*J. Agr. Sci. Tech. (2017) Vol. 19: 1355-1368*

# Determination of Yield Stability in Durum Wheat Genotypes under Rainfed and Supplementary Irrigation Conditions

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## ABSTRACT

**Tests were done to determine high-yielding and stable durum wheat genotypes. An experiment was set up as a RCBD (Randomized Complete Block Design) with three replications on 17 advanced durum wheat genotypes under rainfed and supplementary irrigation conditions in the cropping seasons of 2011-13. Combined analysis of variance indicated that environment main effect accounted for 70.09% of total yield variation; and effects of genotype and Genotype×Environment Interaction (GEI) accounted for 2.95 and 10.71%, respectively. Results indicated remarkable difference in genotypes response across environments. G×E interaction was analyzed following Additive Main effects and Multiplicative Interaction (AMMI) model. The first two interaction Principal Component Axes (IPCA1 and IPCA2) explained 53.75 and 36.99% of total interaction effects, respectively. Based on the AMMI model, AMMI Stability Value (ASV) and Genotype Selection Index (GSI), genotypes G11, G8, and G14 were selected for all environments. According to the AMMI2 biplot, the G15, G16 and G17 exhibited specific adaptation with rainfed (E1) and irrigation (E2) environments. G3 and G4 displayed specific adaptation with rainfed (E3) environment and G10, G9, G1, and G12 indicated specific adaptability with irrigation (E4) environment. The E3 had high discrimination ability, so, this environment was considered sufficient for making genotypes recommendation. Results of this investigation illustrate that the AMMI stability parameters are suitable for characterizing stable genotypes and that the *GSI* parameter can detect genotypes with high grain yield and good stability for plant breeding research in durum wheat.**

**Keywords:** Adaptation, AMMI analysis, *ASV*, *GSI, GEI.*

## INTRODUCTION

Iran is currently an important producer of durum wheat (*Triticum durum Desf.*) in the world. A total of, 0.6 million tons was produced during the crop season 2014-15 (MNR, 2015). The durum wheat cultivated in Iran is considered one of the best, in terms of quality, particularly for pasta, because it generally has good protein content and color (Irani, 2000). There is remarkable demand from native and international milling industries that commands a high market price, so, this presents significant impetus to expand durum wheat cultivation. Iran enjoys magnificent geographical diversity compared to other countries. Durum wheat can be cultivated under rainfed and irrigation conditions but the Genotype×Environment Interaction (GEI) restricts progress in yield improvement strategies under rainfed and unpredictable climatic conditions (Kilic, 2014). G×E interaction cause fluctuating performance of crops in relation to change in environment. This differential response of genotype to environmental change cannot be explained by genotype and environment main effects obtained from combined analysis of variance (Mohammadi *et al*., 2007). The complexity of GEI makes selection of high-yielding and stable genotypes challenging. Therefore, an understanding of the factors that affect GEI is

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essential in plant breeding in order to implement an efficient selection process and selection of environments for evaluation. The G×E interaction can be evaluated using several multivariate statistical methods to reveal multi-directional aspects of data and to elicit more information from the G×E interaction components, all of which are based on genotypes evaluation under Multi-Environment Trials (METs) (Zobel *et al*., 1988; Gauch and Zobel, 1996; Gauch *et al*., 2008). Additive Main Effect and Multiplicative Interaction (AMMI) also designate Factor Analysis Of Variance (FANOVA), combines standard analysis of variance for the main effects of genotype and environment with principal component analysis of the GEI (Zobel *et al*., 1988). This displays more informative results for responses of different genotypes over environments such as describing specific and non-specific adaptibility of genotypes and identification of the most discriminating environments (Kendal and Sener, 2015). Because this method is statistically more intricate, an intended biplot is used which makes simultaneous contributions of each genotype and each environment to the GEI and allows visual investigation of GEI and full exploration of METs (Zobel *et al.,* 1988). Reliable interpretations of this method is a result of a minimum number of degrees of freedom for interaction, the highest of sum squares of the interaction and elimination of the residual effect, which is effective on error (Gacuh, 1992; Gauch and Zobel, 1996). The use of AMMI stability parameters permits evaluation of yield stability after reduction of the noise from effects of the G×E interaction and, thus, enables better understanding of genotypes performance over several environments for selection of stable and high yielding genotypes (Mirosavlievic *et al*., 2014; Kendal, 2015), in order to introduce these genotypes for special and diverse environments (Kendal and Sayar, 2016). Mohamed *et al*. (2013) demonstrated success of the AMMI method in assessing genotypes performance for selection of the best genotypes. Mohammadi *et al*. (2008) indicated that this method was considered as an appropriate and powerful method for stability analysis compared to other methods. But then, a measure is essential in order to quantify and rank genotypes according to yield stability, so, the AMMI Stability Value (ASV) was introduced by Purchase *et al*. (2000) to acquit this case. Naroui Rad *et al*. (2013) represented the developed *ASV* as the most appropriate single method to describe genotype stability. Farshadfar (2008) has recommended a new achievement, known as Genotype Selection Index (GSI). In the unit criterion, *GSI* combines AMMI stability value and mean yield for yield stability. Some researchers have employed AMMI and *GSI* parameters simultaneously. These approaches discriminated genotypes with general adaptability and high grain yield for rainfed and irrigated conditions, which were in agreement with the results of the biplot analysis (Bavandpori *et al*., 2015; Naroui Rad *et al*., 2013). Since Karimizadeh *et al*. (2008) obtained fairly reliable results from *ASV*; this parameter was introduced as the best among AMMI parameters. The present research aimed to evaluate adaptability and stability of 17 advanced durum wheat genotypes in western parts of Iran under conditions of rainfed and supplementary irrigation over two cropping seasons, using stability parameters.

## MATERIALS AND METHODS

Seventeen advanced wheat genotypes including Saji, Zardak and Sardari as the control, were analyzed by tests set up in a Randomized Complete Block Design (RCBD) with three replications. Names of the tested durum wheat genotypes are given in Table 1. The experiment was performed under rainfed and supplementary irrigation conditions during cropping seasons of 2011-2012 and 2012-2013 at the Dryland Agricultural Research Institute (DARI) of Sararood, Kermanshah, Iran.

Geographical coordinates of the Sararood station are 47° 16’ 48” E longitude and 34° 19’ 12” N latitude at altitude of 1,351 meters above sea level. Climate in the region is classified as semi-arid with 445 mm long-term average rainfall. The soil in the experimental field was clay loam with a pH of 7.8. Sowing was done on 15th October in both growing seasons. Seeds were sown using an experimental drill in 1.2×6 m plots consisting of 6 rows with 20 cm space between rows. Data on seed yield were taken from the middle two rows of each plot. Irrigation was done twice at the flowering stage for the

**Table 1.** The tested durum wheat genotypes and their pedigrees.

| No | Name/Pedigree[a] | No | Name/Pedigree |
|---|---|---|---|
| G1 | Saji | G10 | 19E-M141995 |
| G2 | Zardak | G11 | 18E-M142005 |
| G3 | Sardari | G12 | 19E-M142017 |
| G4 | 19E-TOPDY | G13 | 19E-M142025 |
| G5 | 19E-RASCON | G14 | 19E-MI142038 |
| G6 | 19E-M844859 | G15 | 19E-M142045 |
| G7 | 19E-M141979 | G16 | 19E-M142069 |
| G8 | 19E-M141982 | G17 | 19E-M142070 |
| G9 | 19E-M141994 | | |

[a] Sararood Dryland Agricultural Research Institute.

maturity so that each stage received 25 mm. Seed density was 350 seeds $m^{-2}$ and was managed according to the recommended agronomic practices: fertilizers: 41 kg N $ha^{-1}$ and 46 kg $P_2O_5$ $ha^{-1}$ applied at planting. Yield was determined in grams per square meter (g $m^{-2}$). Field conditions such as cropping season, environment, average rainfall and average temperature are summarized in Table 2.

Combined Analysis Of Variance (ANOVA) for grain yield data was conducted. After verifying existence of the GE interaction (F test significant), analysis of adaptability and stability was performed by the AMMI method suggested by Gauch (1988) and Kendal and Tekdal (2016). GEI was partitioned and biplot graphs were utilized to further assess results of AMMI. Analyses were made using SAS statistical software (SAS Institute, 1996). AMMI Stability Value (ASV) was generated as described by Purchase *et al.* (2000). The Genotype Selection Index (GSI) was calculated based on the method described by Farshadfar *et al.* (2008). All statistical analyses were made by SPSS software version 17.0 (SPSS Inc., 2008).

## RESULTS AND DISCUSSION

### Combined Analysis of Variance

Combined analysis of variance was made for grain yield of 17 wheat genotypes over 4 environments. Results revealed significant difference (P< 0.05) for environment and GEI. The effects of Genotype (G) and Environment (E) accounted for 2.95% and 70.09% of total sum of squares, respectively (Table 3). The GEI effect (10.71% of total sum of squares) was higher than the genotypic effect. This may indicate a considerable deferential response among the genotypes to change of environment and the differential discriminating ability of the test environment (Tolessa, 2015).

Previous reports also indicated that the effect of environment accounted for the largest part of the total variation. Rashidi *et al.* (2013) reported that environment effect accounted for about 81.62% of the total variation, while only a small

**Table 2.** Environments description with average rainfall and temperature.

| Environment | | | Rainfall | | Temperature ($^0$C) | | | |
|---|---|---|---|---|---|---|---|---|
| Code | Year | Condition | Ave. annual rainfall | Number of freezing days | Min | Max | Ave[a] | Ave. relative humidity |
| E1 | 2011-12 | Rainfed | 330.63 | 11 | 3.3 | 17.98 | 10.6 | 47.16% |
| E2 | 2011-12 | Suppl.IRR[b] | 330.63+50 | | | | | |
| E3 | 2012-13 | Rainfed | 430.87 | 7 | 4.5 | 19.17 | 12 | 51.31% |
| E4 | 2012-13 | Suppl.IRR | 430.87+50 | | | | | |

[a] Average temperature of 9 months (October-June), [b] Supplementary Irrigation.

**Table 3.** Combined ANOVA for the grain yield under the rainfed and supplementary irrigation.

| Source of variation | Df | Sum Squares (SS) | Mean Squares (MS) | *F*-test | *SS* (%) |
|---|---|---|---|---|---|
| Genotype | 16 | 1159754.38 | 72484.65 | 1.58$^{ns}$ | 2.95 |
| Environment | 3 | 27581916.59 | 9193972.2 | | 70.09 |
| Genotype×Environment (GEI) | 48 | 4216347 | 87840.56 | 200.47* | 10.71 |
| IPCA1 | 18 | 2266215.92 | 125900.88 | 1.92* | 53.75 |
| IPCA2 | 16 | 1559556.79 | 97472.3 | 2.745* | 36.99 |
| Residual | 14 | 390574.29 | 27898.16 | 2.12* | 9.26 |
| Replication | 2 | 248957.6 | 481260.52 | 0.60$^{ns}$ | |
| Error | 134 | 6145567.25 | 45862.44 | 10.49$^{ns}$ | |
| Total | 203 | 39352542.82 | | | 100 |

* Significant at 5% probability level.

portion (6.31%) of the total sum of squares was attributed to the effect of genotype. Similar reports were made by some authors (Shiri, 2013; Mohamed *et al.*, 2013; Farshadfar *et al.*, 2012; Amiri *et al.*, 2013). A large sum of squares evaluation for environment indicated that environments were diverse and this caused the most variation in grain yield. Cooper (1995) mentioned that the magnitude of GE interaction caused more dissimilarity in genetic systems that are controlling physiological processes that are conferring yield stability in different environments. It was possible to proceed and apply statistical stability methods to analyze GEI for identification of the most stable genotypes in different environments and to select specific genotypes for specific environments.

## Stability Analysis by AMMI Model

In the present study, AMMI analysis partitioned the sum of squares of GEI into two terms of AMMI (Interaction Principal Components Axis, IPCA). The first and second IPCA were found to be significant and explained 90.73% of GEI sum of squares. AMMI is a model family rather than a single model. Many methods have been proposed to determine how many IPCA are adequate to fully approximate a two-way table of data for application in determining whether a biplot under-fits or over-fits the data (Gauch, 2013). Gauch (2006) discussed that model diagnosis is useful. There are three sum of squares from ANOVA i.e. Genotype (G), GEI Signal ($GE_S$), and GEI Noise ($GE_N$), that provide a preliminary indication as to whether AMMI analysis will be worthwhile. The *SS* values for G and GEI are direct outputs from ANOVA. To evaluate *SS* for $GE_N$, readily multiply the error mean square by the number of degrees of freedom (df) for GEI. Then $GE_S$ is obtained by subtracting $GE_N$ from GEI. One of the main purposes of applying the AMMI method is to model diagnosis, which enables researchers to distinguish between $GE_S$ causing actual narrow adaptations and $GE_N$ generating varied and spurious complexity (Gauch, 2013; Gauch, 1992). Voltas *et al*. (2002) mentioned that adequacy of the multiplicative terms containing the real structure of GEI ($GE_S$) was decided by estimating the amount of noise present ($GE_N$) in the interaction and comparing it with the sum of squares retained in consecutive AMMI models. AMMI analysis is appropriate for datasets that have substantial $GE_S$. Sometimes GEI is buried in noise, with the *SS* for $GE_N$ approximately equal to that for GEI. In that case, GEI should be ignored, so, AMMI analysis is inappropriate (Gauch, 2013). In the present study, *SS* for $GE_N$ was evaluated at 2,201,397.12, which showed difference from the total of interaction (4,216,347), subsequently, $GE_S$ was evaluated at 2,014,949.88; results that determine outcomes obtained from AMMI analysis will probably be worthwhile. Similar to results obtained using AMMI models for analysis of multi-environment trials of different crops such as fava bean, rice and bread wheat (Tolessa, 2015; Bose *et al*., 2014a, b; Naroui Rad *et al*., 2013), the AMMI model with the first two components was adequate for a predictive model as well as evaluation of grain yield variation explained by GEI in the present dataset. Prediction assessments demonstrated that AMMI with only the first two multiplicative component axes was sufficient for cross-validation of variation explained by the GEI (Zobel *et al*., 1988; Gauch and Zobel, 1996). Mortazavian *et al.* (2014) stated that the simpler AMMI model was fitting because it makes as many mega-environments as practical agricultural considerations. Additionally, other interactions IPCA (more than two IPCA) capture the usual non-predictive variation (noise) and do not merit a predicting validation data set. Thus, approximation of a real interaction pattern of the 17 advanced wheat genotypes across 4 environments was the best estimation with the first two multiplicative terms of genotype and environment. So, the first two AMMI models used in the present investigation facilitated graphical visualization of the genotypes in low dimensions.

## AMMI Biplots and Graphical Visualization

The display of genotype and environment along the first two principal component axes for the interaction table of residuals is called a biplot. This technique provides useful information on clustering similar genotypes and environments and can provide useful information about GEI to recognize genotypes that are particularly well adapted to an environment (Zobel *et al*., 1988; Crossa *et al*., 2002). In the AMMI1 biplot, the main effect means is plotted on the abscissa simultaneously with IPCA1 scores for both genotype and environment on the ordinate. A displacement along the abscissa demonstrates differences in the main effects, whereas a displacement along the ordinate represents differences in interaction effects. The usual interpretation of a biplot assay is that if a genotype has an IPCA1 score close to zero, then it has small interaction effect that indicates more general adaptation. When a genotype and an environment have the same sign on the PCA axis, their interaction is positive, and when they have different signs, their interaction is negative. A large genotypic IPCA1 score (either positive or negative) has high interaction and reflects more specific adaptation to an environment with an IPCA1 value of the same sign. The best cultivar should be high yielding and stable across environments (Carbonell *et al*., 2004; Gauch, 1992; Yan and Rajcan, 2002). Therefore, according to Figure 1, G11, G15, G8, G16, G6, G13, G14, G12 and G5 were identified as the most stable genotypes with lower scores for interaction and, therefore, high rank for stability. A high mean for yield is also very important for selection of genotype. So, G11 with a yield higher than the total mean (678.32) and a low IPCA1 (-1.52), G8 (with a total mean of 713.23 and IPCA1= -3.52), G16 (with a total mean of

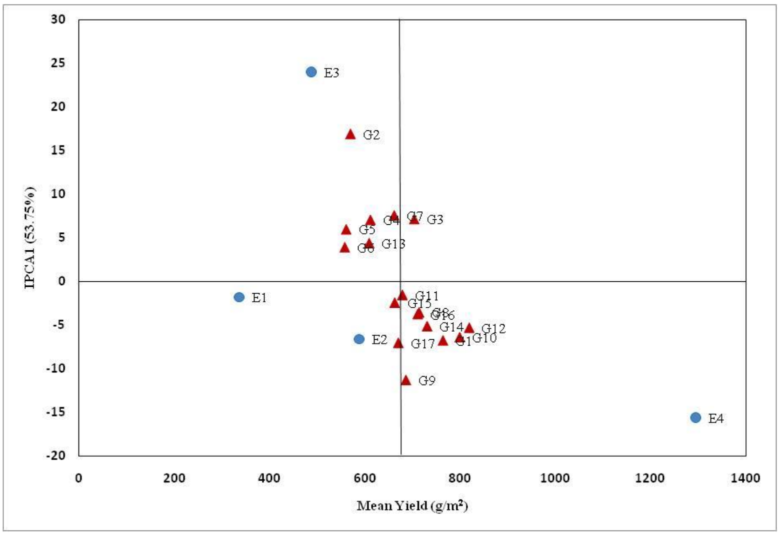


**Figure 1.** The biplot of the first component versus the grain yield of 17 durum wheat genotypes across 4 environments.

710.53 and IPCA1= -3.73) and G14 (with a total mean of 730.05 and IPCA1= -5.12) would be overall winners with relatively less variable yield across environments. G2 and G9 were identified as the most highly unstable genotypes. G9 demonstrated a highly negative IPCA1 score and was determined as better adapted to E2 that had a higher and the same signs for IPCA1 score.

Environment showed variability in both the main effects and interactions. An E3 showed high positive IPCA1 score, E1and E2 showed small negative IPCA1 scores. E2 was determined as a favorable environment for G15 and G17. Similar outcome has been reported by Birla and Ramgiry (2015), Bavandpori *et al.* (2015), and Tolessa (2015) indicating that the AMMI1 biplot statistical model was an effective tool for determining the G×E interaction pattern of grain yield. In the present study, IPCA1 explained 53.75% of GEI followed by IPCA2 (36.99%). Values of IPCA1 and IPCA2 for genotype and environment are presented in Tables 4 and 5. According to Figure 1, E4 showed higher evaluations for both the main effects and interaction effects. This revealed that the relative ranking of genotypes was unstable at E4 making it a less predictable environment for durum wheat evaluation and production compared to the other environments. For better understanding of genotype responses in different environments and determination of patterns of interaction, genotype and environment main effects against their respective (IPCA2) are depicted as points on a plane in the AMMI biplot (Figure 2). The abscissa showed the main effects and the ordinate showed the second multiplicative (IPCA2) axis. Accordingly, G9, G10, G14, G6, G4, G5, G8, G2 and G11 with low IPCA2 scores had less response to the interaction and showed general adaptation to environments. These genotypes were respectively identified as the most stable. G3 demonstrated a highly positive IPCA2 score and was determined as better adapted to E4 that had a higher and the same signs for IPCA2 score. In contrast, G13, G15, G16, G7 and G17, with higher negative IPCA2 scores were adapted to E2 (Figure 2). The best genotype shows high yield and stable performance across a range of environments. G10 with a yield higher than the total mean (798.14) and a low IPCA2 (0.62), G9 (with a total mean of 685.64 and IPCA2= 0.61), G14 (with a total mean of 730.05 and IPCA2= 2.46), G8 (with a total mean of 713.23 and IPCA2= 3.50) and G11 (with a total mean of 678.32 and IPCA2= 4.67) were respectively selectable among the genotypes. G3, G13 and G7 were identified as the more unstable genotypes. Gauch and Zobel (1996) showed that graphical representation of axis, either as IPCA1 or IPCA2, against the main effects was generally informative. Analysis of G×E interaction is crucial for breeders in order to design distribution strategies for new varieties. Precise recommendation of a genotype for general and specific adaptation requires clear understanding of the actual pattern of G×E interaction.

In biplots, it is desirable to use the two

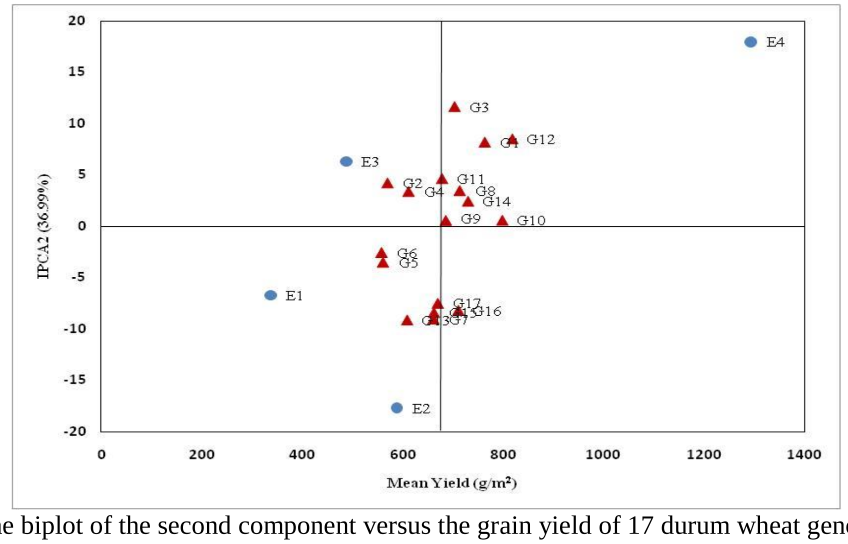


**Figure 2.** The biplot of the second component versus the grain yield of 17 durum wheat genotypes across 4 environments.

components with the highest variance (Zali *et al*., 2009). Interpretation of the GEI pattern using the biplot resulting from genotypic and environmental score of the first two AMMI multiplicative components (using the AMMI2 model) has been reported by several researchers (Bose *et al*., 2014a, b; Akter *et al*., 2014; Bavandpori *et al*., 2015). In AMMI2 biplot, (Figure 3) the environment scores are connected to the origin by vectors. Environments with short lines exert weak interactive forces and those with longer lines exert a harder interaction. According to Figure 3, the E1, E2, E3, and E4 are joined to the origin. E1 has a short line, therefore, it does not exert a hard interactive force. Those genotypes with vector end points distant from the origin contribute relatively more to the interaction and are more sensitive than those with vector end points nearer to the origin (Gauch and Zobel, 1997). Distribution of genotype points in the AMMI2 biplot revealed that the G6, G11, G8, and G14 scattered near the origin, indicate low interaction with environment. This revealed that these genotypes had lower fluctuation to changes in environment. So, they can be introduced as having high general stability. Besides stability, high yield should also be considered for final selection. Accordingly, G11, G14, and G8 were selected as having higher than mean yield and higher general stability based on relative yield of genotype in comparison to the total mean of the studied genotypes. The remaining 13 genotypes were scattered away from the origin in the biplot indicating that they were more sensitive to environment interactive forces. Interaction of genotype with specific environmental conditions was judged by projection of genotype points on to environment lines. Genotypes with IPCA1 score of more than 0, responded positively (adaptable) to the environment that had an IPCA1 score of more than 0, but responded negatively to environments that had an IPCA1 score of less than 0. The reverse applies to genotypes that had an IPCA1 score of less than 0 (Samonte *et al*., 2005). According to the afore-mentioned issues, G15, G16, and G17 with IPCA1 scores below 0 had positive interaction with E1 and E2, hence, exhibited specific adaptation with rainfed and irrigation environments in the first cropping season. In other words, these genotypes showed better responses to these environments. G2, G3, and G4 with IPCA1 score higher than 0 displayed positive interaction with rainfed E3. G10, G9, G1, and G12 with IPCA1 score less than 0 indicated specific adaptability and positive interaction with irrigation E4. According to AMMI2, biplot identified specific adaptability of genotype to both rainfed and irrigation environment over 2 consecutive seasons. In graphical visualization of AMMI biplots, genotypes are demonstrated in clustering form that saves time and accuracy in interpretation and selection (Farshadfar and Sutka, 2003). The discriminating ability of the environments can be explained by the value of IPCA1 and IPCA2. Accordingly, E3 with high IPCA1 and low

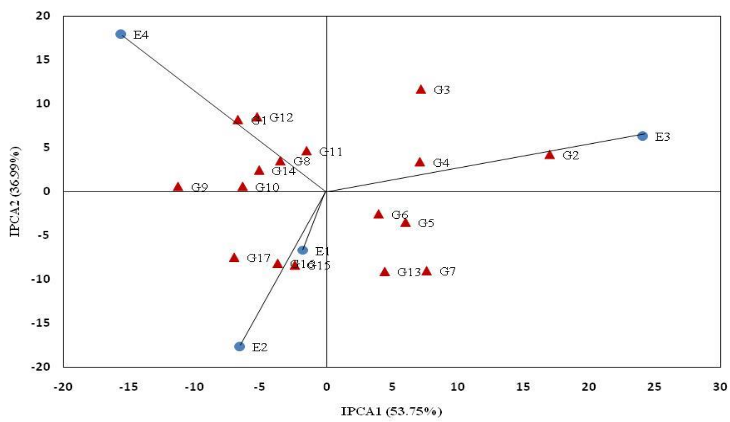


**Figure 3.** The biplot of the first component versus the second component of 17 durum wheat genotypes across 4 environments.

IPCA2 was the most discriminating environment. The angle between the two environment vectors is related to the correlation coefficient between them. An acute angle indicates a positive correlation, an obtuse angle a negative correlation, and right angles indicate no correlation (Yan and Kang, 2003). All environments were negatively correlated because angles were greater than 90°, except E1, which was positively and significantly correlated with E2, whereas the angles between them were less than 90° (Figure 3). Such significant correlation coefficients among tested environments suggest that indirect selection for grain yield can be practical across the test environments. For instance, genotypes adaptable or higher yielding in E1 may show similar responses to E2. Farshadfar *et al*. (2012) reports that rainfed and irrigated conditions in cropping season 2011 produced angles of more than 90° in relation to one another, which indicates opposite response of genotypes to rainfed and irrigated conditions. Similar outcomes were obtained in other studies (Mohamed *et al*., 2013; Kahram *et al*., 2013).

## AMMI Stability Value (ASV) and Genotype Selection Index (GSI)

*ASV* was developed by Purchase *et al.* (2000) in order to resolve unavailability as a quantitative stability measure that is not provided by the AMMI model and is essential for ranking genotypes according to yield stability. Table 4 and 5 indicated IPCA scores and *ASV*. In effect, *ASV* is distant from the coordinate point to the origin in a two-dimensional scatter plot of IPCA1 scores against IPCA2 scores. This approach can be applied to assess stability after diminution of noise from the effects of GEI. Since the IPCA1 score contributes more to the GEI sum of squares, it has to be weighted by the proportional difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 total GE sum of squares (Amiri *et al*., 2013).

In the ASV method, genotypes with lower *ASV* scores are the most stable. On this basis, G11, G8, G6, and G14 were the most stable, while G6 appears as an inappropriate genotype by considering that it had a mean yield evaluation less than that of the total mean. A new approach i.e. the Genotype Selection Index (GSI) has been developed by Farshadfar (2008). *GSI* is calculated by Ranking the mean grain Yield of genotype (RY) across environment and Ranking AMMI Stability Value (RASV). A low value of this parameter indicates an ideal genotype with high mean yield and stability. GSI discriminated G8, G10, G14, and G11 with high general adaptability and yield for the rainfed and supplemental irrigation, which is consistent with

**Table 4.** Mean of yield and stability parameters for examined genotypes.

| Genotype | Mean yield | *RYi* | IPCA1 | IPCA2 | *ASVi* | *RASVi* | *GSI* |
|---|---|---|---|---|---|---|---|
| G1 | 763.13 | 3 | -6.75 | 8.22 | 12.8 | 13 | 16 |
| G2 | 569.8 | 15 | 16.94 | 4.25 | 24.98 | 17 | 32 |
| G3 | 703.08 | 7 | 7.16 | 11.68 | 15.64 | 15 | 22 |
| G4 | 611.53 | 13 | 7.07 | 3.42 | 10.83 | 9 | 22 |
| G5 | 560.8 | 16 | 5.99 | -3.46 | 9.37 | 7 | 23 |
| G6 | 557.87 | 17 | 3.94 | -2.52 | 6.25 | 3 | 20 |
| G7 | 661.14 | 12 | 7.59 | -8.98 | 14.23 | 14 | 26 |
| G8 | 713.23 | 5 | -3.53 | 3.51 | 6.21 | 2 | 7 |
| G9 | 685.64 | 8 | -11.30 | 0.61 | 16.43 | 16 | 24 |
| G10 | 798.14 | 2 | -6.39 | 0.62 | 9.31 | 6 | 8 |
| G11 | 678.32 | 9 | -1.53 | 4.68 | 5.18 | 1 | 10 |
| G12 | 818.09 | 1 | -5.29 | 8.54 | 11.49 | 11 | 12 |
| G13 | 608.83 | 14 | 4.41 | -9.08 | 11.12 | 10 | 24 |
| G14 | 730.05 | 4 | -5.13 | 2.47 | 7.85 | 4 | 8 |
| G15 | 662.18 | 11 | -2.42 | -8.35 | 9.06 | 5 | 16 |
| G16 | 710.53 | 6 | -3.73 | -8.14 | 9.78 | 8 | 14 |
| G17 | 669.78 | 10 | -7.03 | -7.46 | 12.65 | 12 | 22 |

Mean yield (g $m^{-2}$) 676.59

**Table 5.** Mean of yield and stability parameters for examined environments and the AMMI recommendation of genotype for per environment.

| Environment | Mean yield | *RYi* | IPCA1 | IPCA2 | Most suitable genotypes | | | |
|---|---|---|---|---|---|---|---|---|
| E1 | 336.14 | 4 | -1.80 | -6.68 | G15 | G16 | G17 | |
| E2 | 588.16 | 2 | -6.61 | -17.67 | G15 | G16 | G17 | |
| E3 | 487.86 | 3 | 24.04 | 6.34 | G3 | G4 | | |
| E4 | 1294.23 | 1 | -15.63 | 18.00 | G10 | G9 | G1 | G12 |

results of the biplot analysis. These results were similar to those obtained by Bose *et al.* (2014a, b) and Temesgen *et al.* (2015). In these studies, *ASV* and *GSI* were recognized as the most desirable indices for discriminating for the most stable genotypes with high grain yield. In Iran, about two-thirds of crops are cultivated in dryland and rainfed regions. Indeed, rainfall amounts differ and are less stable during the growing period. Also, terminal drought stress is the most important abiotic stress affecting durum wheat productivity in Iran (Sabaghpour *et al.*, 2006). Different genotypes respond to drought stress differently. Genotypes identified as drought resistant have a higher rate of production than others in stress conditions. Adaptable plants have several mechanisms that maintain yield in drought conditions. Escape mechanism allows such plants to reach the stage of maturity before onset of drought, avoidance is a mechanism to maintain plant's water level and tolerant plant has different mechanisms to combat water deficit. They include morphological, anatomical and metabolic traits (Fang and Xiong, 2015; Anjum *et al.*, 2011). In the present study, G3 and G4 displayed specific adaptation with rainfed environment (Table5). These genotypes apply the aforementioned mechanisms for resistance to drought stress. Difference between grain yields in stress condition is hardly affected by difference in drought resistance mechanisms such as escape, as well as intrinsic potential of yield. G15, G16, and G17 exhibited specific adaptation in rainfed and irrigation environments similar to the results of Ruziev *et al.* (1973) who compared several wheat genotypes under rainfed and irrigation conditions. They deduced that, generically, higher yielding genotypes under irrigation also had a higher yield under rainfed. Mudra (1965) showed that the genotypes Azar, Roshan, Reihani, Adl and Sefid had a higher yield under both rainfed and irrigation conditions and were more resistant to drought stress. Numerous researches have been done to understand the GE interaction by the AMMI method and have shown that the method was very effective for studying GEI (Sayar and Han, 2015). Farshadfar *et al.* (2011) analyzed GEI of 14 bread wheat genotypes over 3 consecutive years under two different conditions (irrigated and rainfed) using the AMMI model and used *ASV* and *GSI* parameters. Since they obtained fair results from *ASV*, they introduced this parameter as the most desirable indices for identification of the most stable genotypes with high grain yield. In their studies, AMMI stability value determined G10 and G6 as stable, and based on GSI, the most stable genotypes with high grain yield were G13 and G10. Albert (2004) in his study of GEI compared different methods of stability analysis and finally introduced AMMI as the best method for this purpose. Kahram *et al.* (2013) used 18 durum wheat genotypes over 6 environments to determine genotype stability and to evaluate GEI. They studied stability parameters such as *ASV* and used the graphical method of AMMI. According to results of *ASV*, G13 was specified as adaptable and promising in terms of yield stability (7.454 tons per hectare). According to their results for AMMI biplot, G17, G11, G13 and G15 had lower interaction and G11 and G13 with higher yield were shown to have high general adaptability, and were selected. The improvement of new genotypes with acceptable yield stability in different environments is an important issue in breeding programs. Sabaghnia *et al.* (2013) used AMMI analysis and the *ASV* parameter to determine stability of 20 durum wheat genotypes over 3 years. Their investigation specified G15 and G7 as having higher mean yields and so these genotypes could be regarded as favorable durum wheat genotypes. They proved the stability parameters of AMMI as suitable indices for determining stable genotypes. Sabaghnia *et al*. (2012) analyzed 20 durum wheat genotypes in 15 rainfed environments using the AMMI method. In their study, G13 with a yield of 2,592.45 kg $ha^{-1}$, was determined as the most stable genotype and was recommended for commercial release in semi dry areas in Iran. Many different researches have evaluated wheat genotypes and the AMMI method has been specified for proper identification of genotypes with general and specific adaptability to different environments (Najafian *et al*., 2010; Mohammadi *et al*., 2011; Yan and Kang, 2003; Sayar and Han, 2015). The results of the present investigation illustrate that stability parameters of AMMI are suitable for characterizing stable genotypes and *GSI* parameter can detect high grain yielding genotypes with good stability. Statistical analysis of yield trials of durum wheat under four environments with the AMMI model has revealed practical implications for plant breeding research in durum wheat.

## CONCLUSIONS

The present study demonstrated that G×E interaction was responsible for about 10.71% of total variability in yield performance of durum wheat genotypes. Efficiency of direct selection for grain yield in diverse environments is limited via magnitude of the GEI. The AMMI method was used to reveal aspects of multi dimensionality of the GEI. This model incorporates univariate and multivariate procedures to separate the pattern responsible for the signal interaction from noise, which is an unexplained factor. Noise is of no agronomic interest and is therefore removed to increase the model's predictive ability. In this study, the two-interaction principal component axis was considered as the best predictive model. Based on these two components of the AMMI model, G14 (730.05 g $m^{-2}$), G8 (713.23 g $m^{-2}$) and G11 (678.32 g $m^{-2}$) were selected as having higher than mean yields and high general stability across environments. The G15, G16, and G17 exhibited specific adaptation with rainfed (E1) and irrigation (E2) environments. So, they were considered as having uniform relative superiority under both stress and irrigated conditions. G2, G3, and G4 displayed specific adaptation with rainfed environment (E3), so, they were considered high yielding genotypes under stress conditions. G10, G9, G1, and G12 indicated specific adaptability with irrigation environment (E4) and were considered as having favorable yield under desired irrigated conditions. The E3 was found to have high discriminative ability, so, this environment was considered sufficient for making genotype recommendations. The environment E1 had positive correlation with E2, indicating similar responses of genotypes to rainfed and irrigated conditions in the 2011 cropping season. This finding could be useful for plant breeders in performance trials by targeting appropriate durum wheat genotypes to various environments and by identifying the best environment in relation to economical limitations such as time and cost resources. Both yield and AMMI stability value were considered simultaneously in *GSI* to reduce the effect of GEI and were useful for selecting genotype in a more precise and refined way. GSI discriminated G8, G14, and G11 with high general adaptability and yield for rainfed and supplemental irrigation which indicated that they had the potential to increase productivity in Iran peculiarly in dry regions and should therefore be recommended for further breeding and subsequent release to farmers cultivating durum wheat. Finally, AMMI model analysis was as an effective technique to understand the complex GE interactions in multi-environment trials of durum wheat and this will enable breeders to effectively introduce superior and stable genotypes.

## ACKNOWLEDGEMENTS

The authors would like to thank Dr. Reza Mohammadi from Sararood Dryland Agricultural Research Institute for providing all the necessary facilities. The authors also acknowledge Dr Alireza Etminan for his kind help, guidance and his valuable comments.

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# تعیین پایداری عملکرد در ژنوتیپ‌های گندم دوروم تحت شرایط دیم و آبیاری تکمیلی

**ش. حیدری، ر. عزیزی نژاد و ر. حق پرست**

## چکیده

به منظور تعیین ژنوتیپ‌های پرمحصول و پایدار گندم دوروم، آزمایشی در قالب طرح بلوک‌های کامل تصادفی با سه تکرار روی ۱۷ ژنوتیپ گندم دوروم تحت شرایط دیم و آبیاری تکمیلی در طی سال‌های زراعی ۱۳۹۰-۱۳۹۲ انجام گرفت. تجزیه واریانس مرکب نشان داد که اثر اصلی محیط ۷۰/۰۹ درصد و اثر ژنوتیپ و اثر متقابل ژنوتیپ در محیط به ترتیب ۲/۹۵ و ۱۰/۷۱ درصد از مجموع مربعات کل را توجیه کردند. نتایج، تفاوت قابل توجهی در پاسخ ژنوتیپ‌ها روی محیط‌ها نشان داد. تجزیه اثرمتقابل ژنوتیپ در

محیط بدنبال تجزیه AMMI انجام شد. دو مولفه اول AMMI (IPCA1 و IPCA2) به ترتیب ۵۳/۷۵ و ۳۶/۹۹ درصد از مجموع مربعات اثر متقابل را توجیه نمودند. بر اساس مدل AMMI، ارزش پایداری AMMI (ASV) و شاخص گزینش ژنوتیپی(GSI) ژنوتیپ‌های G11، G8 و G14 برای کلیه محیط‌ها گزینش شدند. بر طبق بایپلات AMMI2، ژنوتیپ‌های G15، G16 و G17 سازگاری خصوصی به محیط‌های دیم و آبیاری نشان دادند. ژنوتیپ‌های G3 وG4 سازگاری خصوصی به محیط دیم و G10، G9،G1 و G12 سازگاری خصوصی به محیط آبیاری داشتند. محیط E3 بیشترین توانایی تمایز را داشت بنابراین به منظور توصیه ژنوتیپ‌ها مد نظر قرار گرفت. نتایج این تحقیق نشان داد که پارامترهای پایداری AMMI برای مشخص کردن ژنوتیپ‌های پایدار مناسب است و پارامتر GSI می‌تواند ژنوتیپ‌های پایدار با عملکرد بالا را به منظور تحقیقات اصلاحی در گندم دوروم شناسایی نماید.