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# YIELD STABILITY OF PERFORMANCE IN MULTI-ENVIRONMENT TRIALS OF BARLEY (*HORDEUM VULGAR* L.) GENOTYPES

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## Abstract

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Fourteen new breeding lines obtained from the barley breeding programs, cultivar Izeh and one local check genotype were evaluated for yield stability at eleven environments. The combined analysis of variance indicated the significance of the environments, genotypes and genotype by environment interaction. According to the environmental variance (EV) and coefficient of variation (CV), genotypes G2, G12, G13 and G14 while based on Wi, P, PP and SH parameters genotypes G4, G10 and G12 were the most stable ones. Regarding both PI and MSPI parameters, genotypes G2, G10 and G11 were the most stable. According to coefficients of three linear regression models, genotypes G1, G6 and G8 were more responsive and had specific adaptability to favorable environments. Considering most of stability parameters, genotypes G4 (3 393 kg ha$^{-1}$) G12 (3 440 kg ha$^{-1}$) can be recommended as the most stable genotype with regard to both stability and yield. In this study, high values of DI were associated with high mean yield, but the other stability methods were not positively correlated with mean yield. The results of principal component analysis and correlation analysis indicated that EV, CV, ER, and DI stability parameters would be useful for simultaneously selecting for high yield and stability.

barley, genotype × environment interaction, stability analysis

### Abbreviations

EV, Environmental variance; PP, Plaisted and Peterson's (1959) mean variance component; P, Plasted's (1960) GE variance component; Wi, Wrike's ecovalance; SH, stability variance; CV, coefficient of variations; PI and MSPI, parameters of superiority index of Lin and Binns; FW, regression model of Finaly and Wilkinson (1963); ER, regression parameters of Eberhart and Russel (1966), PJ and DPJ, regression parameters of Perkin and Jink's (1968); FP and DFP, regression parameters of Freeman and Perkins (1971); ALP and LAM, regression parameters of Tai (1971); D$^2$, Hanson's (1970) genotypic stability; CD, Pinthus's (1973) coefficient of determination, DI desirability index.

Yield stability across a range of environments is a desirable characteristic for all crop genotypes and its assessment is an important feature of every plant improvement program. Therefore, crop researchers have to replicate their experiments over different test locations and across several years as multi-environment trials to assess yield stability of new improved genotypes (Romagosa and Fox, 1993). In most of multi-environment trials, genotype × environment (GE) interaction observed when changes in environmental condition do not have the same effect on all genotypes (Kang, 1998).

Several statistical approaches have been suggested for assessing stability of yield performance for a set of crop genotypes. These stability methods have their own advantages and limitations, but all of them need data from multi-environment trials for yield stability analysis. Some authors preferred to use of univariate parametric stability models due to easy use and interpretation (Mohebodini *et al.*, 2006; Dehghani *et al.*, 2008) and many of them have been presented and compared in the literature (Lin *et al.*, 1986; Flores *et al.*, 1998). Mohebodini *et al.* (2006)

used fifteen univariate stability parameters for assessing yield stability in different lentil genotypes and identified the most stable genotypes with relatively high mean yield arid and semi-arid areas.

In the present paper, a set of 16 barley genotypes, comprising cultivars as well as advanced breeding lines, were evaluated for grain yield performance in a range of test environments characterized by various soil and weather conditions. The investigation was designed to evaluate changes in barley adaptation and yield stability to identify genotypes with high-yield potential and superior yield stability across a range of test environments in arid and semi-arid areas of Iran.

## MATERIALS AND METHODS

The trials were conducted at Gachsaran, Gonbad, Khoramabad and Moghan locations during three years (Tab. I). The third year experiment of Moghan was not in a good manner and so deleted from analysis. Thus, the total number of environment (location × year) evaluated was 11. A total of 16 barley genotypes were constituted using new improved lines, and the two cultivars (Izeh and Gachsaran). All trials used a randomized complete block design with four replicates. Each experimental unit consisted of a 7.35 $m^2$ plot (six rows 7 m long with 0.175 m between rows). Seed density was about 230 seeds $m^{-2}$ according to the standard practices and about 70 kg $ha^{-1}$ of N fertilizer was applied according to standard agronomic practices.

Environmental variance (Roemer, 1917; cited in Becker, 1981), Plaisted and Peterson's (1959) mean variance component, Plasted's (1960) GE variance component (P), Wrike's ecovalance ($W^2$), stability variance of Shukla (1972), the coefficient of variations (CV) of Francis and Kanenberg (1978), and Lin and Binns (1988) superiority index (PI) are used.

Also, some regression models such as of Finaly and Wilkinson (1963), Eberhart and Russel (1966), Perkin and Jink's (1968), Freeman and Perkins (1971), Tai (1971) are caculated. Finaly, Hanson's (1970) genotypic stability ($D^2$), Pinthus's (1973) coefficient of determination (CD) and desirability index (DI) of Hernandez *et al.* (1993) are computed. The ranking of genotypes based on the mentioned stability parameters were computed with spearman's rank correlation procedure and then a principle component analyses (PCA) was done to understand the relationship among stability parameters and grouping tested genotypes. All analyses were carried out using the SAS program of Hussein *et al.* (2000).

## RESULTS AND DISCUSSION

The residuals mean squares were not associated to environment mean yield (r = 0.12, P > 0.05) thus the data were not transformed. Effects of genotype, environment and the GE interaction were significant at P < 0.01 (Tab. II). Of the total variance, a larger portion of variation was caused by the environment effect (94.2%) and the GE interaction (1.8%). The genotypes accounted only about 4% of total variation due to GE+E+G sources. The yield of genotype is a result of the three effects including genotype, environment and GE interaction, but environment variation is said to cause more than 80% of yield variation. Accordingly in this study, both genotype and GE interaction accounted only 5.8% of yield variations while these effects are relevant to genotype evaluation. The high significant GE interaction would result in ranking of genotypes or crossover GE interaction (Baker, 1988), and complicate selection because it measures the degree to which performance in one environment fails to predict performance in the other.

According to the low magnitudes of environmental variance (EV) and coefficient of variation (CV), genotypes G2, G12, G13 and G14 were more stable (Tab. III). It is interesting that among these genotypes, the mean yield performance of G12 following to G13 were high. The most stable genotypes are preferred via most agronomists

II: *Combined analysis of variance for barley multi-environment trials*

| Sources of variation | DF† | Mean Squares | % of GE+E+G |
|---|---|---|---|
| Environment (E) | 10 | 352 222 28** | 94.2 |
| Replication/E | 33 | 702 331 | |
| Genotype (G) | 15 | 148 929 6** | 4.0 |
| GE | 150 | 676 638** | 1.8 |
| Error | 495 | 153 069 | |

† Degrees of freedom
** Significant at the 0.01 probability level

I: *Geographical properties of four test locations*

| Location | Longitude | Altitude | Rainfall | Soil | |
|---|---|---|---|---|---|
| | Latitude | (m) | (mm) | Texture | Type |
| Gachsaran | 50° 50° E<br>30° 20° N | 710 | 430.8 | Silty Clay Loam | Regosols |
| Gonbad | 55° 12° E<br>37° 16° N | 45 | 367.5 | Silty Clay Loam | Regosols |
| Khoramabad | 23 ° 26° E<br>48 ° 17° N | 1 148 | 523.1 | Silt-Loam | Regosols |
| Moghan | 48° 03´E<br>39° 01´N | 32 | 271.2 | Sandy-loam | Cambisols |

III: *Variance-based parameters for stability analysis of barley multi-environment trials*

| | Mean | EV | CV | Wi | P | PP | SH | PI | MSPI |
|---|---|---|---|---|---|---|---|---|---|
| | Kg ha$^{-1}$ | ×$10^9$ | | ×$10^9$ | ×$10^9$ | ×$10^9$ | ×$10^9$ | ×$10^5$ | ×$10^4$ |
| G1 | 3805 | 11.13 | 28.4 | 17.37 | 1.77 | 1.68 | 1.86 | 1.15 | 6.83 |
| G2 | 3690 | 4.95 | 19.1 | 17.31 | 1.77 | 1.68 | 1.86 | 1.43 | 6.08 |
| G3 | 3474 | 6.24 | 22.7 | 16.82 | 1.74 | 1.68 | 1.85 | 2.64 | 8.99 |
| G4 | 3393 | 6.06 | 22.9 | 8.42 | 1.32 | 1.75 | 0.84 | 2.79 | 6.20 |
| G5 | 3165 | 8.45 | 29.0 | 11.63 | 1.47 | 1.72 | 1.21 | 4.41 | 7.68 |
| G6 | 3591 | 10.62 | 28.6 | 17.66 | 1.79 | 1.68 | 1.91 | 1.94 | 7.41 |
| G7 | 3367 | 8.64 | 27.6 | 13.31 | 1.56 | 1.71 | 1.43 | 3.19 | 8.74 |
| G8 | 3483 | 10.75 | 29.7 | 18.03 | 1.81 | 1.68 | 1.94 | 2.30 | 6.06 |
| G9 | 3347 | 7.01 | 25.0 | 11.89 | 1.48 | 1.72 | 1.24 | 3.27 | 8.28 |
| G10 | 3561 | 5.85 | 21.5 | 5.11 | 1.12 | 1.77 | 0.46 | 1.43 | 1.00 |
| G11 | 3549 | 7.26 | 24.0 | 9.74 | 1.37 | 1.74 | 0.99 | 1.76 | 3.82 |
| G12 | 3440 | 4.83 | 20.2 | 9.26 | 1.34 | 1.74 | 0.93 | 2.46 | 5.47 |
| G13 | 3119 | 4.11 | 20.5 | 41.47 | 3.06 | 1.53 | 4.62 | 5.45 | 14.58 |
| G14 | 3488 | 3.22 | 16.3 | 14.49 | 1.62 | 1.72 | 1.54 | 2.30 | 6.37 |
| G15 | 3488 | 6.54 | 23.2 | 11.74 | 1.47 | 1.72 | 1.22 | 2.28 | 6.10 |
| G16 | 3192 | 7.32 | 26.8 | 29.51 | 2.42 | 1.59 | 3.25 | 4.92 | 14.68 |

but the plant breeders prefer the most adaptable genotypes. Fortunately, in this dataset these two different concepts of stability are observed simultaneously in both G12 and G13 genotypes. Analysis of stability using Wi, P, PP and SH parameters gave similar results and identified genotypes G4, G10 and G12 as the most stable ones. Similar to EV, the two dynamic and static concepts of stability are seen simultaneously in G12 genotype. Lin and Binns (1988) suggested the use of two stability parameters (PI and MSPI) when explanting the performance of one genotype across a range of environments. Based on PI values, genotypes G1, G2 and G10 were identified the most stable while regarding both PI and MSPI parameters, genotypes G2, G10 and G11 were the most stable ones (Tab. III). None of the mentioned genotypes had high mean yield and so could not be regarded as the most favorable genotypes.

When no distinct source of the GE interaction can be found, selection of genotypes with broad adaptation would be expected to yield dependably across a wide range of environments (Annicchiarico, 2002; Sabaghnia *et al*., 2008). This strategy indicates both static or dynamic stability and selection for yield stability has been recommended in the mentioned GE investigation for lentil in Iran (Mohebodini *et al*., 2006; Dehghani *et al*., 2008). For each of these investigations, grouping of genotypes with minimal GE was relatively successful. In multi-environment trials, a genotype is regarded to be stable if its performance is relatively constant across different environments. According to Becker and Leon (1988) static concept of stability (biological), a stable genotype is the one with minimal variance for yield across test environments. However, static concept has received little attention from plant breeders and especially agronomists as they prefer genotypes with high mean yields in favorable environments (Becker, 1981). Genotype with a constant high yield referred to as dynamic stability concept is the preferred option in commercial plant breeding (Flores *et al*., 1998). Regarding these comments, it seems that except PI and MSPI parameters, one of the stable genotypes based on the other stability parameters which based on variance components, had high mean yield and so reflected some aspects of dynamic stability concept with detecting genotypes G12 and G13 as the most stable.

The results of the different linear regression models are given in Tab. IV and showed that according to coefficients of linear regression (Finaly and Wilkinson, 1963; Perkin and Jink, 1968; Freeman and Perkins, 1971) genotypes G1, G6 and G8 were more responsive and had specific adaptability to favorable environments while genotypes G2, G13 and G14 were less responsive and had specific adaptability to unfavorable or poor environments. Therefore, genotypes G2, G13 and G14 were most stable while genotypes G1, G6 and G8 adaptable to good environmental conditions. Considering both coefficient of regression and deviation from linear regression parameters in three mentioned regression models, genotypes G1 and G10 could be regarded as the most sable (Tab. IV). All of these stable genotypes showed relatively moderate or low mean yield and so had static stability concept. According to Alpha parameter of Tai's (1971) regression model (ALP), genotypes G4, G10 and G15 were more responsive and with simultaneous consideration of Lambda parameter (LAM), genotypes G4, G10 and G15 were most stable (Tab. IV). Pinthus's (1973) method uses the coefficient of determination (CD) of linear

IV: *Regression-based parameters for stability analysis of barley multi-environment trials*

| | FW | ER | PJ | DPJ | ALP | LAM | FP | DFP | CD | DI |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $\times 10^9$ | | $\times 10^9$ | | | | $\times 10^5$ | | $\times 10^3$ |
| G1 | 1.40 | 12.24 | 0.40 | 0.93 | 0.168 | 3.98 | 1.13 | 1.20 | 92 | 3.93 |
| G2 | 0.79 | 5.23 | –0.21 | 1.66 | –0.086 | 4.77 | 0.59 | 2.73 | 65 | 3.76 |
| G3 | 0.91 | 6.89 | –0.09 | 1.82 | –0.036 | 4.86 | 0.71 | 2.51 | 71 | 3.56 |
| G4 | 0.97 | 6.73 | –0.03 | 0.93 | –0.011 | 2.46 | 0.78 | 0.75 | 85 | 3.48 |
| G5 | 1.16 | 9.23 | 0.16 | 1.13 | 0.067 | 3.22 | 0.92 | 1.45 | 87 | 3.27 |
| G6 | 1.30 | 111.24 | 0.30 | 1.41 | 0.125 | 4.56 | 1.08 | 2.78 | 86 | 3.71 |
| G7 | 1.16 | 9.44 | 0.16 | 1.31 | 0.068 | 3.71 | 0.99 | 1.45 | 85 | 3.47 |
| G8 | 1.31 | 111.31 | 0.31 | 1.43 | 0.128 | 4.63 | 1.11 | 2.72 | 86 | 3.60 |
| G9 | 1.03 | 7.79 | 0.03 | 1.32 | 0.012 | 3.47 | 0.83 | 0.53 | 81 | 3.44 |
| G10 | 0.99 | 6.5 | –0.01 | 0.56 | –0.006 | 1.49 | 0.78 | 1.06 | 90 | 3.65 |
| G11 | 1.07 | 8.03 | 0.07 | 1.05 | 0.030 | 2.81 | 0.82 | 0.75 | 85 | 3.65 |
| G12 | 0.85 | 5.23 | –0.15 | 0.89 | –0.061 | 2.56 | 0.68 | 1.18 | 81 | 3.52 |
| G13 | 0.50 | 3.01 | –0.50 | 3.06 | –0.210 | 10.42 | 0.44 | 1.93 | 26 | 3.16 |
| G14 | 0.66 | 2.88 | –0.34 | 0.91 | –0.141 | 3.47 | 0.41 | 1.81 | 71 | 3.55 |
| G15 | 0.99 | 7.27 | –0.01 | 1.34 | –0.005 | 3.43 | 0.87 | 1.12 | 80 | 3.58 |
| G16 | 0.90 | 8.07 | –0.10 | 3.21 | –0.043 | 8.55 | 0.68 | 3.63 | 56 | 3.27 |

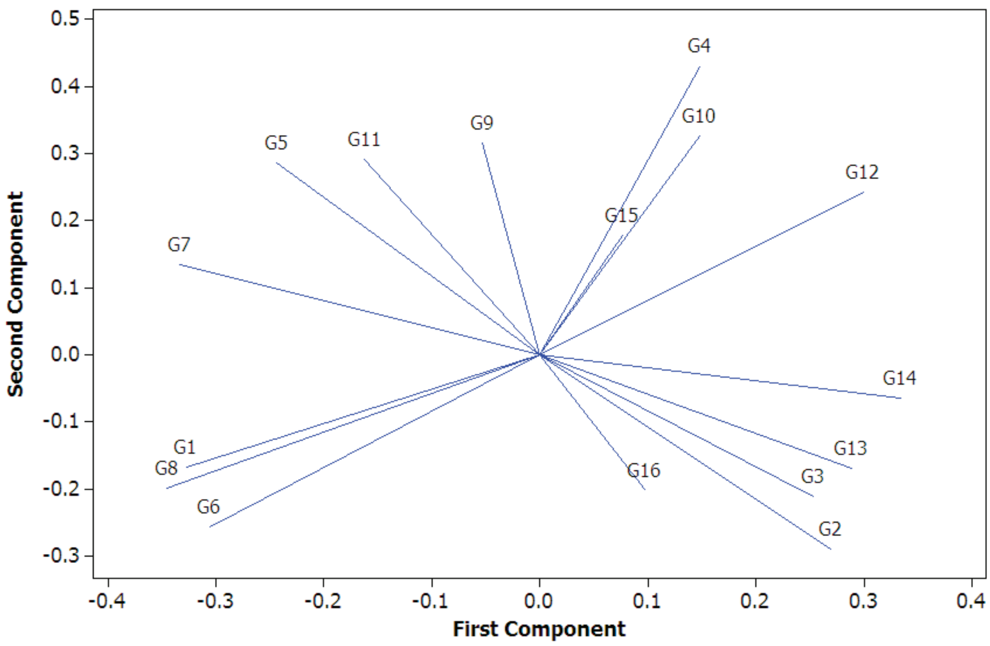
V: *Spearman's rank correlation between various stability parameters for barley multi-environment trials*

| | Mean | EV | CV | Wi | P | PP | PI | MSPI | FW | ER | PJ | DPJ | ALP | LAM | FP | DFP | CD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EV | 0.13* | | | | | | | | | | | | | | | | |
| CV | –0.10 | 0.95 | | | | | | | | | | | | | | | |
| Wi | –0.06 | 0.26 | 0.23 | | | | | | | | | | | | | | |
| P | –0.07 | 0.25 | 0.23 | 1.00 | | | | | | | | | | | | | |
| PP | –0.06 | 0.24 | 0.22 | 1.00 | 1.00 | | | | | | | | | | | | |
| PI | –0.98 | –0.11 | 0.10 | 0.18 | 0.20 | 0.19 | | | | | | | | | | | |
| MSPI | –0.60 | 0.16 | 0.21 | 0.58 | 0.58 | 0.57 | 0.71 | | | | | | | | | | |
| FW | –0.27 | –0.92 | –0.88 | 0.02 | 0.04 | 0.04 | 0.29 | 0.12 | | | | | | | | | |
| ER | 0.09 | 0.99 | 0.97 | 0.26 | 0.25 | 0.24 | –0.07 | 0.14 | –0.91 | | | | | | | | |
| PJ | –0.27 | –0.92 | –0.88 | 0.02 | 0.04 | 0.04 | 0.29 | 0.12 | 1.00 | –0.91 | | | | | | | |
| DPJ | –0.29 | 0.16 | 0.19 | 0.77 | 0.78 | 0.78 | 0.39 | 0.61 | 0.15 | 0.19 | 0.15 | | | | | | |
| ALP | 0.06 | 0.12 | 0.09 | 0.71 | 0.72 | 0.70 | 0.01 | 0.28 | –0.02 | 0.10 | –0.02 | 0.21 | | | | | |
| LAM | –0.13 | 0.15 | 0.11 | 0.95 | 0.95 | 0.95 | 0.26 | 0.66 | 0.16 | 0.14 | 0.16 | 0.87 | 0.58 | | | | |
| FP | –0.23 | –0.90 | –0.87 | 0.00 | 0.01 | 0.01 | 0.25 | 0.07 | 0.98 | –0.90 | 0.98 | 0.09 | 0.00 | 0.12 | | | |
| DFP | 0.02 | 0.14 | 0.12 | 0.79 | 0.81 | 0.80 | 0.10 | 0.41 | 0.14 | 0.17 | 0.14 | 0.67 | 0.58 | 0.79 | 0.13 | | |
| CD | –0.36 | –0.61 | –0.59 | 0.37 | 0.38 | 0.39 | 0.44 | 0.41 | 0.83 | –0.59 | 0.83 | 0.57 | 0.05 | 0.52 | 0.78 | 0.34 | |
| DI | 0.98 | 0.23 | 0.01 | –0.03 | –0.05 | –0.04 | –0.97 | –0.61 | –0.36 | 0.19 | –0.36 | –0.22 | 0.06 | –0.10 | –0.32 | 0.04 | –0.41 |

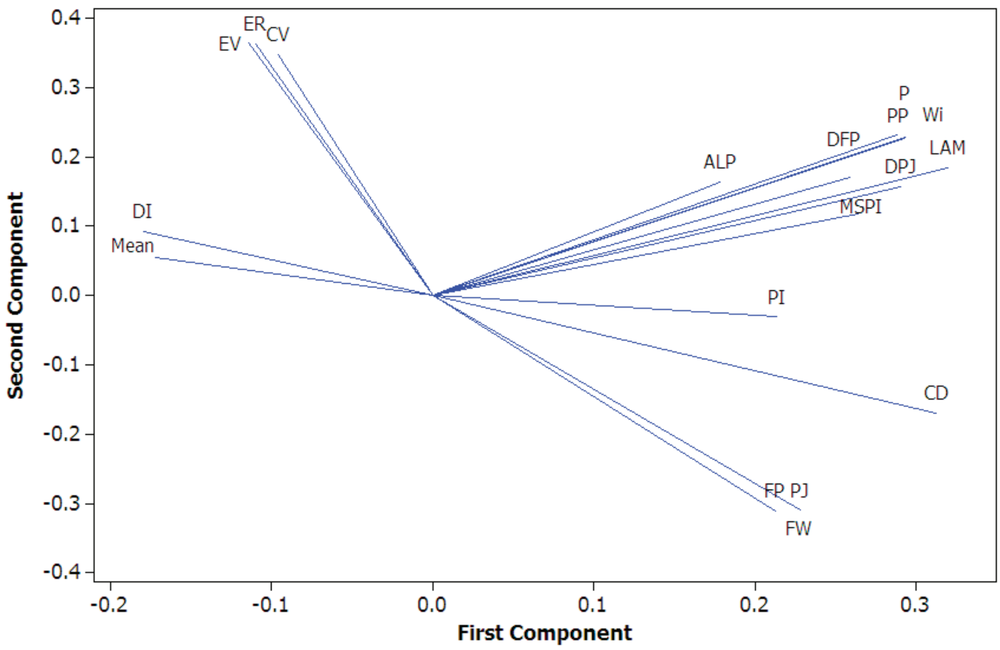
* Critical values of correlation P<0.05 and P<0.01 (D.F. 14) are 0.49 and 0.62, respectively.

regression model for verification of regression model and indicated that genotypes G1, G5 and G10 had high coefficient of determination (Tab. IV). According to desirability index (DI) of Hernandez *et al.* (1993) and regarding combining both yield and regression coefficient, genotypes G5, G13 and G16 were the most stable ones (Tab. IV).

Each one of the stability methods produced a unique genotype ranking and the Spearman's rank correlations between each pair of stability parameters were computed (Tab. V) and demonstrated a highly positive significant rank correlation between DI and mean yield. Dehghani *et al.* (2008) reported similar results for DI and mean yield. The mean yield indicate negative correlation with the both PI and MSPI stability parameters. Also, the mean yield did not show any positive or negative correlation with the other stability parameters (Tab. V). Similar findings were reported by Mohebodini *et al.* (2006) in lentil and Sabaghnia *et al.* (2012) in durum wheat. The EV and CV parameter had positive significant correlation with




1: *Plot of the first two principal components for 16 barley genotypes based on different stability parameters*




2: *Plot of the first two principal components for different stability parameters based on ranks of 16 barley genotypes through these parameters*

each other and ER while had negative significant correlation with FW, PJ and FP coefficient of linear regression. The Wi, P, PP and SH parameters had positive significant correlation with each other and with MSPI, DPJ, Alpha, Lambda and DFP stability parameters (Tab. V). In spite of our results, Dehghani *et al.* (2008) found that all regression models have relatively similar results. The PI and MSPI stability parameters were associated with each other and had negative significant correlation DI. The regression coefficient of FW, PJ and FP models and CD parameter were correlated positively with each other (Tab. V).

To reveal associations among genotypes, a PCA was performed using ranks of barley genotypes based on the stability parameters. The first two PCs explained 70% (42% and 28% by PCA1 and PCA2, respectively) approximately of the barley genotypes. The plot of first two PCA indicated that most of genotypes had clear differences (Fig. 1), which maybe due to different origin of the genotypes and their crossing parents. Also, another PCA based on correlation matrices was performed to understand the relationship among the stability parameters. For better visualization, the two first PCA were plotted against each other. The first two PCs explained 81% (43% and 38% by PC1 and PC2, respectively) approximately of the stability methods. In this plot, the PCA1 axis mainly distinguishes the methods of EV, CV, ER, and DI from the other methods. Mean yield groups near these statistics, and we refer to these as Group 1 stability measures. The second PCA axis separates FP, FW, PJ, CD and PI parameters as Group 2 from the other stability parameters (Group 1 and Group 1 which consist on P, PP, SH, Wi, DFP, DPJ, LAM, ALP and MSPI parameters). It could be conclude that Group 1 reflects dynamic or agronomic stability concept while Groups 2 and 3 reflect static or biologic stability concept. According to Flores *et al.* (1998), the PI and MSPI of Lin and Binns (1988) are associated only with yield and show little or no correlation with stability parameters while some statistics such as Eberhart and Russell (1966) and Shukla (1972) methods are associated only with stability and show little or no correlation with yield.

Plant breeders encounter GE interaction when testing genotypes across a number of test environments. In this investigation, the combined ANOVA was based on random effect of environment and thus we could not get the main effect of year, location and the interaction between them. However, analysis of variance is uninformative in the explanation of GE interaction and it is necessary to use other statistical models such as regression procedures are more useful for understanding GE interaction. The GE interaction is an important source of variation in any crop improvement. According to Freeman (1972) one of the main reasons for growing genotypes over a wide range of environments is to estimate their yield stability the use of two stability concepts may be valuable for some purposes. For a long time, most breeders used static stability to characterize a genotype under variable environmental conditions (Becker and Leon, 1988). In contrast, most farmers prefer a dynamic or agronomic concept of stability.

## CONCLUSIONS

Several stability parameters that were used in this investigation quantified genotype stability with respect to yield and so both mean yield and stability of performance must be considered regarded to exploit the useful effects of GE interaction and to make genotype selection more precise. Genotypes G4 (3 393 kg ha$^{-1}$) G12 (3 440 kg ha$^{-1}$) can be recommended as the most stable genotype with regard to both stability and yield. These genotypes are recommended for commercial release as cultivars by the Dry Land Agricultural Research Institute of Iran for arid and semi-arid areas. In this investigation, EV, CV, ER, and DI stability parameters found to be useful for identification of the most favorable genotypes.

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