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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.

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INTRODUCTION

Durum wheat *(Triticum durum* Desf.*)* is produced ın 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 (kgha^{-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 (GEij) and the residual (εij) 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 e*t 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, identity 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 m^2 (1.2×3 m) at sowing and 2.4 m^2 (1.2×2 m) at harvest time. Totally, 450 seeds were used per m^2. 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...13 genotype, *j*= 1,2...4, environment, *Yij* is the observed mean yield of *i*th genotype in the *j*th environment; μ is the grand mean, *Gi* is the *i*th genotypic effect, *Ej* is the *j*th environment effect, λk is the Eigen value of the Principal Component Analysis (PCA) axis *k*, αik and γjk are the *i*th genotype *j*th environment PCA scores for the PCA axis *k*, θij 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…

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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	Karakılcık	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	Icajihan1 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…

[DOR: 20.1001.1.16807073.2018.20.1.16.8]

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	Diyarbakır-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. 0SD	8013	6.34015	2.41563
G114	Adv. Line	Mck2/Tilo2//Bcrch1/Kund1149..0SD	8420	7.58288	-16.62000
G115	Adv. Line	Marsyr3//Sadi 1989/Chan..0SD	7876	3.16133	9.82049
G116	Adv. Line	Mrb 3/Mna-1ICD91-0760-	7700	10.53494	-10.42913
G117	Adv. Line	DA-6 Black Aqns/3/Bcr//Memo/GooI	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/Altıntoprak-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/Lks4I	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/AwI1/4/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/DİYARBAKIR 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	Bcrch1/3Mrf2//Bcr/Gro1 0SD	8104	-1.38571	-13.24740
G145	Adv. Line	Ter1//Mrf1/Stj2. 0SD	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	Mgnl3/Ainzen-1I	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	400 58' E	217.0+250*	305.6
2012-13	Kiziltepe	486	37° 19' N	400 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

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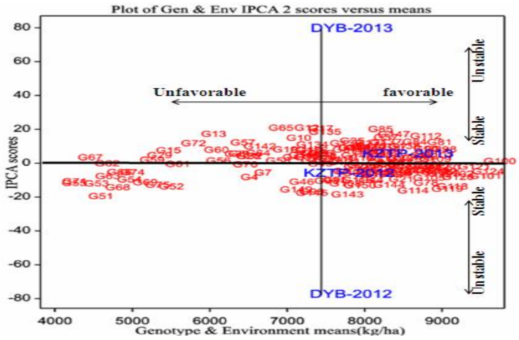

Figure 1. The AMMI 1 model showing grain yield (kg ha^{-1}) of 150 durum wheat genotypes in four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

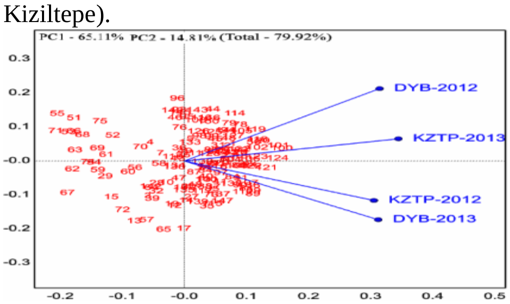

Figure 2. The AMMI 2 biplot graph showing interaction of PCA1 to PCA2 scores of 150 durum wheat genotypes in four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

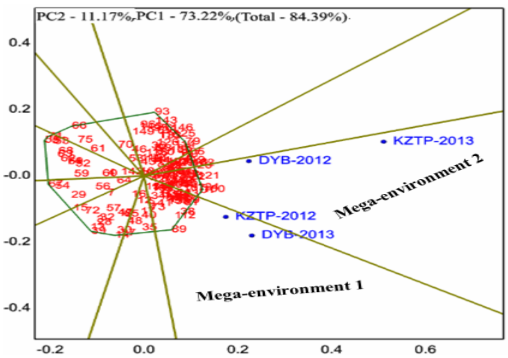

Figure 3. AMMI model showing "which-won-where" and sectors of 150 durum wheat genotypes in four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

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 Mirosavlievic *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 wining 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-

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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 grap. 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 totaly 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.

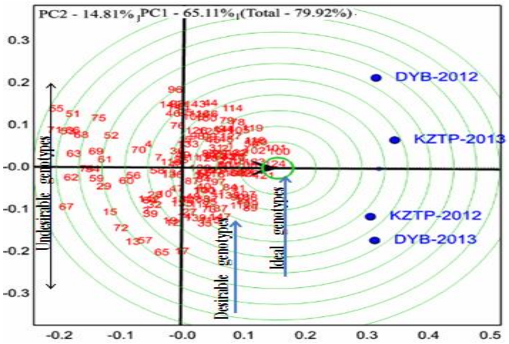

Figure 4. The Biplot graph showing ideal genotypes on four environments (DYB-Diyarbakir, KZTP-Kiziltepe).

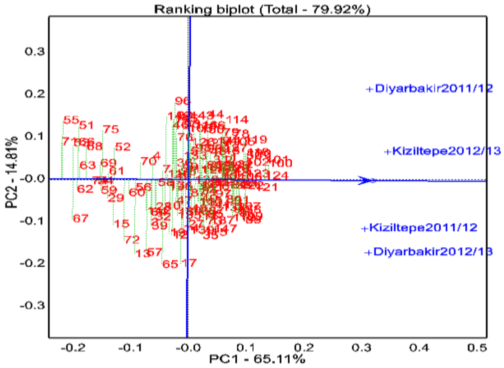

Figure 5. GGE biplot of SREG analysis showing the performance of the genotypes with the highest grain yield, G24, at different location.

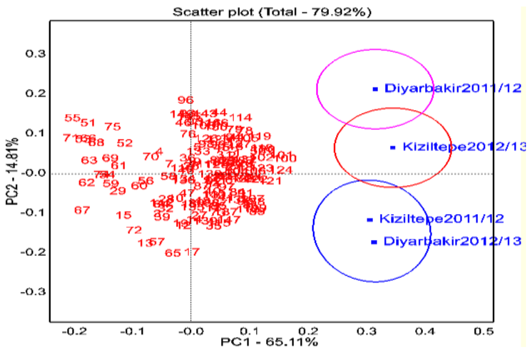

Figure 6. GGE biplot analysis showing the mega-environments.

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

س. تکدال، و ا. کندال

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 ۲۰۱۲-۲۰۱۱ و ۲۰۱۳-۲۰۱۲ 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 اخیرمورد توجه زیاد بهنژادگران بوده است. نتایج AMMIحاکی 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، معمولا 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 GEIچنین 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.

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