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## STABILITY OF GRAIN YIELD OF DURUM WHEAT GENOTYPES BY AMMI MODEL

### SUMMARY

Quick seed germination and stand establishment are significant factors to lentil. This study was performed to determine the yield performances of 20 durum wheat genotypes across five sites in warm dryland areas of Iran, during 2004-2006 growing seasons. The experimental design was a randomized complete block design with four replications. The combined analysis of variance indicated that effects of environments, genotypes and genotype  $\times$  environment (GE) interactions were significant, suggesting differential responses of the genotypes to environments and the need of stability analysis. Analysis of variance for AMMI (additive main effects and multiplicative interactions) model revealed the first four interaction principal components (IPC 1, IPC 2, IPC 3, IPC 4) were highly significant by Gollob's F-test and accounted for 78.32% of GE interaction. The genotypes have high variation around the mean yield (3358.68 kg ha<sup>-1</sup>). According to IPC1, genotypes G17, G3, G1 and G8 were the most stable genotypes. Based on EV4 parameter, genotypes G17, G8, G12, and G18 and according to EV1, genotypes G4, G6, G19, G7 and G20 were the most stable genotypes. Genotypes G10, G9, G4, G14, G11, G6 and G18 based on SIPC4 parameter and genotypes G8, G1, G12, G18 and G17 based on ASV parameter were the most stable genotypes. MASV indicated that G17, G12, G8, G18, G1 and G3 were most stable genotypes. Overall based on the all AMMI parameters, genotypes G3, G8, G1, G12, G17 and G18 were the most stable genotypes which had relatively high mean yield and can be used as superior genotypes in relation with the warm dryland environments.

**Keywords:** Multi-environment trial, Principal component analysis, genotype  $\times$  environment interactions, Yield

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## INTRODUCTION

Durum wheat (*Triticum turgidum* L. subsp. durum (Desf.) Husn.) is a tetraploid species with two diploid genomes AA and BB. It is characterized by possessing grains showing a high degree of virtuousness, relatively high endosperm hardness and being amber in color (El-Khayat *et al.* 2003). It has a hardest tissue than bread wheat (*T. aestivum* L.). Durum wheat is the important wheat for producing the best kinds of pasta because of its hard dense texture and grain with high protein and gluten particles. Iran has had an important durum breeding program in recent years, supported by the International Centre for Agricultural Research in the Dry Areas (ICARDA) (Mohammadi *e al.*, 2010), because is a species of great economical interest owing to the nutritional quality of its grain, as well as its high grain yield (Sabaghnia *e al.*, 2012a).

In most of the plant breeding programs, GE interaction effects are of special interest for identifying the most stable genotypes, mega-environments and other adaptation targets. Various methods for yield stability analysis are based on different stability concepts and can be classified accordingly (Flores *et al.*, 1998). Information regarding to crop stability is applicable for selection of genotypes with constant yield across environments. Many of researchers have been reported to depict the responses of genotypes to the different condition of environments for simultaneous selection of yield and stability. Each of these techniques put to use statistical parameters to estimate stability of genotypes to variation in environments. Linear regression approach is used widely for identifying of high yielding and stable genotypes (Alberts, 2004). The additive main effect and multiplicative interaction (AMMI) method is an approach for evaluation of genotypes stability under different environments. The AMMI method merges principal components analysis and analysis of variance into an integrated approach and can be used to analysis of the multi-location experiments (Zobel *et al.*, 1988). The AMMI analysis is effective because it provides agronomically meaningful interpretation of data (Gauch, 1992). The AMMI model is utilized for three main purposes (Gauch, 1988; Crossa *et al.*, 1990): (i) to suitable in the initial statistical analyses of yield experiments, (ii) to summarize the relationships between genotypes and environments (GE) and (iii) to applicable for understanding complex genotypes  $\times$  environment interaction effects. AMMI analysis has been applied extensively with great success to interpret genotype  $\times$  environment interaction in wheat (Petrovic *et al.*, 2009; Petrovic *et al.*, 2010; Mahmoodi *et al.*, 2011; Oikeh *et al.*, 2004; Mohammadi *et al.*, 2013).

There are several AMMI parameters. The AMMI stability value (ASV) has many similarities with the other AMMI stability parameters which calculated from the first two IPCs scores (Sabaghnia *et al.*, 2012b), However, this stability parameter and its modified parameter (MASV) have several priority to other AMMI stability parameters. Sabaghnia *et al.* (2008) reported ASV as a good dynamic criteria stability for detecting stable genotypes. Karimizadeh *et al.* (2012) were also revealed that ASV and MASV was as repeatable parameters and they were proposed that researcher use ASV and MASV parameters for

evaluating adaptability and stability of genotypes or cultivar because these parameters had high significant correlated with grain yield and also they are repeatable in single year, pair years and triple years. The other reason of priority of these two AMMI parameters is because of its benefit dynamic concept of stability and they could be useful for simultaneous selection of yield and stability. In the other word, ASV and MASV parameters of AMMI model was a reliable statistic to describe GE interaction and simultaneous selection of yield and stability (Adugna and Labuschagne, 2003).

The objective of this study is to determine high-yielding and stable durum wheat genotypes, with experiments carried out in fifteen locations..

## MATERIAL AND METHODS

### Experimental data

Twenty durum wheat genotypes, including 18 experimental lines selected from the durum wheat joint project of Iran/ICARDA and two local checks (Seimareh and Koohdasht) were evaluated during three cropping seasons (2004 - 2006) at five research sites, representative of major durum wheat rainfed and warm winter growing areas of Iran. A list of durum wheat genotypes are given in Table 1. A further description of the used genotypes is given in Table 1.

Table 1. Code, pedigree, and origin of 20 durum wheat genotypes.

Code	Pedigree/Name	source
G1	E90040/MFOWL13	ICARDA
G2	SRN1/LARU/3/YAV /FGO//ROH/4/LICAN	ICARDA
G3	TANTLO//CREX/ALLA/3TANTLO	ICARDA
G4	ZEGZAG/ALTAR84//DIPPER	ICARDA
G5	31-19-2-2	Iran
G6	18-18-1-4	Iran
G7	43-25-2-4	Iran
G8	Arislahn-4	ICARDA
G9	Lgt3/4/Bcr/3/Chi//Gta/Stk	ICARDA
G10	Bcr//Memo/goo	ICARDA
G11	Bcr//Memo/goo/3/Stjy	ICARDA
G12	D68-1-93A-1A//Ruff/Fg/3/Mtl-5/4/Lahn	ICARDA
G13	Terbo 167-3	ICARDA
G14	Bcr//fg/snbipe/3/Gdovz 578/swan//Ddra2	ICARDA
G15	Fadda-98	ICARDA
G16	Villemur/3/Lahn//gs/stk/4/Dra2/Bcr	ICARDA
G17	Terbo 197-4	ICARDA
G18	Stj3//Bcr/LKS4	ICARDA
G19	Koohdasht (Check)	Iran
G20	Seimareh (Check)	Iran

The locations used are: Ghachsaran in the south of Iran; Moghan in the northwest of Iran; Gonbad in the north of Iran; Khoram abad and Ilam in west of Iran. The altitude of testing sites varies from 45 to 1125 m. More descriptions of the experimental sites are given in Table 2.

Table 2. Name, latitude, longitude, altitude, precipitation and soil texture classes of different testing locations

Locations	Code	Year	Coordinates	Altitude (m)	Rainfall (mm) a	Temperature b			Soil type	Climate c
						Max	Min	Annual average		
Gachsaran	E1	2004	50° 46' N; 50° 46' E	710	515.2	47.8	-0.6	18.9	Silty-clay-loam	HSA d
	E6	2005			570.6	44.6	-2.6	19.9		
	E11	2006			511.2	45.0	-1.6	18.6		
Khoramabad	E2	2004	33° 29' N; 48° 22' E	1,125	482.9	39.0	-7.0	13.4	Silty-clay-loam	MSR
	E7	2005			438.3	41.0	-6.0	14.1		
	E12	2006			658.1	40.0	-6.6	12.6		
Gonbad	E3	2004	37° 15' N; 55° 10' E	45	700.6	41.0	-3.0	15.3	Silty-clay-loam	MSR
	E8	2005			605.4	40.0	-2.0	15.5		
	E13	2006			456.8	40.4	-3.6	15.7		
Ilam	E4	2004	33° 38' N; 46° 25' E	973	591.2	40.4	-2.8	12.78	Clay-loam	HSA
	E9	2005			574.5	42.0	-0.4	17.2		
	E14	2006			470.3	41.0	-2.4	13.9		
Moghan	E5	2004	38° 44' N; 47° 01' E	100	256.7	35.0	-5.2	11.7	Clay-loam	MSR
	E10	2005			182.8	36.4	-4.8	15.1		
	E15	2006			173.7	37.0	-6.0	11.8		

a\* Precipitation from October to June.

b\*\* Temperature includes months from October to June.

c According to Köppen classification system. The Köppen climate classification is one of the most widely used climate classification systems. It was developed by Wladimir Köppen, a Russian climatologist, around 1900 (with several further modifications by Köppen himself, notably in 1918 and 1936). It is based on the concept that native vegetation is the best expression of climate; thus, climate zone boundaries have been selected with vegetation distribution in mind. It combines average annual and monthly temperatures and precipitation, and the seasonality of precipitation (McKnight and Darrel 2000).

d HSA: Hot and Semi-Arid ; MSR: Mediterranean with Spring Rains

The genotypes were grown in a randomized complete block design with four replications at each site. Plot size was 7.35 m<sup>2</sup>, 7 m long, 6 rows, and 17.5 cm between rows. Where an area of 6.3 m<sup>2</sup> was harvested to estimate grain per plot and then converted to kg ha<sup>-1</sup>.

### Statistical analysis

The grain yield data were subjected to combined analysis of variance and AMMI analysis which is a combination of analysis of variance and multiplication effect analysis. Briefly, analysis of variance is conducted to determine the effect of environment (E), genotype (G) and GE interaction. Subsequently, multiplication effect analysis is used to partition GE deviations into different interaction principal component axes (IPC), which can be tested for statistical

significance through ANOVA. The IRRISTAT software was used for combined analysis of variance and AMMI analysis.

The eigenvalue (EV) stability parameter of AMMI (Zobel, 1994) was calculated according to this expression:

$$EV = \sum_{n=1}^N \gamma_{in}^2 / n$$

In this formula,  $\gamma_{in}$  is the genotype eigenvector for axis  $n$  and  $N$  is the number of IPC that were retained in the AMMI procedure via different F-tests.

The SIPC (Sum of IPC scores) (Sneller et al., 1997) parameter is expressed as:

$$SIPC = \sum_{n=1}^N \lambda_n^{0.5} \gamma_{in}$$

Where,  $\lambda_n$  is the eigenvalue of the IPC analysis axis  $n$ . In this equation  $N=1$  for SIPC1; for SIPC<sub>F</sub>,  $N$  was the number of IPC that were retained in the AMMI model.

The AMMI stability value (ASV) as described by Purchase (1997) was calculated as follows:

$$ASV = \sqrt{\left[ \frac{SSIPC1}{SSIPCA1} (IPC1)^2 \right] + (IPC2)^2}$$

Where  $\frac{SSIPCA1}{SSIPCA2}$  is the weight given to the  $IPC_1$  value by dividing the  $IPC_1$  sum of squares by the  $IPC_2$  sum of squares. The larger the IPC score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASV scores indicate a more stable genotype across environments.

For effective interpretation of GE interactions via AMMI model a new parameter as modified AMMI's stability value (MASV) is introduced as below formula (Adugna and Labuschagne, 2002):

$$MASV = \sqrt{\sum_{n=1}^{N-1} \left( \frac{SSIPC_n}{SSIPC_{n+1}} \right) (IPC_n)^2 + (IPC_{n+1})^2}$$

In this modified AMMI stability parameter, all significant IPCs were used. All analyses were performed using the statistical package Genstat release 12.0 (Genstat, 2010) and SAS release 9.1 (SAS, 2004).

## RESULTS AND DISCUSSION

Homogeneity of variance tests indicated homogenous error variance for grain yield in the fifteen environments and allowed for a combined analysis across environments. The combined analysis of variance (Table 3) indicated that the main effects of random environments and fix genotypes were significant for

grain yield that exhibiting the presence of variability in genotypes and diversity of growing conditions at different environments.

Table 3. Combined and AMMI analysis of variance and contributions of the first four principal components for grain yield of 20 durum wheat genotypes in 15 environments.

Source	df	Mean Squares	% of G×E Interaction SS
Environment	14	91725091**	
Replication within Environment	45	398875	
Genotype	19	4510540**	
Genotype × Environment	266	678590**	
AMMI 1	32	475792.**	33.74
AMMI 2	30	285737.**	19.00
AMMI 3	28	249503.**	15.48
AMMI 4	26	175256.**	10.10
GXE RESIDUAL	150	65201.6 <sup>ns</sup>	21.68
Error	855	162628	
Coefficient of Variation (CV)		12	

ns, not significant, \* and \*\* significant at the 0.05 and 0.01 probability level, respectively.

AMMI: additive main effect and multiplicative interaction

The significant effects of genotype × environment interaction reflected to the differential response of genotypes in various environments. This demonstrated that GE interaction was highly significant and had remarkable effect on genotypic performance in different environments. As GEI was significant, it was possible to proceed and calculate stability (Lin *et al.*, 1986). The GEI was accounted for 11% of TSS and was greater than the G effect. Grain yield is the net effect of G, E and GE interaction, and although E is responsible for about 75% of the total variability, only G and GE interaction are relevant to the evaluation of genotypes in multi-environment trials (Yan and Kang, 2002). The magnitude of the GEI sum of squares was about two times larger than that for genotypes. It is very common for mega-environmental trials (METs) data to embody a mixture of crossover and non-crossover types of GEI (Ahmadi *et al.*, 2012). Cooper *et al.* (1995) mentioned that the large magnitude of GE interaction causes more dissimilarity in the genetic systems that are controlling the physiological processes that are conferring yield stability in different environments. The relative contributions of GE interaction effects for grain yield in this study were similar to findings in other studies (Bertero *et al.*, 2004; Sabaghnia *et al.*, 2006; 2013). Therefore, GE interaction makes it difficult to select the best performing and most stable genotypes. The large E and GEI in this study suggest the possible existence of different mega-environments with

different top-yielding genotypes (Yan and Kang, 2002). This result revealed that there was a differential yield performance among genotypes across testing environments due to the presence of GEI. The presence of GEI complicates the selection process as GEI reduces the usefulness of genotypes by confounding their yield performance through minimizing the association between genotypic and phenotypic values (Crossa, 1990).

The AMMI analysis of variance revealed the IPC 1, IPC 2, IPC 3, IPC 4 axes were highly significant ( $P < 0.01$ ) by the F-test that was proposed by Gollob (1966). IPC 1, IPC 2, IPC 3 and IPC 4 axes explained 33.74%, 19.00, 15.48 and 10.10% of the total GEI, respectively. The four IPCs retained by Gollob's F-test accounted for 78.32% of GE interaction. The mean squares for IPC 1 and IPC 2 cumulatively contributed to 52.74% of the total GEI. However, if the number of significant IPCs were more than two IPCs, the visual interpretation of GE interaction through biplot is not valid due to low explanation of first two IPCs (Gauch, 2006). The AMMI model in this study indicated that there was a more complex interaction of GE and it could not facilitate graphical visualization of the genotypes in low dimensions and so it is essential to use an alternative procedure to interpretation of GE interaction using AMMI parameters (Sabaghnia et al., 2008).

Mean yield performance along with mean rank of genotypes across environments is presented in Table 4. The genotypes have high variation around the mean yield ( $3358.68 \text{ kg ha}^{-1}$ ). The range of grain yield was from  $2794.05 \text{ kg ha}^{-1}$  (G5) to  $3809.95 \text{ kg ha}^{-1}$  (G10). Thirteen genotypes produced higher grain yield than the grand mean. In general, G10, G9 and G18 give the best yield performance, while G5, G6 and G7 had the lowest mean yield performance across environments.

Tables 4 display the first four principal component axes scores for genotypes and mean of four IPCs. The IPC scores of a genotype in the AMMI analysis are an indication of the stability or adaptation over environments. The greater IPC scores, negative or positive, (as it is a relative value), the more specific adapted is a genotype to certain environments. The more IPC scores approximate to zero, the more stable or adapted the genotype is over all the environments (Purchase, 2000). The lowest IPC1 was observed for genotypes G17 and G3 followed by G1, G8, G20, G6, G9 and G12, respectively (Table 5). Between these genotypes, G17, G3, G1, G20, G9 and G12 had higher mean yield than grand mean. The highest IPC1 was belonged to G5 followed by G4, G7 and G11, respectively. Overall, according to mean of IPC1-4, G1, G12, G8, G17 and G18 had the lowest values and were recognized as the most stable genotypes. IPC scores of genotype and environment also took both positive and negative values (Table 4). Consequently, a genotype that has large positive IPC score with some of environments, most have negative interaction with the other environments. Thus, these scores presented a disproportionate genotype response (Yan and Hunt, 2001), which was the major source of variation for any crossover (qualitative) interaction. This disproportionate genotype response is referred to as

crossover GEI for convenience. Diversely, scores with the some sign or near zero represent a non – crossover (quantitative) GEI or a proportionate genotype response (Mohammadi and Amri, 2008).

Table 4. Average yield and First four Interaction Principal Component Analysis parameters for 20 durum wheat genotypes.

Genotypes	Yield	Rank	IPC1	IPC2	IPC3	IPC4	Average IPC1-4
G1	3461.07	8	2.54	-3.397	8.73	-0.72	3.27
G2	3497.36	7	-11.77	4.812	16.98	-10.87	2.36
G3	3371.53	12	-2.019	-11.19	3.32	5.52	2.81
G4	3211.39	17	-30.74	7.08	-20.67	10.10	4.29
G5	2794.05	20	32.17	-10.76	-12.54	11.31	2.06
G6	2814.5	19	4.154	25.75	-31.17	-7.73	6.60
G7	2838.33	18	28.01	2.082	1.90	16.71	8.60
G8	3337.64	14	3.228	-1.148	-4.47	5.15	4.37
G9	3706.5	2	-4.346	-21.74	-3.12	-11.54	9.87
G10	3809.95	1	-8.462	-19.6	-10.78	-4.93	9.49
G11	3533.3	4	-15.71	-1.489	2.54	0.98	10.97
G12	3367.37	13	-4.777	-1.987	4.41	-0.33	10.19
G13	3510.65	6	8.819	0.3667	10.98	-4.37	10.94
G14	3405.82	11	9.981	-10.17	-7.74	-18.57	12.16
G15	3245.47	16	-10.97	8.377	9.31	11.61	11.32
G16	3512.48	5	-9.865	5.3	4.51	15.02	12.18
G17	3419.42	10	-1.501	-7.797	2.79	-0.51	20.35
G18	3586.22	3	-5.288	-2.785	4.34	-4.79	11.65
G19	3296.51	15	12.67	24.92	8.31	-20.35	25.71
G20	3454.01	9	3.878	13.36	12.40	8.31	19.45

IPC1- IPC4 are first four interaction principal component environment, respectively,

Table 5 indicates results for stability of different durum wheat genotypes according to several AMMI parameters. According to the EV4 stability statistic, a genotype is considered to be more stable provided that the EV4 is lower. Therefore, G17, G8, G12, and G18 were the most stable genotypes which had relatively high mean yield performance, whereas G4, G19, G6, G2 and G5 were the most unstable genotypes which had relatively low mean yield performance. According to EV1 which benefits only IPC1 scores, genotypes G4, G6, G19, G7 and G20 were the most stable genotypes and based on EV4 (IPC1-IPC2), genotypes G17, G8, G12, and G18 were the most stable genotypes (Table 5).



Thus, different numbers of IPCs in EV computation results in obtaining relatively different conclusions in identification of the most stable genotypes. It is important to notice that EV1 parameter is based on only 33.74% of GE interaction variability, while EV4 are based on AMMI models that explain 78.32% of GE interaction sum of squares. The values of the SIPC4 parameter could be useful in identifying genotypes stability and so G10, G9, G4, G14, G11, G6 and G18 were the most stable genotypes whereas, G7, G20, G19 and G5 were the most unstable genotypes. It is interesting that most of stable genotypes according this parameter had high mean yield except G4 and G6.

Table 5. Values of AMMI stability parameters for 20 durum wheat genotypes.

Genotypes	EV1	EV4	SIPC4	ASV	MASV
G1	0.057	0.027	7.15	4.49	17.76
G2	0.048	0.075	-0.84	14.40	41.53
G3	0.055	0.026	-4.36	11.43	20.74
G4	0.020	0.123	-34.23	36.15	67.13
G5	0.048	0.072	20.18	38.63	61.27
G6	0.033	0.082	-8.99	26.19	69.02
G7	0.044	0.070	48.70	32.37	53.33
G8	0.057	0.017	2.76	3.90	13.88
G9	0.055	0.038	-40.74	22.31	37.87
G10	0.056	0.025	-43.77	21.90	38.93
G11	0.049	0.032	-13.67	18.18	23.03
G12	0.058	0.017	-2.68	5.86	13.21
G13	0.055	0.030	15.79	10.18	27.23
G14	0.051	0.055	-26.49	15.36	40.50
G15	0.056	0.045	18.32	15.17	34.96
G16	0.053	0.065	14.96	12.55	32.43
G17	0.059	0.016	-7.01	7.99	13.05
G18	0.059	0.017	-8.52	6.70	16.26
G19	0.041	0.099	25.55	28.89	56.12
G20	0.045	0.068	37.94	14.09	34.70

ASV: AMMI stability value, MASV: Modified AMMI stability value, SIPC: Sum of IPC scores, EV: Eigenvectors

The AMMI stability value (ASV) was the other stability parameter. According this stability parameter, a genotype with least ASV score is the most stable. The high interaction of genotypes with environments was also confirmed

by high ASV and rank, suggesting erratic (unstable) yield across environments. Results of ASV parameter showed genotypes G8, G1, G12, G18 and G17 as the most stable genotypes, respectively. The most unstable genotypes were G5, G4 and G7 (Table 5). Although, ASV parameter was reported to produce a balanced measurement between the two first IPC's (IPC1 and IPC2) scores, but it seems that this parameter is useful when the portion of explained total variation was relatively high (Sabaghnia *et al.*, 2008). It should be noticed that the ASV parameter uses IPC1 and IPC2 scores as well as magnitude of their sum of squares and so is different from the other AMMI parameters which use only genotypic or environmental IPCs scores or their modifications (Sabaghnia *et al.*, 2012c). The PC1 and PC2 variance explanations were low in this study; therefore we used modified AMMI's stability value (MASV) which benefits all four significant IPCs. The results of MASV indicated that genotypes G17, G12, G8, G18, G1 and G3 were most stable which had relatively high mean yield performance, whereas genotypes G6, G4 and G5 were the most unstable genotypes which had relatively low mean yield performance (Table 5). Therefore, MASV parameter introduced some of the high mean yielding genotypes (G17 and G18) as the most stable ones. Therefore, according to our results, AMMI parameters which are computed from four IPCs, were more useful and introduced relatively the high yielding genotypes as the most stable genotypes. Considering the mean ranks of all of the AMMI stability parameters, genotypes G3, G8 and G1 following to genotypes G12, G17 and G18 were the most stable genotypes. All of these stable genotypes, except of G8 had the high mean yield performance over grand mean.

The AMMI model used in the present study indicated a more complex GE interaction which required as many as four IPCs. This phenomenon could be related with the nature of the crop, environmental conditions or diverse genetic background obtained from different sources. Multivariate statistical methods such as AMMI can explore multi-directionality aspects and try to extract more information from GE interaction component. According to Gauch (2006) and Gauch *et al.* (2008), AMMI procedure has several advantages to the other multivariate statistical methods. They declared that AMMI is superior or equal to GGE and proposed to avoid needless multiplication of methodologies; there is no call for a mix-and-match strategy using both procedures. It seems that simultaneous assessment of four IPCs scores of the AMMI method for durum wheat genotypes facilitates the interpretation of GE interaction and identification of superior genotypes. Plant breeders have used firstly the stability concept for identifying a genotype with constant yield in different environments (static concept) but later simultaneous considering of both mean yield and stability is proposed (dynamic concept). The ASV and MASV benefit dynamic concept of stability and could be useful simultaneous selection of yield and stability (Dehghani *et al.*, 2010). The results of present study are in agreement with Adugna and Labuschagne (2002) who found that the ASV parameter of AMMI model was a reliable statistic to describe GE interaction and simultaneous

selection of yield and stability. In dynamic concept of stability, it is not needed that the genotypic response to environmental conditions should be equal for all genotypes (Becker and Leon, 1988)..

## CONCLUSIONS

The AMMI model gives a simple measure of yield stability which allows a ranking of genotypes. This model was also as an effective tool in understanding complex GE interactions in multi-environment trials of durum wheat. Also, besides differences in crops and regions (climatic conditions, soil properties etc), the observed GE interactions may be partly explained by the structure of the dataset that was considered and by the selection of the genotypes. The interaction of 20 genotypes with 15 environments was best predicted by the first four principal components of genotypes and environments. The AMMI stability parameters helped breeders to have an overall picture in behavior of the genotypes, the environments and GEIs. The results obtained by AMMI analysis indicated that genotypes G1 (E90040/MFOWL13), G8 (Arislahn-4), G12 (D68-1-93A-1A/Ruff/Fg/3/Mtl-5/4/Lahn), G17 (Terbo 197-4) and G18 (Stj3//Bcr/LKS4) were as the stable genotypes and can be used as superior genotypes in durum wheat breeding for warm dryland areas.

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## REFERENCES

- Ahmadi, J., Vaezi, B. & Fotokian, M.H. (2012): Graphical analysis of multi-environment trials for barley yield using AMMI and GGE-biplot under rain-fed conditions. *J. Plant Physiol. Breed.* 2(1), 43–54.
- Adugna, W. & Labuschagne, M.T. (2002): Genotype, environment interactions and phenotypic stability analyses of linseed in Ethiopia. *Plant Breed.* 121, 66–71.
- Adugna, W. & Labuschagne, M.T. (2003): Parametric and nonparametric measures of phenotypic stability in linseed (*Linum usitatissimum* L.). *Euphytica* 129, 211–218.
- Alberts, M.J.A. (2004): A comparison of statistical methods to describe genotype  $\times$  environment interaction and yield stability in multi-location maize trials. *Plant Breeding MSc Thesis, University of the free state Bloemfontein.* 100 p.
- Becker, H.C. & Léon, J. (1988): Stability analysis in plant breeding. *Plant Breed.* 101, 1–23.
- Crossa, J., Gauch, H.G. & Zobel, R.W. (1990): Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. *Crop Sci.* 30, 493–500.
- Crossa, J. (1990): Statistical analyses of multilocation trials. *Advan. Agron.* 44: 55–85.
- Dehghani, H., Sabaghpour, S.H. & Ebadi, A. (2010): Study of genotype  $\times$  environment interaction for chickpea yield in Iran. *Agron. J.* 102, 1–8.

- El-Khayat, G.H., Samaan, J. & Brennan, C.S. (2003): Evaluation of vitreous and starchy Syrian durum (*Triticum durum*) wheat grains: The effect of amylose content on starch characteristics and flour pasting properties. In *Starch/Stärke*, 55, 358-365.
- Gauch, H.G. (1988): Model selection and validation for yield trials with interaction. *Biometrics* 44, 705–715.
- Gauch, H.G. J. (1992): *Statistical Analysis of Regional Yield Trials: AMMI Analysis of Factorial Designs*. Elsevier, Amsterdam.
- Gauch, H.G. (2006): Statistical analysis of yield trials by AMMI and GGE. *Crop Sci.* 46, 1488–1500.
- Gauch, H.G., Piepho, H.P. & Annicchiarico, P. (2008): Statistical analysis of yield trials by AMMI and GGE: Further considerations. *Crop Sci.* 48, 866–889.
- Genstat, (2010): *Genstat for Windows*. 12th ed. VSN Int., Hemel Hempstead, UK.
- Gollob, H.F. (1968): A statistical model which combines features of factor analytic and analysis of variance techniques. *Psychometrika* 33, 73–115.
- Karimizadeh, R., Mohammadi, M., Shefazadeh, M.K., Mahmoodi, A.A., Rostami, B. & Karimpour, F. (2012): Relationship among and repeatability of ten stability indices for grain yield of food lentil genotypes in Iran. *Turkish J. Field Crop.* 17(1), 51-61.
- Lin, C.S., Binns, M.R. & Lefkovitch, L.P. (1986): Stability analysis: Where do we stand? *Crop Sci.* 26, 894– 900.
- Mahmoodi, N., Yaghotipour, A. & Farshadfar, E. (2011): AMMI stability value and simultaneous estimation of yield and yield stability in bread wheat (*Triticum aestivum* L.). *Australian J. Crop Sci.* 5(13), 1837-1844.
- Mohammadi, M. (2012): Parameters of additive main effects and multiplicative interaction model for interpreting of genotype×environment interaction. *J. Food, Agric. & Environ.* 10 (1), 777-781.
- Mohammadi, R. & Amri, A. (2008): Comparison of parametric and non-parametric methods for selecting stable and adapted durum wheat genotypes in variable environments. *Euphytica*. 159, 419–432.
- Mohammadi, R., Mohammadi, M., Karimizadeh, R. & Amri, A. (2010): Analysis of genotype-by-environment interaction for grain yield of rainfed durum wheat genotypes in warm winter areas of Iran. *J. Crop Sci. Biot.* 13, 267–274.
- Mohammadi, M., Karimizadeh, R. & Hosseinipour, T. (2013): Parameters of AMMI model for yield stability analysis in durum wheat. *Agric. Con. Sci.* . 78, 119-124.
- Oikeh, S.O., Menki A., Maziya-Dixon, B., Welch, R.M., Glahn, R.P. & Gauchjr, G. (2004): Environmental stability of iron and zinc concentrations ingrain of elite early-maturing tropical maize genotypes grown under field conditions. *J. Agric. Sci.* 142, 543–551.
- Petrovic, S., Dimitrijevic, M., Belic, M., Banjac, B. & Vukosavljev. M. (2009): Spike stability parameters in wheat grown on solonetz soil. *Genetika*, 41(2), 199 -205.
- Petrovic, S., Dimitrijevic, M., Belic, M., Banjac, B., Boskovic, J., Zecevic, V. & Pejic, B. (2010): The variation of yield components in wheat (*Triticum aestivum* L.) in response to stressful growing conditions of alkaline soil. *Genetika*, 4(3), 545-555.
- Purchase, J.L. (1997): Parametric analysis to describe G × E interaction and yield stability in winter wheat. Ph.D. thesis. Dep. of Agronomy, Faculty of Agriculture, Univ. of the Orange Free State, Bloemfontein, South Africa.
- Purchase, J.L., Hatting, H. & Vandeventer, C.S. (2000): Genotype × environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: II. Stability analysis of yield performance. *South African J. Plant Soil* 17:101-107.

- SAS Institute, 2004. SAS/STAT user's guide. v. 9.1. SAS Inst., Cary, NC.
- Sabaghnia, N., Sabaghpour, S.H. & Dehghani, H. (2008): The use of an AMMI model and its parameters to analyze yield stability in multi-environment trials. *J. Agric. Sci.* 146, 571–581.
- Sabaghnia, N., Karimizadeh, R. & Mohammadi, M. (2012): Model selection in additive main effect and multiplicative interaction model in durum wheat. *Genetika.* 44(2), 325-339.
- Sabaghnia, N., Karimizadeh, R. & Mohammadi, M. (2012): Grain yield stability analysis of lentil genotypes by additive main effects and multiplicative interactions model. *YYU. J. AGR. SCI.* 22(3), 155-164.
- Sabaghnia, N., Mohammadi, M. & Karimizadeh, R. (2013): Parameters of AMMI model for yield stability analysis in durum wheat. *Agric. Cons. Sci.* 78, 119-124.
- Sabaghnia, N., Mohammadi, M. & Karimizadeh, R. (2012c): The evaluation of Genotype  $\times$  environment interaction of durum wheat's yield using of the AMMI model. *Agriculture and Forestry* 55, 5-21.
- Sneller, C.H., Kilgore-Norquest, L. & Dombek, D. (1997): Repeatability of yield stability statistics in soybean. *Crop Sci.* 37, 383–390.
- Yan, W., Hunt, L. A. (2001). Interpretation of genotype  $\times$  environment interaction for winter wheat yield in Ontario. *Crop Science*, 41: 19–25.
- Yan, W., & Kang, M.S. (2002): GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists. CRC Press, Boca Raton, FL. pp 271.
- Zobel, R.W. (1994): Stress resistance and root systems. p. 80–99. In Proc. Of the Workshop on Adaptation of Plants to Soil Stress. 1–4 Aug. 1993. INTSORMIL Publ. 94–2. Inst. of Agriculture and Natural Resources, Univ. of Nebraska, Lincoln.
- Zobel, R.W., Wright, M.J. & Gauch, H.G. (1988): Statistical analysis of a yield trial. *Agron. J.* 80, 388–393.