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Yield Stability in Chickpea (*Cicer arietinum* L.) and Study Relationship among the univariate and multivariate stability Parameters

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Chickpea (*Cicer arietinum* L.) is traditionally grown as a rain fed crop globally, specifically in Middle East. Its seed is a rich source of protein for human consumption in developing countries such as Iran. The development of genotypes, which can be adapted to a wide range of diversified environment, is the ultimate goal of plant breeders in a crop improvement program. In this study, several univariate and multivariate stability methods were used to evaluate the genotype × environment (GE) interaction in 17 chickpea genotypes. Field experiments were carried out in 16 environments of Iran's chickpea producing areas to characterize GE interaction on grain yield of 17 chickpea genotypes. Combined analysis of variance across environments indicated that both environments and GE interactions influenced significantly the genotypes performance for yield. Twenty univariate and multivariate stability methods and techniques were used to describe the GE interaction and to define stable genotypes in relation to the yield considered in this study. The different stability statistics which measured the different aspects of stability was substantiated by Spearman's rank correlation coefficient. According to Spearman's rank correlation coefficient three groups of stability parameters can be defined that the results of these different stability methods were variable. We used group 1, include Lin and Binns superiority measure (P_i), Hernandez et al (1993) parameter (D_i), GGE Biplot method and Principal coordinate method for introduction some genotypes to farmers. The identified superior genotypes significantly differ from the local check cultivars and therefore farmers in semi arid areas of Iran can use these genotypes.

Key words: Genotype × environment interaction - *Cicer arietinum* L. - Regression analysis - univariate and multivariate stability statistics

Legumes and specially chickpea (*Cicer arietinum* L.) are important productions of food in the arid and semi-arid countries of west Asia such as Iran. They are important sources of good quality protein in the diets of people and are valuable as animal feed. Food legume in Iran accounts for nearly 1.32% of the world pulses area and 0.9% of the world production (Sabaghpuour et al, 2003). Chickpea is the third most important food legume with a total annual global production of 7.5 million tones from 10.3 M ha (FAO, 2004). Chickpea is grown on

700,000 hectares in the Iran and ranks fourth in world after India, Pakistan and Turkey. It is the most important legume of the country and grown on more than 64% of the total food legume area (FAO, 2001). Its seed is a rich source of protein for human consumption in developing countries such as Iran. Although chickpea-breeding programs have some priorities in common, the major objective of increasing the genetic potential of yield for most, if not for all, can be achieved via breeding for higher yield potential or eliminating hazards that reduce yield. The development of cultivars or varieties, which can be adapted to a wide range of diversified environments, is the ultimate goal of plant breeders in a crop improvement program. Major goal of plant breeding programs is to increase stability and stabilize crop yield across environments. The study of the genotype × environment (GE) interaction may assist understanding of stability concept. Understanding the structure and nature of GE interaction is important in plant breeding programs because a significant GE interaction can seriously impair efforts in selecting superior genotypes relative to new crop introductions and cultivar development programs. It can help determine if they need to develop cultivars for all target environments or if they should develop specific cultivars for specific target environments. Phenotypic stability has been extensively studied by biometricians who have developed numerous methods to analyze it (Eberhart and Rusell, 1966; Shukla, 1972; Lin and Binns, 1988; Kang and Pham, 1991). According to Lin et al. (1986) there are three Types of parametric stability of known as Type 1, 2 and 3. In type 1, (Roemer, 1917), a genotype is considered to be stable provided that the environmental variance is small; in Type 2, stability variance (Shukla, 1972) and ecovalence (Wricke, 1965), a genotype is considered to be stable if its response to environment is parallel to the mean response of all genotypes in the trial and in Type 3, squared deviations from regression (Eberhart and Russell, 1966) and coefficients of determination (Pinthus, 1976), a genotype is considered to be stable if the residual mean squares from the regression models on the environment index is small. Wricke (1962) proposed that the contribution of a genotype to the interaction sum of squares can be used as a measure of its stability. This statistic was designated ecovalence (W_i). Shukla (1972) modified the ecovalence in order to give an unbiased estimate of the G × E variance for every genotype: it was called 'stability variance (σ_i^2). Francis and Kannenberg (1978) used the conventional coefficient of variation CV of each genotype as a stability measure. Lin and Binns (1988) developed a superiority measure of genotypic performance (P_i), defined as the mean square distance between the genotype's response and the maximum response averaged across environments. In chickpea, several studies of stability have been performed (Bakhsh et al., 1995; Nleya et al., 2001) but it is still very important information that should be available for the chickpea genotypes. In Iran, the information pertaining to genotype × environment interaction for chickpea content is limited. This study evaluates some genotypes of chickpea for their grain yield stability under different locations and compares the stability parameters that are used in genotype by environment interactions analyses. The objectives of this study were (1) to identify chickpea genotypes that have high yield and stable performance across different locations (2) to study the relationship among univariate and multivariate stability statistics.

Materials and methods

Experiments

Data analyzed in this study obtained from sets of chickpea yield trials conducted during for three years (2002-2004) at six different research stations in Iran included Ghachsaran, Gorgan, Urmia, Ilam, Kermanshah and Lorestan, except for Ilam and Ghachsaran locations, which trials performed during two years (2003-2004).

Description of the experimental sites is indicated in Table 1. In each environment (year × location), 17 genotypes were tested. The genotypes developed by various breeders at different research institutes/stations of Iran and International Center for Agricultural Research in Dray Areas (ICARDA). Names, cods and origin of these genotypes are given in Table 2. At each environment a randomized complete block design with four replications was used. The trial fields were plowed with tractors usually from January to March and disc harrowed few days prior to planting time. The recommended fertilizers of both nitrogen and phosphate were manually incorporated into the soil at planting. The experimental plots consisted of four rows of 4 meters length. Row to row and plant-to-plant distances was kept at 30 cm and 10 cm respectively at all environments. Data on seed yield were taken from the middle two rows of each plot, leaving aside the guard rows on either side of a plot. Upon harvested seed yield was determined for each genotype at each test environments, the average was computed in accordance with the experimental design.

Table 1. Description of the experimental sites and their overall agro-climatic conditions, like total annual rain fall and average minimum and maximum temperature

Environments		Mean	Latitude	Altitude	Temp(°C)[a]		Rainfall	Soil Condition	
Location	Year	Kg ha^{-1}	Longitude	(meter)	Min	Max	(mm)[b]	Texture	Type[c]
Gorgan	2002	2026.84	36°51'N	13.3	4.4	31.5	290.3	Sandy-Loam	Cambisols
	2003	1998.37	54°16'E		4.1	33.5	543		
	2004	2616.47			3.8	34.2	425		
Kermanshah	2002	1248.96	34°19'N	1322	3.8	38	358.6	Silt-Loam	Cambisols
	2003	1157.50	47°07'E		3	39.5	216		
	2004	1456.79			5.3	37	398.5		
Lorestan	2002	1115.09	23°26'N	1147.7	5.6	38.2	499	Silt-Loam	Regosols
	2003	957.62	48°17'E		3.4	34.2	369.5		
	2004	1181.95			4	32	430.8		
urmia	2002	1214.11	37°32'N	1313	5.3	30.4	338.2	Sandy-Loam	Cambisols
	2003	1283.81	45°5'E		4.1	31.7	304.1		
	2004	1376.33			4.5	32	350		
Ghachsaran	2002	2053.31	30°10'N	669.5	5.2	38.1	400	Silt-Loam	Regosols
	2003	2011.90	50°50'E		6.4	39.1	487.5		
Ilam	2002	1904.04	33°38'N	1363.4	4.2	35.6	750.2	Silt-Loam	Cambisols
	2003	1833.99	46°25'E		5	32.1	564		

[a]Mean Seasonal Temperature; [b]Annual means rainfall; [c]According to FAO system of soil classification.

Table 2: Genotype code, name and origin of 17 chickpea genotypes

Genotype code	name	Origin	Genotype code	name	Origin
G1	S 96002	ICARDA	G10	Flip 93-48C	ICARDA
G2	S 95293	ICARDA	G11	Flip 94-60C	ICARDA
G3	S 96003	ICARDA	G12	Flip 94-30C	ICARDA
G4	S 96027	ICARDA	G13	ILC 482-205C	ICARDA
G5	S 96078	ICARDA	G14	Flip 94-123C	ICARDA
G6	S 96032	ICARDA	G15	Flip 85-57 × 12-071-1005	ICARDA
G7	S 96019	ICARDA	G16	Kurosh × 12-071	IRAN
G8	Flip 93-93	ICARDA	G17	Bivanij	IRAN
G9	ILC 6142	ICARDA			

Statistical Analysis

Combined analyses of variance were performed over environments using GenStat software version 9. Then, stability analyses were conducted using eleven parametric measures of phenotypic stability using SAS (SAS Institute, 1996) and GenStat version 9. The univariate stability

parameters were performed in accordance with environmental variance (Roemer, 1917), Coefficient of variation (Francis and Kannenberg, 1978), Wrick's (1972) ecovalence, Shukla's (1972) stability variance, Plaisted and Peterson's (1959) parameter, Plaisted's (1960) stability parameter Lin and Binns' (1988) cultivars superiority measure, Hanson's (1970) stability parameter, Hernandez et al (1993) parameter and regression methods (Finlay and Wilkinson (1963); Eberhart and Russell, (1966); Freeman and Perkins (1971); Perkins and Jinks (1968); Tai (1971). Also, the multivariate stability parameters were performed in accordance with additive main effects and multiplicative interaction (AMMI) model (Zobel et al., 1988), site regression model (Yan *et al*., (2000), principal coordinate analysis (Gower, 1966). The Spearman's coefficient of rank correlation was computed for all possible pair-wise comparisons of the stability parameters using SAS. Also, a hierarchical cluster analysis with average linkage method based on nonweighted values of 17 stability parameter and mean yield was used to classification.

Univariate stability measures

Wricke's ecovalance (W_i^2)

Wricke's (1962) ecovalence (W_i^2) is calculated, and given by $\sum_{j=1}^{q}(X_{ij}-\overline{X}_{i.}-\overline{X}_{.j}+\overline{X}_{..})^2$. Where X_{ij} is the mean yield of the i genotype in the j environment, $\overline{X}_{i.}$ is the mean of the genotype i in all environments, $\overline{X}_{.j}$ is the mean of all genotypes in j environments and $\overline{X}_{..}$ is the mean of all genotypes in all environments. Ecovalence measures the contribution of a genotype to the total GE interaction. High ecovalence reflects the capacity of a genotype to yield more consistent results among environments than other genotypes. A genotype with low ecovalence ($W_i^2 = 0$) is regarded as stable in all environments.

Stability variance of Shukla (1972)

Shukla (1972) modified the ecovalence in order to give an unbiased estimate of the GE variance for every genotype: it was called 'stability variance (σ_i^2). He also gave a i criterion for testing the significance of σ_i^2 to determine whether a genotype was stable or not. The stability statistic is estimated as follows:

$$\sigma_i^2 = \frac{g}{(g-2)(e-1)}\sum_{j=1}^{q}(X_{ij}-\overline{X}_{i.}-\overline{X}_{.j}+\overline{X}_{..})^2-\frac{SS(GE)}{(g-1)(g-2)(e-1)}$$

Where X_{ij} is the mean yield of the i genotype in the j environment, $\overline{X}_{i.}$ is the mean of the genotype i in all environments, $\overline{X}_{.j}$ is the mean of all genotypes in j environments and $\overline{X}_{..}$ is the overall mean of genotypes in all environments. The stability variance is a linear combination of the ecovalence therefore both W_i^2 and σ_i^2 is equivalent for ranking purposes.

Pair-wise genotype-environment interaction (Plaisted and Peterson, 1959)

Mean variance component for a pair-wise GE interaction ($\overline{\theta}_i$) was proposed by Plaisted and Peterson (1959). This stability statistic measures a variety's contribution to the GE interaction and was computed from a total of g (g-1)/2 pair-wise analyses. In each analysis, the GE variance component was estimated. The stability statistic is estimated as follows:

$$\frac{g}{2(g-1)(e-1)}\sum_{j=1}^{q}(X_{ij}-\overline{X}_{i.}-\overline{X}_{.j}+\overline{X}_{..})^2+\frac{SS(GXE)}{2(g-1)(e-1)}$$

The lower $\overline{\theta}_i$ indicates the more stable the genotype.

Coefficient of variations

Francis and Kannenberg (1978) used the conventional coefficient of variation $CV\%$ of each genotype as a stability measure. The coefficient of variation is plotted against the mean yield across environments for every genotype. According to this method, genotypes with yield above mean and CV below mean are considered more stable than the others. Genotypes with a low

CV and high yield are regarded as most desirable.

Finlay and Wilkinson's regression coefficient

Finlay and Wilkinson (1963) used the estimated regression coefficient b_i of individual performance against site means to measure stability and relative adaptability. This methodology uses the regression coefficient (slop) of each genotype on the average yield of all genotypes evaluated in different environments as a measure of a genotype's yield responsiveness.

Eberhart and Russel's deviations from regression

Eberhart and Russel (1966) developed Finlay and Wilkinson's (1963) regression concept of stability and suggested the use of two stability parameters. They proposed that the regression of each cultivar on an environmental index and a function of the squared deviations from regression would provide more useful estimates of yield stability parameters.

Perkins and Jinks's regression method

Perkins and Jinks (1968) regression coefficient (β_i) is similar to Finlay and Wilkinson's (1963) regression coefficient (b_i) except the observed values which are adjusted for location effects before the regression.

Freeman and Perkins's regression method

Freeman and Perkins (1971) pointed out that if the environmental mean or the environmental index is used in place of a measure of an environment as in Finlay and Wilkinson's and Eberhart and Russell's models, then the sum of squares due to heterogeneity of regression lines with only 1 d.f. will be the same as the sum of squares for environment with q-1 d.f, not merely part of it. They suggested the use of an independent measure like one replicate to determine the environment index and the remainder of replicates to determine genotype means that in this method, a stable genotype was defined as one with $b_i = 1$ and $S_{di}^2 = 0$.

Tai's method

The stability parameter of α_i and λ_i according to Tai (1971) were used as two measurement of stability. These two stability parameters are very similar to the regression coefficient (Finlay and Wilkinson, 1963) and the deviation from regression (Eberhart and Russell, 1966), but obtained in a manner that is the continuation of the analysis of variance and are obtained by using the principle of structural relationships. The usual partition of the GE interaction into regression sum of squares and sum of squares of deviation from regression is feasible if the environmental effects can be measured without error. Tai (1971) was used the alternative method above, because the environmental effects can not be measured without error. The linear response to environmental effects was measured by statistic (α_i) and the deviation from the linear response was measured by another statistic (λ_i). A perfectly stable genotype has a $\alpha_i = -1$ and $\lambda_i = 1$. Also a genotype with average stability has a $\alpha_i = 0$ and $\lambda_i = 1$.

Superiority measure of Lin and Binns (1988)

Lin and Binns (1988) defined this superiority measure as the "cultivar general superiority" and defined it as "The distance mean square between the cultivar's response and the maximum response over locations". The smaller this mean square the more superior the new cultivar is.

The superiority measure P_i can be given as

$$P_i = \sum_{j=1}^{q} (X_{ij} - M_j)^2 / 2q$$

Where X_{ij} is the yield of the *i*th genotype grown in the *j*th location, M_j is the maximum yield in the *j*th location (check or test-cultivar).

Desirability index

Hernandez et al (1993) proposed a desirability index that would combine both yield and regression coefficient. They defined this index as "the area under the linear regression function divided by the difference between the two extreme environmental indices". Genotypes are identified as desirable if they have high D_i values.

D_i is defined as follows:

$$D_i = \overline{Y}_{i.} + (b_i)C_1$$

Where C1 = $(I_b + I_a)/2$ and $\overline{Y}_{i.}$ and bi are the mean yield and slope of the variety and I_a and I_b are the minimum and maximum values of the environmental indices respectively.

Hanson's (1970) stability parameter

Hanson's (1970) genotypic stability (D_i^2) is founded on the regression analysis since it uses the minimum slope from Finlay and Wilkinson's method. This parameter helps classify genotypes according to their coordinate positions. Hanson (1970) gives the concepts of relative genotypic stability as the measure of homeostasis and comparative genotypic stability measure as the proximity between two genotypes. The cultivars with the lowest D^2 are stable.

Multivariate stability measures

Additive main effects and multiplicative interaction (AMMI)

The AMMI model, which combines standard analysis of variance with PC analysis (Zobel et al., 1988), was used to investigate of GE interaction.

The AMMI model is:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_N \lambda_n \gamma_{in} \delta_{jn} + \rho_{ij} + \varepsilon_{ijk}$$

where Y_{ij} is the observed mean yield of genotype i in environment j, μ the grand mean, α_i the genotype main effect, β_j the environment main effect, λ_n the eigen value of the interaction PCA (IPCA), n, γ_{in} and δ_{jn} are the genotype and environment scores for the IPCA axis, n, ρ_{ij} interaction residual, N the number of IPCA retained in the model and ε_{ijk} the random error term.

AMMI statistics ($SIPC_1$, SIPCV) are sums of the absolute value of the IPC scores $\sum_{n=1}^{N} \lambda_n^{0.5} \gamma_{in}$ for the ith genotype for $SIPC_1$, N was one; for SIPCV, N was the number of IPC that were retained in the AMMI model via cross validation (Gauch and Zobel 1996). The other better option is, to calculate ASV, using a principle of the Pythagoras theorem and to get estimated values between IPCA1 and IPCA2 scores. ASV was reported to produce a balanced measurement between the two IPCA scores (Purchase 1997). ASV was calculated using the following formula:

$$ASV = \sqrt{\frac{SS_{IPCA1}}{SS_{IPCA2}} (IPCA1)^2 + (IPCA2)^2}$$

Where, AMMI's stability value (ASV), sum of squares interaction of first PC analysis (SS_{IPCA1}) sum of squares interaction of second PC analysis (SS_{IPCA2}).

Principal Coordinate analysis

The stability of grain yield for each genotype also, was calculated by principal coordinate analysis. Principal coordinate analysis is a generalization of the PCA analysis in which any measure of similarity between individuals can be used; this type of analysis was first used by Gower (1966). This method is based on a suitable measure of similarity between genotypes. This method of similarity between two genotype yield X and Y (in a particular environment) is defined by

$$S_i(X,Y) = (H_i - (X_i + Y_i)/2 / H_i - L_i$$

Where H_i highest mean yield of a genotype in environment i, L_i lowest mean yield of a genotype in environment i (Westcott, 1967). When a set of environments are being considered, the similarity between X and Y is just the mean of the similarities between X and Y across environments (Westcott, 1967). According this method the

environments are first ranked in descending order of mean yield and the low and high-yielding environments are then examined in Cycles. Thus, for the low-yielding environments, the first cycle (L1) in involves the analysis of the lowest-yielding environment. The second cycle (L2) involves analyzing the two lowest-yielding environments and so on, the lowest-yielding environment of those remaining being added at each cycle. Similarity, cycles H1, H2, etc, involve the highest-yielding environment, the two highest-yielding environments, etc. each analysis produces a two-dimensional picture, in which the first two principal coordinates are plotted for each genotype. The analysis determines a point (genotype) from which all other genotype radiate (Crossa, 1990). This point, which maximum value for S is the center of the scattergram. Therefore, genotypes with higher values for S are represented by points clustered near the center of the scattergram and genotypes with smaller values for S are represented by points far from the center. The stable genotypes are the ones that are consistently good cycles (Westcott, 1967).

GGE Biplot analysis

Yan et al. (2000) presented standard biplots of the site regression model enhance its interpretation for selecting the best performing cultivars in subsets of sites. In analyzing Ontario winter wheat performance trial data, Yan and Hunt (2001) used a GGEbiplot, constructed from the first two principal components (PC1 and PC2) derived from principal component analysis of environment-centered yield data. A GGE biplot is a biplot that display the G and GE interaction of a genotype by environment two-way data. An application of the biplot geometry is to visually identify the mean performance and stability of genotypes. In this study, GGE biplot method was used to estimate the stability of the genotypes. In this method an ideal genotype is one that has both high mean yield and high stability.

Results and Discussion

Analysis of Variance

Analysis of variance was conducted to determine the effect of environment (E), genotype (G) and interaction among these factors, on grain yield (Table 3). Analysis of variance indicated significant genotype × environment interaction ($p < 0.01$) and showed the influence of changes in environment on the yield performance of the genotypes evaluated. The environment effect was significant ($p < 0.01$). Highly significant environment also showed that the response of genotype to changes in the environments was under genetic control. G effects also were significant ($p < 0.01$).

Table 3: Analysis of variance on grain yield

Source	Df	MS	F	P
Environment (E)	15	15212986	674.88**	0.00
repeat (E)	48	247129	10.96**	0.00
Genotype(G)	16	2249345	99.79**	0.00
G × E	240	363027	16.10**	0.00
Error	768	22542		
Total	1087		CV = 11.88%	

** Significant at the 0.01 probability level

Stability Analysis

Stability analyses were conducted using 20 univariate and multivariate stability measures of stability. The ranks of genotypes based on these measures are summarized in table 6. According to environmental variance (S_i^2), phenotypic

stability was measured by the magnitude of the variance of a genotype across environments. In this method a genotype is considered to be stable provided that the environmental variance is small. Hence genotypes G17, G13 and G5 were the most stable genotypes, whereas, G8, G10 and G1 were classified as the least stable ones.

Wrick's ecovalence (W_i) is an alternative method that is frequently used to determine stability genotypes based on the GE interaction effects. It indicates the contribution of each genotype to the GE interaction. The cultivars with the lowest ecovalence contributed the least to the GE interaction and are therefore more stable. According to this method G3, G2 and G5 were the most stable genotypes.

Lin et al (1986) classify Shukla's stability statistic within the agronomic concept of stability, where (σ_i^2) is a test of a particular genotype's parallelism to the mean response pattern over environments of all evaluated genotypes. A significant (σ_i^2) indicates that a genotype's performance was unstable across environments (Shukla, 1972). Hence, G3, G2 and G5 were the most stable genotypes, whereas G17, 16, G15 and G9 were classified as the least stable ones. These types of measures are useful to breeders and agronomists because they can pinpoint contributions of individual genotypes in a test to total genotype × environment interaction.

According to Francis and Kannenberg's (1978) coefficient of variability (CV), genotypes with minimum value are considered more stable. Hence G17, G5 and G13 were most stable genotypes. Genotypes such G16, G10 and G8 had relatively higher value, indicating lower stability.

The regression of yield on environmental index was performed separately for each genotype to estimate their regression coefficients (b_j). A t-test employing each genotype's standard error of regression was used to test each regression coefficient for statistical difference from 1.0, while the deviations from regression (S_{di}^2) were tested by the F-test based on pooled error estimates in combined ANOVA. The high yielding genotypes, G8 and G14 were more responsive (b_i >1) to improved environmental conditions than the other genotypes. The better response of G8 as compared to the other genotypes indicated the possibility of developing responsive genotypes with high mean grain yield. The genotypes G17 and G16 had regression coefficients below unity (b_i <1) indicating their average responsiveness to the favorable environmental conditions. In addition, their mean grain yields were less than the grand mean which indicated their inferior performance as compared to G8. All of the genotypes had a significant deviation mean square from linear regression (S_{di}^2) implying that these genotypes were unstable across environments. The S_{di}^2 was highest for G17. The high yielding genotypes, G8 and G14 had also significant S_{di}^2 implying unstable performance across the testing environments. In general, when the adaptability parameters of mean yield, regression coefficient and deviation mean square from the linear regression were considered genotypes G3, G12 and G2 exhibited general adaptability.

Their coefficients of determination, R_i^2 (Pinthus, 1973), were as high as 0.003% and 0.94% confirming their stability. The coefficient of determination (R_i^2) measures the proportion of the variation in the mean yield of a genotype which is accounted for by the fitted model. Estimates of coefficient of determination for G17, G16 and G6 were 0.003%, 0.34% and 0.64, respectively indicating that this model is not fit for these genotypes.

Regression coefficients (Perkins and Jinks 1968) represent type 2 stability, that is, a genotype is stable when its response approaches the average response of all tested genotypes ($b_i = 0$). The genotypes have different b_i values, suggests that they responded differently to different environments. Genotypes with b_i values greater than zero (such as, G8, G14, G1 and G10) indicated higher yield in more favorable environments whereas, G16, G13 and G6, with values less than zero were adapted to marginal environments. Genotypes, G2, G17, G11 and G3, with values closer to zero were would have an average adaptation to all environments (Table 5). Thus, genotypes with variances in regression deviations equal to zero would have highly predictable behavior, whereas with a regression deviation greater than zero, they would have low predictability because of the environmental stimulus. Genotype G11 had a high general mean and a regression coefficient greater than one, thus characterizing it as a cultivar adapted to environments with a high level of technology. Another important regression procedure for analyzing stability of two-way classification dataset was the Freeman and Perkins (1971) linear regression method. In Freeman and Perkins method, regression coefficient for the 17 genotypes ranged from -0.15 - 1.43. The results of this model (Table 5) showed that genotype G5 and G3 were stable, but genotype G17 and G8 was unstable.

According to Hanson's (1970) stability parameter (D_i^2), genotypes G17, G13, G5 and G6 had the lowest D^2 values and thus were stable but genotypes G8, G10 and G1 had the most values of D^2 and were unstable. Ranks of genotypes based on this stability parameter were very similar to the ranks of the environmental variance (S_i^2).

According to Lin and Binns (1988), the superiority measure (P_i) of cultivars is estimated by the squares of differences between an entry mean and maximum entry mean, summed and divided by twice the number of environments. Cultivars with the lowest P_i values are considered the most stable. Accordingly, the superiority measure of the tested genotypes revealed that G8, G7 and G15 were the most stable genotypes whereas G17, G16 and G6 were the least stable ones (Table 5). Fox et al (1990) criticize Lin and Binns's superiority measure, indicating that this parameter can be influenced is the range of when range is very wide, as in the cases of international experiments.

According to Hernandez et al (1993) parameter (D_i) genotypes are identified as desirable if they high D_i values. In this study, genotypes G8, G14 and G7 had higher values of desirability index were stable and genotypes G17, G16 and G13 were unstable.

The use of the AMMI model revealed successively smaller patterns within the GEI. Partitioning of GE interaction indicated the AMMI5 model described the GE interaction patterns for yield using the first five IPCA scores based on cross validation. Results from AMMI analysis also showed that the first PC axis (IPCA1) of the interaction captured 47.49% of the interaction sum of squares in 24.21% of the interaction degrees of freedom. Similarly, the second PC axis (IPCA2) explained a further 25.25% of the G × E interaction sum of squares. The five IPCAs accounted for 92.45% of the total interaction, the remaining 7.54% being the residual or noise, which is not interpretable and thus discarded. Three stability statistics were derived from AMMI analyses (Table 4). According to the SIPC1 scores, G2 was the most stable genotype, followed by G3, G9 and G11. According to the SIPCV stability parameter genotypes G3, G13 and G10 which had lower values of SIPCV were stable but genotypes G6, G17 and G8 were unstable. In proportion to better option ASV, the genotypes G3, G12 and G5, with lower value were stable.

Table 4; Stability parameters based on GE variance and AMMI parameters parameters for the 17 chickpea genotypes grown in 16 environments.

Genotypes	S_i^2	CV	W_i	σ_i^2	θ_i	$\overline{\theta}_i$	SIPC1	SIPCV	ASV
G1	404400	37.5	984480	68333	80245	92158	0.467	0.227	0.658
G2	248541	32.3	395396	23824	59382	94940	0.018	0.481	0.350
G3	276390	34.4	240921	12153	53911	95669	0.024	0.033	0.077
G4	265257	31.7	1038980	72451	82176	91901	0.164	0.887	0.292
G5	217460	29.5	414983	25304	60076	94847	0.185	0.768	0.257
G6	235539	32.6	1345320	95596	93025	90454	0.229	1.460	0.659
G7	332143	33.0	1210470	85407	88249	91091	0.320	0.358	0.646
G8	508346	37.9	1365210	97099	93729	90360	0.563	1.300	0.807
G9	377708	37.7	1378120	98074	94187	90299	0.127	1.080	0.680
G10	416607	38.6	1339730	95173	92827	90481	0.506	0.103	0.703
G11	297111	31.8	647504	42872	68311	93749	0.139	0.429	0.416
G12	328532	34.1	463108	28940	61780	94620	0.162	0.549	0.253
G13	199297	31.6	742921	50081	71690	93299	0.367	0.068	0.507
G14	389952	35.5	707191	47382	70425	93468	0.236	0.170	0.496
G15	387791	37.1	1384890	98586	94427	90267	0.309	0.847	0.756
G16	276955	41.7	3138790	231103	156544	81985	0.721	0.623	1.176
G17	93329.4	27.2	4983570	370486	221880	73274	1.160	1.450	1.590

S_i^2, Environmental variance; CV, Coefficient of variation; W_i, Wricke's ecovalence; σ_i^2, Shukla's stability variance; θ_i, Plaisted and Peterson (1959); $\overline{\theta}_i$, Plaisted (1960); SIPC1, SIPCV and ASV, tree AMMI stability parameters.

According to GGE biplot methodology an ideal genotype is one that has both high mean yield and high stability. In this method the performance of genotypes G17, G16 and G13 is highly variable (less stable), whereas genotypes G8, G1, G10 and G14 are highly stable.

Principal coordinate analysis performed for eight low-yielding environments indicated that genotypes G7, G8 and G14 were the most stable in the L cycles, because genotypes G7, G8 and G14 were the remotest points in majority of the L cycles. Genotype G14 also performed well in the H cycles, particularly in H1 to H8. Genotypes G8, G9, G1 and G14 were the most stable in the H cycles. Genotype G7 and G8 showed reasonable stability in completed cycles (In cycles L1- L16) for 16 environments (Table 6). Its objectives and limitations are similar to those of PCA, and also has the following advantages as pointed out by Crossa (1990): (a) it is trustworthy when used for data that include extremely low or high yielding sites; (b) it does not depend on the set of genotypes included in the analysis; and (c) it is simple to identify stable varieties from the sequence of graphic displays.

Relationship between mean yield and stability statistics

Spearman's coefficient of rank correlation among mean yield and parametric statistics for chickpea data set are shown in Table 5. Mean yield was significantly ($P < 0.01$) correlated with Hernandez et al (1993) parameter (D_i), Lin and Binns superiority measure (P_i), GGE Biplot method and Principal coordinate method. The high correlation among mean yield and stability statistics is expected as the values of these statistics were higher for high yielding genotypes. Mean yield also moderately correlated with Coefficient of determination (R_i^2). Spearman's coefficient of rank correlation among mean yield whit environmental variance (S_i^2) and Hanson's (1970) genotypic stability (D_i^2) were negatively significant ($P < 0.01$). The procedures of Environmental variance and Hanson's (1970) stability parameter had a

total correspondence ($r = 1.00$). Wricke's ecovalence (W_i^2), Shukla's stability variance (σ_i^2), Plaisted and Peterson parameter (θ_i), Plaisted's parameter ($\overline{\theta}_i$), Freeman and Perkins method (FP), Perkins and Jinks method (PJ), ER, Tai, SIPC1, ASV and R_i^2 were highly significantly correlated indicating that they measured similar aspects of stability. The procedures of Wricke's ecovalence, Shukla's stability variance, Plaisted and Peterson parameter and Plaisted's parameter had a total correspondence ($r = 1.00$), these procedures were equivalent for ranking purposes which correspond with previous findings in other crops (Mohebodini et al, 2006).

Table 5; Stability parameters based on regression models for the 17 chickpea genotypes grown in 16 environments.

Geno types	Mean	b_i	S_{di}^2	R_i^2	$b_i(FP)$	$S_{di}^2(FP)$	$b_i(PJ)$	$S_{di}^2(PJ)$	α_i	λ_i	P_i	D_i^2	D_i
G1	1697	1.25 ns	54473	0.87	1.31 ns	63967	0.26 ns	417438	0.261*	9.04**	81584	6356300	1945
G2	1543	0.99 ns	28240	0.89	0.97 ns	70250	-0.00 ns	266292	-0.004	4.71**	144128	3959000	1739.5
G3	1527	1.08 ns	15604	0.94	1.06 ns	42932	0.08 ns	294527	0.083	2.6**	164603	4396200	1740.8
G4	1623	0.93 ns	73292	0.74	1.02 ns	76535	-0.06 ns	283284	-0.063	12.22**	151088	4196400	1808.5
G5	1582	0.92 ns	28263	0.87	0.96 ns	42750	-0.08 ns	231614	-0.077	4.71**	154314	3476300	1764.4
G6	1490	0.82 ns	88834	0.64	0.80 ns	131992	-0.17 ns	245103	-0.177	14.79**	270317	3725100	1653.2
G7	1748	1.06 ns	85542	0.76	1.14 ns	103391	0.06 ns	354948	0.063	14.26**	61366	5228000	1957.7
G8	1880	1.43 **	52634	0.90	1.43**	97754	0.43 **	499776	0.44**	8.65**	20352	7955500	2162.9
G9	1631	1.13 ns	93819	0.76	1.14 ns	138232	0.14 ns	400068	0.141	15.63**	179211	5928900	1856
G10	1672	1.23 ns	82852	0.81	1.30 ns	99582	0.23 ns	433522	0.235	13.78**	95501	6533500	1914.6
G11	1714	1.06 ns	45157	0.85	1.07 ns	98546	0.07 ns	317240	0.069	7.53**	107007	4703700	1924.2
G12	1680	1.16 ns	26534	0.92	1.12 ns	81615	0.17 ns	345454	0.168*	4.41**	97821	5197300	1909.5
G13	1413	0.83 ns	46518	0.78	0.77 ns	100231	-0.17 ns	206984	-0.168	7.74**	269184	3183500	1577.5
G14	1760	1.26 ns	33535	0.92	1.30 ns	54903	0.27 ns	400827	0.271**	5.54**	83152	6141600	2009.8
G15	1679	1.16 ns	92758	0.77	1.18 ns	116306	0.16 ns	409328	0.163	15.45**	76953	6085100	1907.7
G16	1263	0.65 *	195055	0.34	0.56*	240656	-0.35 *	267593	-0.355	32.44**	459210	4306600	1391.2
G17	1124	-0.03 **	99724	0.01	-0.15**	123247	-1.03 **	156248	-1.051**	15.9**	699748	1396100	1117.2

Mean = Mean yield; b_i and S_{di}^2 = regression coefficient and Deviation from the regression (Eberhart and Russell,1966); R_i^2 = Coefficient of determination; $b_i(FP)$ and $S_{di}^2(FP)$ = regression coefficient and Deviation from the regression in Freeman and Perkins method; $b_i(PJ)$ and $S_{di}^2(PJ)$ = regression coefficient and Deviation from the regression in Perkins and Jinks method; α_i and λ_i Tai's (1971) parameters; P_i = Lin and Binns superiority measure; D_i = Hernandez et al (1993) parameter, D_i^2 = Hanson's (1970) stability parameter; ns, * and**: Non significant, significant at the 0.05 and 0.01 probability level, respectively.

The correlations were also significant (P < 0.01) among regression coefficient (b_i), PJ, Tai, SIPC1 and ASV , but these measures did not correlate with environmental variance (S_i^2) and Hanson's (1970) genotypic stability (D_i^2).

Table 6: Ranks of the 17 chickpea genotypes for the 20 univariate and multivariate stability measures.

statistics	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
Mean	5	12	13	10	11	14	3	1	9	8	4	6	15	2	7	16	17
S_i^2	15	5	7	6	3	4	11	17	12	16	9	10	2	14	13	8	1
CV	13	6	10	4	2	7	8	15	14	16	5	9	3	11	12	17	1
W_i	8	2	1	9	3	12	10	13	14	11	5	4	7	6	15	16	17
σ_i^2	8	2	1	9	3	12	10	13	14	11	5	4	7	6	15	16	17
θ_i	8	2	1	9	3	12	10	13	14	11	5	4	7	6	15	16	17
$\overline{\theta}_i$	8	2	1	9	3	12	10	13	14	11	5	4	7	6	15	16	17
b_i	13	1	6	2.5	5	11	2.5	16	7	12	4	9	10	14	8	15	17
ER	8	3	1	9	4	12	11	16	14	10	6	2	7	5	13	15	17
R_i^2	6.5	5	1	14	6.5	15	12.5	4	12.5	9	8	2.5	10	2.5	11	16	17
FP	4	5	2	6	1	13	11	16	14	9	8	7	10	3	12	15	17
PJ	13	4	6	5	2	3	9	16	10	14	7	8	1	11	12	15	17
Tai	14	2.5	1	6	2.5	9	8	16	11	7	4	13	5	15	10	12	17
P_i	4	9	12	10	11	15	2	1	13	6	8	7	14	5	3	16	17
D_i^2	15	5	8	6	3	4	11	17	12	16	9	10	2	14	13	7	1
D_i	4	13	12	10	11	14	3	1	9	6	5	7	15	2	8	16	17
SIPC1	13	1	2	6	7	8	11	15	3	14	4	5	12	9	10	16	17
SIPCV	5	8	1	13	11	17	6	15	14	3	7	9	2	4	12	10	16
ASV	10	5	1	4	3	11	9	15	12	13	6	2	8	7	14	16	17
GGE	2	13	11	10	12	14	7	1	8	3	5	6	15	4	9	16	17
PC	11	14	15	5	9	10	1	2	7	8	4	6	16	3	12	17	13

ER, Eberhart and Russell (1966) method; FP, Freeman and Perkins method; PJ, Perkins and Jinks method; GGE, GGE Biplot method; PC, Principal coordinate method.

Figure 1. Dendrogram showing hierarchical classification of mean yield and 17 yield stability measures based on Spearman's coefficients values of 17 chickpea genotypes.

To better understand the relationships among the these methods, a hierarchical cluster analysis with average linkage method based on non weighted values of 17 stability parameter and mean yield, was used to classification. The coefficient of correlation was used as similarity measure required in average linkage method. Dendrogram showing hierarchical classification of stability methods is illustrated in Figure 1. tree group can be defined as follows:

Group 1 include Lin and Binns superiority measure (P_i), Hernandez et al (1993) parameter (D_i), GGE Biplot method and Principal coordinate method. These stability parameters have significantly positively correlated with grain mean yield. These methods usually recommend genotypes that it has dynamic or agronomic stability. Stability can be defined as both static and dynamic. In dynamic or agronomic stability, a genotype changes in a predictable manner across a wide range of environmental conditions. In this concept of stability, it is not required that the genotypic response to environmental conditions should be equal for all genotypes (Backer,

1981; Backer and Leon, 1988). Stable genotypes according to this concept of stability have more responsive to improved environmental conditions. According to these methods, the most stable genotypes were Flip 93-93, S 96019 and Flip 94-123C.

Table 7: Spearman's coefficients of rank correlation for mean yield and the 17 stability measures of 17 chickpea genotypes evaluated in 16 environments of Iran

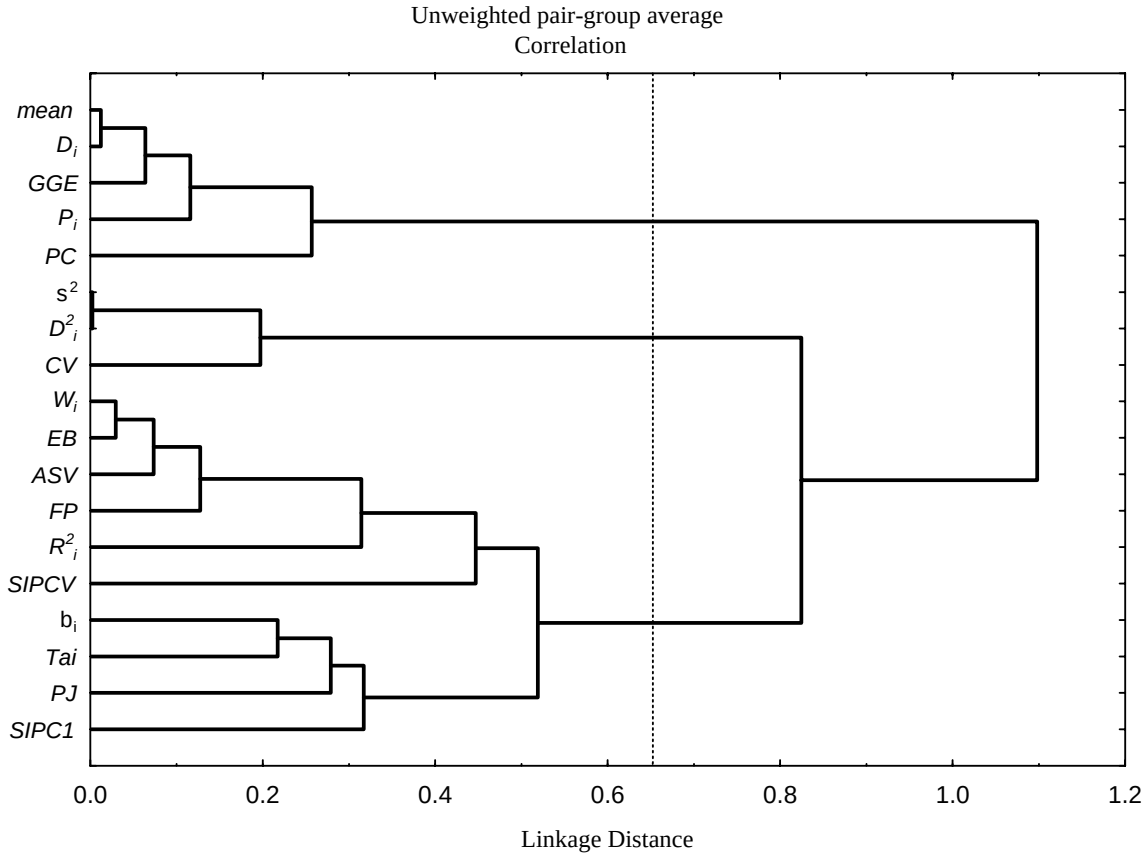
Statistics	Mean	S_i^2	*CV*	W_i	b_i	*ER*	R_i^2	*FP*	*PJ*	Tai	P_i	D_i^2	D_i	SIPC1	SIPCV	ASV	GGE
S_i^2	-0.80**																
CV	-0.35	0.81**															
W_i	0.14	0.17	0.34														
b_i	0.07	0.24	0.39	0.56*													
ER	0.10	0.16	0.29	0.97**	0.52*												
R_i^2	0.49*	-0.35	-0.14	0.76**	0.12	0.73**											
FP	0.18	0.04	0.23	0.88**	0.47	0.90**	0.66**										
PJ	-0.25	0.58*	0.60*	0.66**	0.68**	0.63**	0.16	0.52*									
Tai	-0.26	0.40	0.37	0.63**	0.78**	0.59*	0.17	0.53*	0.76**								
P_i	0.91**	-0.78**	-0.37	0.13	0.11	0.10	0.49*	0.20	-0.26	-0.17							
D_i^2	-0.81**	1.00**	0.79**	0.13	0.22	0.12	-0.39	0.00	0.55*	0.38	-0.79**						
D_i	0.99**	-0.84**	-0.41	0.13	0.02	0.09	0.49*	0.20	-0.29	-0.26	0.90**	-0.85**					
SIPC1	0.05	0.18	0.25	0.68**	0.77**	0.67**	0.41	0.55*	0.66**	0.62**	-0.05	0.14	0.00				
SIPCV	0.16	-0.18	-0.12	0.59*	0.17	0.63**	0.53*	0.59*	0.18	0.40	0.23	-0.20	0.22	0.12			
ASV	0.10	0.25	0.42	0.93**	0.67**	0.93**	0.60*	0.84**	0.74**	0.63**	0.05	0.22	0.07	0.77**	0.43		
GGE	0.92**	-0.89**	-0.50*	0.14	-0.06	0.11	0.53*	0.21	-0.34	-0.26	0.84**	-0.90**	0.95**	0.00	0.25	0.06	
PC	0.83**	-0.51*	-0.07	0.04	0.15	-0.04	0.19	0.03	-0.12	-0.23	0.63**	-0.51*	0.81**	0.09	-0.13	0.12	0.71**

* and**: significant at the 0.05 and 0.01 probability level, respectively.

Group 2 include environmental variance (S_i^2), Coefficient of variation (CV) and Hanson's (1970) stability parameter (D_i^2). These methods usually recommend genotypes that it has dynamic or agronomic stability. Lin et al. (1986) while ascribing these measures to a Type 1 stability concept. In static or biological the performance of a genotype remains unchanged regardless of the environmental conditions and it showing a constant performance in all environments dose not necessarily respond to improved growing conditions with increased yield. These stability parameters, which were not generally associated with yield, were measured independently for grain yield. In this concept of stability, stable genotypes don't have more responsive to improved environmental conditions, therefore stable genotypes according to these parameters recommend for locations where growing conditions are unfavorable. This concept of stability is useful for quality traits, disease resistance, or for stress characters. According to these methods, the most stable genotypes were Bivanij, S 96078 and ILC 482-205C. However, these genotypes may not be as good as the responsive ones under favorable conditions.

Group 3 include Wricke's ecovalence, Shukla's stability variance, Plaisted and

Peterson's (1959) parameter; Plaisted's (1960) stability parameter, regression methods (Finlay and Wilkinson (1963); Eberhart and Russell, (1966); Freeman and Perkins (1971); Perkins and Jinks (1968); Tai (1971)), coefficients of determination (Pinthus, 1973), Superiority measure of Lin and Binns (1988), Hernandez et al (1993) parameter and AMMI stability parameters. Group 3 was intermediate between group 1 and group 2, it consists of the methods that were influenced simultaneously by both yield and stability.



Becker and Leon (1988) stated that all stability procedures based on quantifying GEI effects belong to the dynamic concept. This includes the procedures for partitioning the GEI of Wricke's (1962) ecovalence and Shukla's (1972) stability of variance, procedures using the regression approach such as proposed by Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Perkins and Jinks (1968), Freeman and Perkins (1971). According to these methods, a genotype is considered to be stable if its response to environments is parallel to the mean response of all genotypes in the trial. A stable genotype has no deviations from the general response to environments and thus permits a predictable response to environments. The most severe limitation of the regression approach is the poor repeatability of both regression coefficient and Deviation from the regression. Also, stable genotype according to Wricke's ecovalence (W_i^2), σ_i^2, $\overline{\theta}_i$ and θ_i are not generally associated with yield level. The ecovalenc strongly depends on the group of genotypes tested and environments included in the test, thus the breeder can manipulate the G × E dynamics by choosing specific genotypes and specific environments.

According to these methods, the most stable genotypes were S 96003 and S 95293. However, these genotypes may not be as

good as the responsive ones under favorable conditions.

Based on each type of stability that was requested, we can use each of these groups for introduction some genotypes to farmers. The identified superior genotypes significantly differ from the local check cultivars and therefore farmers in semi arid areas of Iran can use these genotypes.

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