G112 (promising line), respectively.

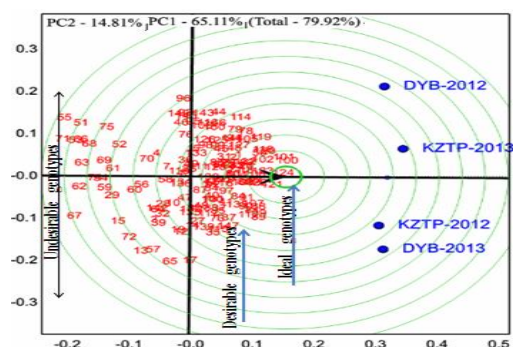


Figure 4. The Biplot graph showing ideal genotypes on four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

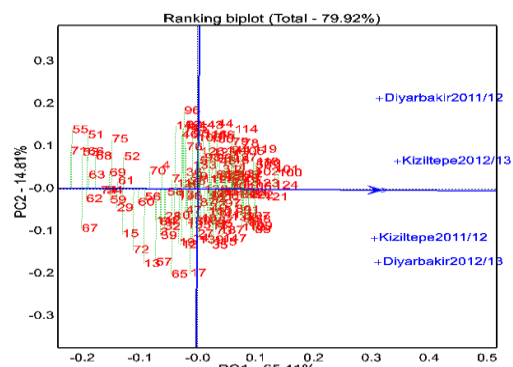


Figure 5. GGE biplot of SREG analysis showing the performance of the genotypes with the highest grain yield, G24, at different location.

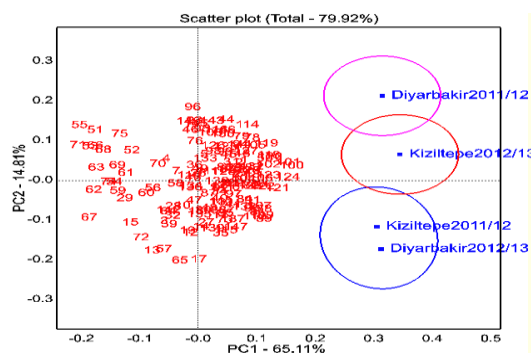


Figure 6. GGE biplot analysis showing the mega-environments.



Additionally, G100 (promising line) came about vertex polygon of sector 2 and displayed favorable for Diyarbakir 2012 and Kiziltepe 2013 environments. Furthermore, a few promising strains (G100, G121, and G124) were enough for Diyarbakir 2012 and Kiziltepe 2013. However, when all genotypes were evaluated, the majority of promising lines and some cultivars were located to side of the four test environments in sectors 1 and 2, while the majority of cultivars and landraces were located in the reverse side of the test environments. Therefore, this study showed that test environments located in two sectors (DYB 2013 and KZTP 2012 in first sector, DYB 2012 and KZTP 2103 in the second) and the promising line (G89) located in vertex polygon of first sector, while G100 for second. On the other hand; some genotypes (G93, G68, G39..) which located in top of other sectors are not suitable for study to test environments, because they located in the opposite side of study environments. According to Jaradat (2011), wheat landraces have been rarely cultivated in developed countries because of their low yield potential and susceptibility to diseases when compared with high-yielding cultivars under high external input farming systems. According to Sabaghnia *et al.* (2010), the polygon view model are mostly validated from the original data, but, not totally. Nevertheless, Gauch (1988) and Sayar and Han (2015) demonstrated that the outcome of this model is suitable and widely suited for recommendation purposes. Also, this model has more advantage to use, because of being adapted to a wide set of different conditions so as to provide their yield stability (Kendal and Sayar 2016; Sabaghnia *et al.* 2012a).

The GGE biplot of SREG analysis was used to show the adaptation of genotypes with the highest grain yield, G24 (cultivar) and G100 (advanced line), across environments (Figure 5). The length of environment projections onto G24 axis evaluated the performance of G24 and G100 at different environments, relative to other genotypes. The broken perpendicular line to the G24 axis and passing through the origin, divided the environments where G24 could yield above and below averages. Therefore, G24 had the highest yield in both

years and four environment. Figure 5 shows the "Average Environment Coordination" (AEC) of the GGE biplot for 150 durum wheat genotypes evaluations regarding the mean vs. stability. This AEC is based on genotype-focused Singular Value Partitioning (SVP) (Yan and Kang, 2003). Because of the inner-product property of the biplot, the projections of the genotype markers on the "average environment axis" are proportional to the rank-two approximation of the genotype means representing the main effects of the genotypes (Yan *et al.*, 2007). Genotype G24 and some other genotypes had the shortest AEC ordinate, so it is the most stable genotypes while G17, G65 (cultivars) and G96 (landrace) are the least stable genotypes placed under average mean performance with long perpendicular line from stable line. With regard to both stability and high mean performance, genotypes G21, G24, and G100 with some other genotypes which were unreadable due to density on axis, can be preferred to be selected. Considering AMMI1 and GGE SREG results, G24 (cultivar) and G100 (line) were recommended as the two ideal genotype among the studied genotypes and recommended for these four environments. Some researchers reported that AMMI and GGE SREG analysis have informative methods to facilitate visual comparison and explore stability and adaptation pattern of genotypes in practical plant breeding and in subsequent variety recommendations (Ahmadi *et al.*, 2012; Mortazavian *et al.*, 2014; Kendal *et al.*, 2016).

AMMI Recommendation of Genotype per Environment

The recommendation of genotype for environments is shown in Table 4. The genotype G100 (promising line) had high yield (mean of four environments), while G74 (landrace) was low yielding (Figure 1).

The promising lines (G79, G121, G100 and G86) in Diyarbakir 2012, the promising lines (G119, G101, G118, G124) in Kiziltepe 2012, the promising lines (G112, G89, G81, G38) in Diyarbakir 2013, the promising lines (G101, G89, G124, G100) in Kiziltepe 2013, could be

recommended. As mentioned above, while some promising lines are recommended for specific environment, and some promising lines (G89, G100, and G101) may be suitable for the two environments. The results of Table 4, confirm that we can advise the right genotype for all environments or specific genotype for specific environments through AMMI evaluation. Moreover, the AMMI analysis indicates recommendations of correct genotype for special environment (Bantayehu, 2013).

CONCLUSIONS

The research showed that AMMI model can be successfully used to evaluate the performance of large number of genotypes over several test environments. The AMMI biplot indicated that there were large differences in the additive main effect for genotypes and environments. The AMMI biplot indicated that the genotypes could be outstanding in three groups, because of their yields. The promising lines were high yielding and consisted of more stable genotypes, the cultivars were moderate yielding and some of them stable, the landraces were low yielding and the majority of them were unstable in the test environments. The AMMI biplot confirmed that some promising lines (G100, G101, G121, and G124) were stable in test environments, while only G124 was the ideal genotype for all test environments. The results of this study showed that promising line (G124) could be a candidate for the studied environments. Finally, the promising lines (G100, G101, G121, and G124) represented an important material for the further durum wheat breeding study, and they could potentially be used as donors of adaptability in different agro-ecological conditions.

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Table 4. The first four AMMI selections per environment.

| Environment | IPCAe[1] | IPCAe[2] | Mean | Score | 1 | 2 | 3 | 4 |
|-----------------|------------|------------|------|--------|------|------|------|------|
| Diyarbakir-2012 | -2.157.955 | -7.788.601 | 7289 | 114.46 | G79 | G121 | G100 | G86 |
| Kiziltepe-2012 | -5.959.455 | -638.172 | 7209 | -21.58 | G119 | G101 | G118 | G124 |
| Diyarbakir-2013 | -3.328.095 | 7.923.544 | 7299 | -33.28 | G112 | G89 | G81 | G38 |
| Kiziltepe-2013 | 11.445.505 | 503.228 | 7968 | -59.59 | G101 | G89 | G124 | G100 |



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مدل AMMI برای ارزیابی ژنوتیپ های گندم دوروم در آزمایش های چند منطقه ای

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چکیده

هدف این پژوهش ارزیابی پایداری و مقدار عملکرد ۱۵۰ ژنوتیپ گندم دوروم در آزمون های چند منطقه ای در دو ناحیه دیاربکر و کزل تپه در فصل رشد های ۲۰۱۱-۲۰۱۲ و ۲۰۱۲-۲۰۱۳ بود. طرح آزمایش لاتیس با دو تکرار (طرح بلوک ناقص) بود. تجزیه تحلیل با استفاده از تغییر اثرات اصلی جمع پذیر و اثرات متقابل ضرب پذیر (AMMI) برای ارزیابی عملکرد دانه و درک الگوی برهمکنش (تعامل) ژنوتیپ x محیط (GEI) انجام شد که در سال های اخیر مورد توجه زیاد بهنژادگران بوده است. نتایج AMMI حاکی از آن بود که ژنوتیپ ها بیشترین سهم (۵۹/۸٪) را در جمع مربعات (SS) تیمارها داشتند و تاثیر محیط (۳/۵٪) و برهمکنش این دو (۳۶/۷٪) بود. بر این اساس، عملکرد دانه در ژنوتیپ ها تحت تاثیر محیط بود. محورهای IPCA 1 و IPCA 2 (جزء اصلی) معنادار بودند ($P < 0.01$) و به ترتیب ۶۳/۸٪ و ۳۶/۲٪ را توضیح می دادند. همچنین، نتایج نشان داد که تیمار کزل تپه ۲۰۱۳ پایداری و عملکرد بالاتری داشت در حالیکه دیاربکر ۲۰۱۲ و دیاربکر ۲۰۱۳ محیط هایی نا پایدار و کم تولید بودند. بر اساس واریانس پایداری، معمولاً لاین های استان (province lines) در مقایسه با چند کولتیوار قدیمی و توده ها (landraces) موثرتر بوده و از پایداری بیشتری برخوردار بود. افزون بر این، ژنوتیپ G24 در همه محیط ها کارآیی بیشتری داشت. بر اساس مدل AMMI، از مدل GEI چنین بر می آید که با توجه به سازگاری گسترده و عملکرد بالای این ژنوتیپ در همه محیط ها، می توان آن را به عنوان کاندید (نامزد) مناسبی قلمداد کرد.