Turkish Journal of Field Crops, 2012, 17(1): 51-61

RELATIONSHIP AMONG AND REPEATABILITY OF TEN STABILITY INDICES FOR GRAIN YIELD OF FOOD LENTIL GENOTYPES IN IRAN

Rahmatollah KARIMIZADEH[1], Mohtasham MOHAMMADI[1], Mohammad Kazem SHEFAZADEH[2], Ali Akbar MAHMOODI[3], Barzo ROSTAMI[4], Farzad KARIMPOUR[5]*

[1]Dryland Agriculture Research Institute, Gachsaran Agriculture Research Station, Gachsaran, IRAN
[2]Department of agronomy, Yasooj branch, Islamic Azad University, Yasooj, IRAN
[3]Dryland Agriculture Research Institute, Shirvan Agricultural Research Station, Shirvan, IRAN
[4]Dryland Agriculture Research Institute, Sararood Agricultural Research Station, Kermanshah, IRAN
[5]Medical Science University of Yasuj, Food and Drug Department., Yasuj, IRAN.
*****Corresponding author: karimizadeh_ra@yahoo.com*

Received: 02.04.2012

ABSTRACT

The objective of this research work was to evaluate whether different stability indices of phenotypic stability vary in their repeatability. Lentil yield data of eighteen genotypes, proprietary of Dryland Agricultural Research Institute, evaluated in twelve environments over the 2002-2005 year period in four locations of Iran were used for combined analysis of variance in three datasets. I: Across locations in a single evaluation year (dataset A), II: Across locations in each of two single evaluation year (dataset B) and III: Across all of locations in three years (dataset C). Single year data of yield, of response parameters: coefficient of variation (CVi), Shukla stability variance, deviation mean squares (ER), coefficient of determination (R^2), coefficient of regression bi, Wricke ecovalence, and AMMI parameters including: SIPC!, ASV, MASV and D1 were correlated with multi year results. Among different ten stability statistics, only desirability D1 index of Annicchiarico (1997) had highly significant correlation with mean yield. CVi was significant correlated with Shukla variance and Wricke ecovalence, bi, SIPC1 parameter. Shukla variance and Wricke ecovalence indices showed highly significant rank correlation each other and also indicated significant correlated with ER, bi and ASV. Pinthus's coefficient of determination (R^2) showed significant positive correlation with ASV, MASV and bi indices. The ER statistic had positive significant correlations with the mean yield, bi, ASV and MASV stability statistics. SIPC1 parameter indicated positive significant correlation with CVi, Shukla variance, ASV and MASV. D1 Parameter had no significant correlation with ASV and MASV parameters and positive significant correlation with mean yield. Repeatability of three pair years' results (data set C) were highest for bi, R^2, MASV and D1 parameters where rank correlation coefficients amounted to about 0.70. Repeatability of two pair years' results were highest for yield, SIPC1 and ASV parameters where rank correlation coefficients amounted to about 0.60. The bi, R^2, MASV and D1 parameters were relatively more repeatable than SIPC1 and ASV parameters in single (dataset A) and 2-year comparisons (dataset B). Although these parameters are indices depended and proportional to yield, provides a superior way to integrate mean performance and stability into a single measure, which can be assessed visually on biplots.

Keywords: AMMI, Repeatability, Yield, GE Interaction, Stability, nonparametric

INTRODUCTION

Legumes and especially lentil (*Lens Cullinaris* Medik) are an important food crops in a lot of developing countries. Lentil seed is a rich source of proteins (up to 28%) in human diets in arid and semi-arid areas of west Asia (Arshad et al., 2003). The major constraints are non-availability of improved varieties for early-spring or winter planting, high weed pressure, poor agronomy management, and lack of quality seed. To date, the only variety released in Iran for early-spring sowing is 'Gachsaran', which originated from ICARDA material (Sarker et al., 2003; Sabaghnia et al., 2006; Karimizadeh et al., 2008). Iranian farmers currently use landraces (e.g., Kermanshah) and pure lines (e.g., Gachsaran Cultivar), which have large seed size and are adapted to local rainfed conditions. The yield performance of landraces is very low (typically about 475 $kg.ha^{-1}$) compared with the highest global yields (1306 kg ha^{-1}, produced in Canada). Iran has developed an important lentil-breeding program in recent years (FAO, 2008), in what way-technical, financial etc. do the provide genotypes for adaptation by the International Center for Agricultural Research in Dry Areas (ICARDA). Increasing the genetic potential of yield is an important objective of lentil breeding programs in Iran and other countries. The improved lentil genotypes are evaluated in Multi-environment Trials (METs) to test their performance across different environments and to select the best genotypes in specific environments (Rajput and Sarwar, 1989; Rao and Yadav, 1989). In most cases, GE interaction is observed, complicating selection for improved yield (Sabaghnia et al., 2006). Ten years ago lentil breeder in Iran introduced Gachsaran cultivar from ICARDA materials that has appropriate features such as large seed size, early maturing, acceptable height and good grain yield (Karimizadeh et al., 2011).

High and stable yield performance under variable farming conditions is required for crop cultivars, including lentil, to become commercially successful. This presents the challenge for breeders to develop such cultivars and for extension agronomists to effectively identify and recommend to farmers. Therefore performance evaluation over a range of cropping environments, including unfavorable and/or stress ones, is required for this challenge to be met. Multi-environment trials (MET) are necessary to allow for estimating cultivar's genotypic value and it's consistency with the corresponding phenotypic value across environments. Conventionally the analysis of variance for MET data provides estimates of the genotype (G) and environment (E) main effects along with the corresponding genotype by environment interaction (GEI) effect. Increased GEI variance is associated with decreased correlation between genotypic and phenotypic cultivar values and thus ineffective identification and selection of the desired genotypes (Comstock and Moll, 1963). According to Bernardo (2002) there are three approaches for coping with GEI. It could be ignored, reduced or exploited. When it is ignored, cultivar recommendation is based on the mean performance across all testing environments. In the other two cases, partitioning of the target population environments into homogeneous subgroups and/or stability analysis is required. Then cultivar recommendation is made separately for each subgroup (reduction) or for particular environments (exploitation). Several stability analysis methods have been proposed to address the GEI interaction and study each cultivar's performance relative to other cultivars in different environments. They are based either on joint regression or in principal components analysis (Bernardo, 2002). Each method results in a corresponding stability parameter (index) as means for effective genotype/cultivar classification. Finlay and Wilkinson (1963) regression coefficient (b_i), Eberhart and Russel (1966) deviation from regression (S_{di}^2), Shukla (1972) stability variance (σ_i^2) and Kang (1993) yield stability parameter (YS_i), are some of the most widely used stability parameters. The additive main effects and multiplicative interaction (AMMI) model has been suggested as efficient means in determining stable and high yielding genotypes (Gauch, 1992; Zobel and Gauch, 1988). AMMI partitions the overall variation into genotype main effects (G), environment main effects (E) and genotype environment (GEI) effects and utilize principal components analysis (PCA) to study GEI. In AMMI analysis, genotypes having low absolute values in the principal components are regarded as stable, while their mean performance could be predicted from the main effect model. Thus the use of the absolute values of the first principal component (IPCA1) or in combination with the second (IPCA2) were proposed as stability parameters (Gauch and Zobel, 1996). Stability analysis has been applied in a wide variety of crops. Yet, the usefulness of the stability parameters in rank genotypes remains an important issue for breeders and agronomists. That is, to what extent statistics are under genetic control and how repeatable are they across years? Generally, genotype ranking based on bi has been reported repeatable (Bever and Johnson, 1981; Ntare and Aken'Ova, 1985; Leon and Becker, 1988; Helms, 1993; Jalaluddin and Harrison, 1993) although low repeatability values have been also reported (Fatunla and Frey, 1976; Virk et al., 1985). Furthermore, bi has been reported to be genetically controlled (Eberhart and Russel 1966; Lin and Binns 1991; Zavala-Garcia et al., 1992). Regarding the repeatability of S_{di}^2 was reported as generally low (Lin and Binns 1991; Helms 1993; Jalaluddin and Harrison 1993; Leon and Becker 1988; Pham and Kang 1988) although it was genetically controlled with a higher heritability than bi (Zavala-Garcia et al., 1992). Genotype ranking based on Shukla's σ_i^2 index had low repeatability (Eagles and Frey 1977; Helms 1993; Jalaluddin and Harrison 1993; Pham and Kang 1988). Similarly moderate repeatability (Annichiarico 1997) and heritability (Zavala-Garcia et al., 1992) have been reported for the AMMI 1 (IPCA1) parameter. On the contrary Sneller et al. (1997) reported generally low repeatability for b_i; S_{di}^2, σ_i^2, and the AMMI parameters. A variable interrelationship among the stability parameters is expected since they are all measures of the GEI. The σ_i^2 and S_{di}^2 statistics rank correlated well with each other (Pham and Kang 1988; Sneller et al., 1997) and the same holds true for the rank correlation of σ_i^2 and S_{di}^2 with AMMI1 statistics (Sneller et al., 1997). On the contrary the rank correlation of bi with σ_i^2 and S_{di}^2 was reported very low (Pham and Kang 1988). Rank correlation of mean yield with σ_i^2 and S_{di}^2 was reported inconsistent, ranged from –0.29 to 0.73 depending on the set of testing environments (Pham and Kang 1988) or consistently very low between mean yield and σ_i^2; S_{di}^2 or AMMI statistics (Sneller et al., 1997). GGED was highly correlated with YS_i (Yan and Kang 2003; Blanche 2005), whereas GGEIN was with σ_i^2; S_{di}^2 and AMMI1 (Blanche 2005). Summarizing the brief account of the voluminous literature on the subject, it seems that generally parameters based on GE (σ_i^2; S_{di}^2, AMMI1, GGEIN) are well correlated to each other. However their repeatability seems to be inconsistent and dependent on the dataset. Moreover their use in genotype evaluation could be misleading, since if used alone. On the other hand parameters based on G + GE (YS_i, GGED) are well correlated to each other. However their effectiveness as selection tools in cultivar development and recommendation programs has rarely been reported.

The objectives of this research were: (i) to evaluate the grain yield of promising lentil genotypes in dryland environments in Iran, ii) to study the interrelationships among eight stability parameters and their associations with mean grain yield and iii) the repeatability of these parameters across consecutive years.

MATERIALS AND METHODS

Data Set

This research data set involves eighteen lentil genotypes tested in 12 environments (year–location combinations during 2002–2005), extracted from the Iran lentil performance trial programs. Of eighteen lentil genotypes used, seventeen were from the ICARDA lentil improvement program and one (G12) was local check cultivar (Gachsaran) typically grown by Iranian farmers. Four research sites, representative of major lentil rainfed areas of Iran. The locations used are: Gachsaran in Western south of Iran; Gonbad in eastern north; Ilam and Kermanshah in west of Iran. The altitude of testing sites varies from 45 m to 1315 m, the longitude of testing site varies from 46 to 58 and latitude of those was from 30 to 37. More descriptions of the experimental sites are given in Table 1.

Table 1. Geographical Parameters and Mean of Lentil Grain Yield for various Environments

Code	Location	Altitude (meter)	Longitude/Latitude	Soil Texture	Rainfall (mm)	Yield (kg.ha^{-1})
1	Gonbad	45	55 12 E /37 16 N	Silty Clay Loam	367	767
2	Kermanshah	1351	47 19 E /34 20 N	Clay Loam	455	1923
3	Ilam	975	46 36 E /33 47 N	Clay Loam	350	805
4	Gachsaran	710	50 50 E /30 20 N	Silty Clay Loam	460	1747

The experiments were planted according to local practice with seed density of about 200 seeds per m^2. Plots were 4 m^2 with four rows each 4 m long and 25 cm between rows.

Statistical procedures

The obtained dataset for all 12 environments were analyzed as randomized complete block design (data and results not presented) to plot residuals and identify outliers. Bartlett's test was used to determine the homogeneity of variances among environments to determine the validity of the combined analysis of variance. A combined analysis of variance was done from the mean data from each environment, to create the means data for the different statistical analyses methods. Environments were considered as random variables while the genotypes were treated as fixed variables. The model AMMI analysis was used to investigate GE interactions. The model AMMI equation is:

$$Y_{ger} = \mu + \alpha_g + \beta_e + \Sigma_n \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger} \qquad (1)$$

Where Y_{ger} is the yield of genotype g in environment e for replicate r, μ is the total yield mean, α_g is the genotype g mean deviation (genotype mean minus total yield mean), β_e is the environment e mean deviation, λ_n is the singular value for IPCA axis n, γ_{gn} is the genotype g eigenvector value for IPCA axis n, δ_{en} is the environment e eigenvector value for IPCA axis n, ρ_{ge} is the residual, and ε_{ger} is the error.

The SIPC1 and SIPCF stability parameters of AMMI are sums of the absolute value of the IPC scores for each genotype and so the lower the IPC scores, the more stable a genotype is to environments.

$$SIPC = \sum_{n=1}^{n} \lambda_n^{0.5} \gamma_{in} \qquad (2)$$

In this equation N=1 for SIPCA1; for SIPCF, N was the number of PC that were retained in the AMMI procedure via F tests. Another stability parameter of AMMI according to the below equation was proposed by Annicchiarico (1997).

$$D = \sqrt{\sum_{n=1}^{N} (\lambda_n \gamma_{in})^2} \qquad (3)$$

Where for D1, N was one, for DF, N was the number of IPC which were significant. AMMI's stability value (ASV) was calculated using as suggested by Purchase (1997):

$$ASV = \sqrt{\frac{SSIPC1}{SSIPC2}(PC1)^2 + (PC2)^2} \qquad (4)$$

Where, ASV is the AMMI's stability value, SS, sum of squares, IPCA1, interaction of principal component analysis one, IPCA2, interaction of principal component analysis two. For effective interpretation of GE interactions via AMMI model a new parameter as modified AMMI's stability value (MASV) is introduced as below formula:

$$MASV = \sqrt{\sum_{n=1}^{N-1}\left(\frac{SSIPC_n}{SSIPC_{n+1}}\right)(PC_n)^2 + (PC_N)^2} \quad (5)$$

In this modified AMMI stability parameter, all significant IPCs were used. The AMMI stability parameters were compared using their ranks for each genotype via calculating Spearman's rank correlation (Steel and Torrie, 1980). All analyses were performed using the statistical package Genstat release 12.0 (Genstat, 2010) and SAS release 6.12 (SAS, 1996). Calculations were performed by GENSTAT 12 software using the full data (including all replicates data) for AMMI model. For calculation of environmental variance, Wricke ecovalence and regression coefficient parameters used of macro program that wrote in MATLAB software. Spearman rank correlation coefficients were determined as a measure of repeatability for each stability parameter as well as mean yield as follows using the afore-mentioned three datasets.

RESULTS

A combined analysis of variance showed high magnitude of GE interaction. The AMMI analysis showed that environments, genotypes and GE interactions were highly significant (P<0.001). Bartlett's homogeneity test showed that the mean squares of individual environments were homogeny and so the combine analysis of variance could be done. The significances among the environments indicate that these environments can be used as test of stations for different environments while significant differences among genotypes reveals the differential response of genotypes to different environments. The GE interaction is composed of seven components (IPCA) along with their contribution of sum of square (SS) with decreasing importance.

AMMI stability parameters

The genotypes showed significant differences in grain yield. In Table 2, taking mean yield as the first parameter for evaluating, the genotypes, G1, G2, G11, G12 and G14 gave the best mean yields while G6, G8, G10 and G17 had the lowest mean yields across environments. The IPCA scores of genotypes in AMMI method are indicators of the stability of a genotype over environment (Sabaghnia, 2008). The lowest IPCA1 was observed genotype for G3 followed by G6 and G18 (Table 3). According to IPCA1, G18 (FLIP 92-15L) was the most stable genotype with the mean yield (1182 kg ha^{-1}) higher than total yield mean (average of all genotypes yield 1175 kg ha^{-1}). The highest IPCA1 was belonging to G9 followed by G1 and G17 that only G17 had lower mean yield than total yield mean.

Ilker et al. (2011) determined the stability and yield performances of 20 bread wheat cultivars grown in nine different environments. AMMI components demonstrated that cultivars with larger PCA 1 and lower PCA 2 scores were high yielding and stable cultivars and cultivars with lower PCA 1 and larger PCA 2 scores were low yielding and unstable cultivars in tested locations. It could be concluded that the Basribey 95 had the highest yield performance and also the stable genotype in the test locations. The GE interaction was further analyzed with the AMMI model for seed yield stability which model including IPCA1 and IPCA2 accounted for 47.5% of the GE variation of seed yield in studied Lentil genotypes. Table 1 shows the seven IPCA axes declared significant by the F-test that was proposed by Gollob (1968). The five IPCAs retained by Gollob's F-test accounted for 84.9% of GE interaction. The AMMI model revealed that there was a more complex interaction of GE and which it could not facilitate graphical visualization of the genotypes in low dimensions and so it is essential to use an alternative procedure to interpretation of GE interaction using AMMI parameters (Sabaghnia et al., 2008).

The values of the SIPC1 parameter of AMMI model could be useful in identifying genotypes stability and so genotypes G3, G18, G2 and G7 were the most stable genotypes whereas genotypes G1, G17 and G9 were the most unstable genotypes which both stable and unstable genotypes except G17 and G3 had relatively high mean yield performance (Table 3). According to Dehghani et al. (2010), the values of the SIPC statistics (SIPC1 and

Table 2. Analysis of Variance and Interaction PCs in AMMI Model

S. O. V.	Degree of Freedom	Sum of Squares	Mean of Squares
Total	863	407225	471.87
Treatments	215	323050	1502.56***
Genotypes	17	22037.5	1296.32***
Environments	11	227462.5	20678.41***
Block	36	5562.5	154.51^{ns}
G × E	187	73550.0	393.32***
IPCA1	27	20350.0	753.70***
IPCA2	25	14575.0	583.00***
IPCA3	23	12712.5	552.72***
IPCA4	21	8212.5	391.07***
IPCA5	19	6612.5	348.03***
IPCA6	17	4650.0	273.53*
IPCA7	15	3550.0	236.67^{ns}
Residuals	40	2887.5	72.19
Error	612	78612.5	128.45

***, ** and * Indicates significance at *P*=0.001, 0.01 and 0.05.

Table 3. First three Interaction Principal Component Analysis parameters for Lentil Genotypes

CODE	GENOTYPE	Yield	IPCA 1	IPCA 2	IPCA 3	IPCA 4	IPCA 5
G1	FLIP 96-7L	1277	-18.91	4.38	-3.67	-9.54	5.85
G2	FLIP 92-12L	1229	5.44	-0.94	4.08	-16.47	5.00
G3	FLIP 96-13L	1159	1.32	-16.10	-4.97	5.61	-9.42
G4	FLIP 96-8L	1145	-4.74	7.49	3.02	-2.81	-21.16
G5	FLIP 96-4L	1192	-0.81	6.20	-2.45	-5.93	-9.99
G6	FLIP 96-14L	987	-2.32	8.97	5.82	6.52	-4.17
G7	ILL 5583	1174	5.00	-6.97	21.03	-7.11	1.76
G8	FLIP 96-9L	1072	-2.63	-4.52	-2.06	19.67	3.40
G9	ILL 6002	1197	19.67	17.86	6.42	7.77	-0.70
G10	ILL 6030	1069	12.25	-22.46	10.23	-1.52	3.41
G11	Gachsaran	1237	-4.64	6.87	5.47	10.52	9.49
G12	ILL 7523	1202	-13.15	1.45	11.23	2.77	2.92
G13	ILL 6468	1163	-5.78	-3.32	-6.01	4.14	12.31
G14	ILL 6206	1262	-12.25	-7.84	-14.70	3.51	-4.58
G15	ILL 62-12	1177	-11.34	9.36	-1.35	-9.23	6.00
G16	FLIP 82-1L	1145	9.52	-7.29	-14.95	-7.85	0.54
G17	CABRALIA	1083	18.33	9.54	-16.25	-1.94	6.85
G18	FLIP 92-15L	1183	2.93	-2.69	-0.90	1.88	-7.51

SIPCF) could be useful in identifying stable genotypes using eigenvectors of genotypes.

According to results of Table 4 for D1 stability parameter genotypes G2, G3, G11 and G17 were the most stable genotypes whereas genotypes G4, G7 and G15 were the most unstable genotypes which had relatively high mean yield performance. DF stability parameter which derived from five significant IPCs of AMMI model revealed that genotypes G2, G11 and G14 were the most stable genotypes while genotypes G1, G4 and G15 were the most unfavorable genotypes. It seems that various AMMI stability parameters indicate different aspects of yield stability and GE interaction nature. Although SIPC1 and D1 parameters use only one IPC and can explain only 27.7 percent of variation for GE interaction, but they cloud identify genotype G2 as the most favorable genotype which had high mean yield. Overall according to SIPCF and DF parameters with 84.9 percent explanation of GE interaction variation, genotype G3 had the most stability with low mean yield and genotype G2 could be introduced as the most favorable genotype with both high mean yield and stability.

The ASV as described by Purchase (1997) is comparable with the other stability parameters of AMMI model in the study of GE interaction. Table 3 indicates the ASV values of the AMMI model for each genotype. Results of ASV parameter showed that genotypes G2, G5 and G18 were the most stable. The most unstable were genotypes G9, G10 and G17. Although, ASV parameter was reported to produce a balanced measurement between the two first PC's (PC1 and PC2) scores, but it seems that this parameter is useful when the portion of explained total variation was relatively high (Sabaghnia et al., 2008). The results of the modified AMMI's stability value (MASV) which benefits all five significant IPCs, indicated that genotypes G2, G5 and G18 were most stable which had relatively high mean yield performance whereas genotypes G4, G10 and G17 were the most unstable genotypes which had relatively low mean yield performance (Table 4).

Table 4. Values of eleven stability parameters for Lentil Genotypes

Entry	Yield	CV_i	σ_i^2	S_{di}^2	R^2	b_i	W_i^2	SIPC1	*ASV*	*MASV*	*D1*
G1	1277	20.16	1011.4	484752	0.94	1.01	1037	-18.91	22.72	27.1	1115.3
G2	1316	18.27	430.5	502676	0.99	1.01	508.1	5.44	6.39	19.5	1056.4
G3	1159	19.89	683.5	465949	0.89	0.82	716.4	1.32	16.16	24.3	1088.4
G4	1145	26.86	735.9	731696	0.91	1.17	767.7	-4.74	9.35	34.7	2752.0
G5	1192	25.59	236.5	547559	0.95	1.25	279.4	-0.81	6.23	18.4	1130.0
G6	987	23.30	455.1	701314	0.96	0.85	493.1	-2.32	9.38	15.7	1142.1
G7	1208	18.18	996.9	584571	0.95	0.69	1022.9	5.00	9.14	29.1	3771.1
G8	1072	18.61	456.6	706080	0.95	0.73	582.5	-2.63	5.49	23.4	1916.5
G9	1197	24.74	1724.5	590633	0.96	0.92	1734.3	19.67	30.26	28.2	1537.0
G10	1069	22.83	1399.1	694727	0.83	0.74	1416.1	12.25	26.12	30.8	2219.7
G11	1309	16.12	229.3	449184	0.96	1.03	265.6	-4.64	8.79	22.0	1081.0
G12	1202	22.73	671.4	820608	0.87	1.01	704.6	-13.15	15.61	21.7	2476.0
G13	1163	21.41	411.1	597330	0.84	0.95	450.0	-5.78	7.59	22.4	2858.8
G14	1262	18.14	943.4	886250	0.94	1.05	970.5	-12.25	16.46	26.1	1626.5
G15	1177	21.24	717.1	700716	0.95	1.25	749.3	-11.34	16.35	21.8	2545.7
G16	1145	26.00	802.8	733278	0.95	1.11	833.0	9.52	13.40	24.7	1412.3
G17	1088	30.27	641.4	471654	0.95	1.04	652.6	18.33	25.78	34.7	1078.4
G18	1182	22.12	184.4	794079	0.91	1.05	228.4	2.93	4.38	12.7	1871.4

CV_i = Coefficient of Variance of Francis and Kannenberg (1978), σ_i^2 = Shukla Variance 1972, S_{di}^2 = deviation from regression, R^2 =coefficient of determination, b_i = Correlation coefficient of Finlay and Wilkinson(1963), W_i^2 = Ecovalence of Wricke 1962, SIPC1= Sum of IPC scores, ASV= AMMI Stability Value, MASV= Modified AMMI Stability Value, *D1*= Genotypic stability.

Univariate parametric indices of stability analysis

Nine univariate stability methods classified into four groups. Type one is based on deviation from average genotype effect, Type II on GE interaction term, and Type III and IV on either group I or group II. Lin and Binns (1988) proposed Type IV stability concept on the basis of predictable and unpredictable non-genetic variation; the predictable component related to sites and the unpredictable component related to years. According to Type I stability concept (Table 4), genotypes G11, G2, G7, G8 and G15 were the most stable genotypes based on coefficient variation (CVi) and genotypes G18, G5, G11 and G2 were the most stable genotypes based on Shukla stability variance (σ_i^2) and Wricke's ecovalence. It seems that based on three stability parameters which show Type I stability concept, genotypes G11 and G2 were the most stable genotypes (Table 4). Although Type I is theoretically sound, the most plant breeders do not use it frequently as they would like to select genotypes with high yields besides having Type I stability (Lin et al., 1986).

In this research we used regression coefficient of Finlay and Wilkinson (1963) as Type II of stability concept and result of this method indicated that genotypes G1, G2, G11 and G12 were the most stable genotypes. Akçura et al. (2009) used of 4 parametric and 2 nonparametric stability indices for evaluating 20 durum wheat genotypes in 14 environments. Result showed that these relationships reveal that only one of them could be sufficient to select genotypes of interest in a durum wheat breeding program (Akçura et al., 2009). Regression slops represent Type II stability, that is, a genotype is stable when its response approaches the average response of all genotypes. In other word, these genotypes are considered to be stable because their response to environment is parallel to the mean response of all studied genotypes (Mekbib, 2003).

The result of deviation from regression (Eberhart and Russell, 1966) as Type III of stability concept showed that genotypes G11, G17, G1, G2 and G3 were the most stable genotypes G6, G8, G16 and G18 were the most unstable genotypes (Table 4). Deviation from regression is the measure of agronomic stability and predictability of estimated response (Lin et al., 1986). Such these genotypes are acceptable over a wide range of environmental conditions (Allard and Bradshaw, 1964). Deviation from regression is the measure of agronomic stability and predictability of estimated response (Lin et al., 1986). Such these genotypes are acceptable over a wide range of environmental conditions (Allard and Bradshaw, 1964).

Evaluation of environments and selected genotypes in them

In each environment, AMMI selected best genotypes that were suitable and adaptable for that location. First four AMMI selection of stable genotypes in each environment (location × year) showed in Table 5.

Table 5. First four AMMI method selections of genotypes per environment

Env. Code	Location/Agronomic Year	Mean Yield	SCORE[A]	AMMI 1	AMMI 2	AMMI 3	AMMI 4
E1	Gonbad 2002-03	1086	-14.7	G2	G3	G1	G16
E5	Gonbad 2003-04	1118	-26.2	G2	G1	G15	G7
E9	Gonbad 2004-05	1210	11.6	G14	G10	G2	G7
E2	Kermanshah 2002-03	1232	3.21	G1	G11	G3	G4
E6	Kermanshah 2003-04	1168	-8.89	G9	G2	G14	G11
E10	Kermanshah 2004-05	1113	10.1	G2	G1	G5	G11
E3	Ilam 2002-03	1133	5.82	G7	G2	G11	G3
E7	Ilam 2003-04	1219	1.42	G1	G17	G2	G14
E11	Ilam 2004-05	1126	4.58	G11	G2	G17	G4
E4	Gachsaran 2002-03	1082	-13.9	G3	G11	G2	G17
E8	Gachsaran 2003-04	1295	9.65	G2	G11	G1	G16
E12	Gachsaran 2004-05	1318	4.00	G2	G11	G1	G16

[A] Mean of IPCA1 and IPCA2 for each environment.

Environment mean yield and score show in this table. Genotype G2 (FLIP 92-12L) selected by AMMI1 as a first choice in five environments (Gonbad and Gachsaran in two years and Kermanshah at third year). Also in three environments (Kermanshah 2003-04, Ilam 2002-03 and Ilam 2003-04) genotype G2 selected by AMMI2 as a second choice. Genotype G1 (FLIP 96-7L) selected by AMMI1 as a first choice in two environments (E2 and E7). Also G1 in two environments (E5 and E10) selected by AMMI2 as a second choice and in three environments (E1, E8 and E12) selected by AMMI3 as a third choice. Genotype G11 (Gachsaran cultivar) was eleven times in

Table 6. Spearman correlation coefficient for yield and ten stability indices in pair years

Years Combination	Yield	CV_i	σ_i^2	S_{di}^2	R^2	b_i	W_i^2	SIPC	*ASV*	*MASV*	*D1*
2002-03 & 2003-04	0.54*	0.57*	-0.32	-0.21	0.67*	0.67**	-0.38	-0.61*	0.66	0.82	0. 6**
2003-04 & 2004-05	0.58*	0.17	0.61	0.12	0.68*	0.71**	0.19	0.59	0.49*	-0.71**	0. **
2002-03 & 2004-05	0.33	0.29	-0.09	0.39	0.72**	0.69**	0.06	0.33	0.28	0.77**	0.6 **

AMMI1, AMMI2, AMMI3 and AMMI4 as the first four priorities of genotypes. The scores of E7, E2, E12, E11 and E8 were lowest score in this research and these environments had more stable yield than other environments, also we can nominate these environments as favorite environments. In six environments, mean grain yield was higher than and other six environments lower than total mean yield. Only in Gachsaran location, Mean yield in two years (E8 and E9) was higher than total mean yield (1295 and 1318 kg ha^{-1}), but in Gonbad (E9), Kermanshah (E2) and Ilam (E7) mean yield in one year was higher than total mean yield.

DISCUSSION

Each one of the mentioned stability statistics produced a unique genotype ranking. The Spearman's rank correlations between each pair of stability statistics were calculated (Table 7). Among different ten stability statistics, only desirability D1 index of Annicchiarico (1997) had highly significant correlation with mean yield. CVi as the indicator of Type I stability concept was significant correlated with Shukla variance and Wricke ecovalence (single years 1 and 2; pair years 2002 & 2003; triple year 2002-2005), bi regression coefficient (in all single, pair and triple years except single year 2003), SIPC1 AMMI parameter (only in two single year 2002 and 2003). Shukla variance (1972) and Wricke ecovalence (1962) indices showed highly significant rank correlation each other and also indicated significant correlated with ER, bi and ASV (two single years and one pair years). Also, results of Table 7 revealed that Shukla stability variance had negative significant correlation with ASV, MASV and positive correlation significant with ER, W2, SIPC1 indices and no significant correlation with D1 and yield parameters.

Pinthus's (1973) coefficient of determination (R^2) showed significant positive correlation with ASV (two single years 2002 and 2004; two pair years 2002-03 and 2003-04 and triple years 2002-2005), MASV (three single years 2002, 2003 and 2004; two pair years 2003-04 and 2004-05 and triple years 2002-2005), bi (one pair years 2002-04). The ER statistic (Type III stability concept) of Eberhart and Russell (1966) had positive significant correlations with the mean yield, bi, ASV and MASV stability statistics. ER stability parameter showed high significant positive correlation with W2 Wricke ecovalence. Maybe this stability statistic reflects distinct aspect of yield stability. These result corresponded with Karimizadeh et al. (2009).

Each of the AMMI stability parameters produced a value for each genotype and the rank correlation matrix was performed on a set of durum wheat stability dataset. The results of Table 7 demonstrate that there was a lot of positive or negative significant correlations between seed mean yield and AMMI stability parameters, these result corresponded with Karimizadeh et al. (2009). SIPC1 parameter indicated positive significant correlation with CVi (Francis and Kannenberg, 1978) at first and second year separate (0.52 and 0.49 respectively). SIPC1 had no significant correlation with ER, bi and D1 parameters. Also, SIPC1 parameter showed positive significant correlation with Shukla variance, ASV and MASV parameters and negative significant correlation with mean yield (Table 7). Some result of this research validates result of Sneller et al. (1997) and Karimizadeh et al. (2009). D1 Parameter had no significant correlation with ASV and MASV parameters and positive significant correlation with mean yield (Table 7).

Spearman rank correlation coefficients were determined as a measure of repeatability for each stability parameter (Table 6). First, correlation of stability parameters measured with its values at two pair years and then correlation coefficients of three pair years compared. Each parameter that is shown significant correlation in at least two pair years is repeatable. In this research result showed that CVi coefficient of variation had significant correlation only in first pair years also this parameter is not repeatable (Table 6). This is an agreement with data reported for other crops (Karimizadeh et al., 2009) and contrary to result of Bever and Johnson (1981) and Jalaluddin and Harrison (1993). Pinthus's (1973) coefficient of determination (R^2) showed significant positive correlation by itself at all pair years and we can nominate a repeatable parameter. This result contrary to report of Leon and Becker (1988) and agreement with result of Jalaluddin and Harrison (1993). The bi regression coefficient had significant correlation in three pair years (Table 6), also this parameter is repeatable. This is an agreement with data reported for other crops (Bever and Johnson, 1981; Ntare and Aken'Ova, 1985; Leon and Becker, 1988; Helms, 1993; Jalaluddin and Harrison, 1993) and contrary to result of Karimizadeh (2009) and Baxevanos et al. (2008). Wricke ecovalence, Shukla variance and deviation of regression (ER) showed non-

Table 7. Rank Correlation among lentil genotypes mean yield and ten stability parameters

Parameter	By Parameter	Year 1 2002	Year 2 2003	Year 3 2004	2002 and 2003 Mean	2003 and 2004 Mean	2002 and 2004 Mean	Mean of 3 Years
CVi	Shukla	0.48*	0.52*	0.39	0.52*	0.36	0.16	0.53*
CVi	ER	-0.27	0.08	-0.31	-0.44	0.29	0.37	0.42
CVi	R^2	0.03	0.19	-0.28	-0.18	-0.22	-0.17	-0.22
CVi	bi	0.61*	0.41	0.56*	0.67*	0.72**	0.50*	0.66*
CVi	W^2	0.49*	0.52*	0.11	0.48*	0.32	0.41	0.51*
Shukla	ER	-0.33	-0.65*	0.78**	0.19	-0.44	0.61*	0.42
Shukla	R^2	-0.16	0.31	-0.03	-0.07	0.31	0.18	0.11
Shukla	bi	0.51*	0.26	0.49*	0.33	0.43	0.54*	0.38
Shukla	W^2	0.88**	0.79**	0.81**	0.83**	0.94**	0.89**	0.91**
Shukla	SIPC1	-0.56*	-0.33	0.49*	0.44	-0.61*	-0.28	0.41
ER	R^2	0.23	0.29	0.38	0.33	0.41	0.28	0.26
ER	bi	0.55*	0.61*	0.52*	0.55*	0.49*	0.57*	0.51*
ER	W^2	-0.29	-0.71**	0.66*	0.49*	-0.39	0.55*	0.51*
ER	SIPC1	-0.12	-0.09	0.21	0.19	0.12	0.33	-0.28
ER	ASV	-0.39	0.51*	-0.59*	0.44	0.58*	0.31	0.55*
R^2	bi	0.003	0.05	0.14	0.32	0.29	0.49*	0.24
R^2	W^2	-0.22	0.24	-0.08	-0.11	0.22	0.31	0.19
R^2	SIPC1	0.14	0.04	0.31	0.09	0.05	0.13	0.17
R^2	ASV	0.61*	0.29	0.58*	0.49*	0.55*	0.29	0.51*
R^2	MASV	0.55*	0.71**	0.63*	0.44	0.53*	0.61*	0.68*
bi	W^2	0.61*	0.18	0.54*	0.31	0.45	0.71**	0.44
bi	SIPC1	0.13	0.19	0.24	0.11	0.09	-0.08	0.15
bi	ASV	0.49*	-0.34	0.61*	0.44	0.58*	0.51*	0.49*
bi	MASV	0.27	0.61*	037	049*	0.64*	0.58*	0.54*
bi	*D1*	0.41	-0.36	-0.24	0.59*	0.71**	0.42	0.38
W^2	SIPC1	-0.48*	0.51*	0.24	-0.39	0.59*	-0.55*	0.42
W^2	ASV	0.09	0.15	0.04	-0.11	0.24	0.16	-0.20
W^2	MASV		-	*			0.57*h	
W^2	*D1*	*	*	*		*	*	*
W^2	Yield			*	*			
SIPC1	CVi	*	*					
SIPC1	ASV	*	*	*	**	**	*	*
SIPC1	MASV		*		*	*		*
SIPC1	*D1*							
SIPC1	Yield	-		- *	- *		- *	
ASV	CVi		0.16					
ASV	Shukla	- *	-	-	-0.54*	- *		*
ASV	MASV		*			**		*
ASV	*D1*			-0.08				
ASV	Yield	*	*			*	*	*
MASV	CVi							-0.11
MASV	Shukla	-	- *	- *	-		-	*
MASV	ER	**		4	*			*
MASV	*D1*							
MASV	Yield							
D1	CVi			-				
D1	Shukla	-						
D1	ER		-	-	-			
D1	R^2		-	-	-	-	*	*
D1	Yield	1*	*	*	**	*	*	*
Yield	CVi							
Yield	Shukla		-	-	-			
Yield	ER	*		-	0.49*	**	*	*
Yield	R^2	-		-				-
Yield	bi	*			- *	-0.19	- *	*

significant correlation each other in all pair years and they are unrepeatable parameters (Table 6). These results agreement with data result of Baxevanos et al. (2008) and do not agreement Karimizadeh et al. (2009) completely because Karimizadeh et al. (2009) reported Shukla stability parameter and Wricke ecovalence were very significant correlation at 0.01 probability level.

AMMI parameters including MASV and D1 had high significant correlation in three pair years and showed that are repeatable (Table 6). Repeatability of these parameters measured in this research for the first time and also we can't compare with other researches. The other AMMI parameters including SIPC1 and ASV had significant correlation at two pair years and they were repeatable parameters. Some of these results agreement with Sneller et al. (1997), Karimizadeh et al. (2009) and Baxevanos et al. (2008).

In summary, R^2, Shukla variance, Wricke ecovalence, SIPC1 were less correlated with mean yield (Table 7), Shukla variance was correlated with SIPC1, ASV and MASV; and R^2 was better correlated with MASV than ASV. Data provide evidence that evaluation based on data in a single year (Table 7) was sufficiently reliable. Ranking could be based on mean yield performance, along with stability parameters. Genotype evaluation based on data from two consecutive years seemed to be more effective as compared to a single year evaluation. Regarding the repeatability of stability parameters, data were rather inconsistent. In spite of this MASV and D1 parameters, were highly repeatable in most cases indicating its value to integrate mean performance and stability into a single measure, which can be assessed visually on biplots. It was more informative regarding the repeatability of the stability parameters and the mean yield. Repeatability of three pair years' results (data set C) were highest for bi, R^2, MASV and D1 parameters and for two pair years' results (data set B) were highest for SIPC1 and ASV. Also we propose that researcher use of bi, ASV, MASV and SIPC1 parameters for evaluating adaptability and stability of genotypes or cultivar because these parameters showed that they had high significant correlated with grain yield and also they are repeatable in single year, pair years and triple years.

Abbreviation: AMMI= Additive Main Effect and Multiplicative Interaction; GE= genotype × environment; ICARDA = international centre for agricultural research in the dry areas; CV= coefficient of variability; W_i^2 = Wricke ecovalance; σ_i^2 = Shukla stability variance; bi, regression coefficient; ER= Eberhart and Russel deviation from regression; R^2= Coefficient of determination; SIPC1= Sum of IPC scores, ASV= AMMI Stability Value, MASV= Modified AMMI Stability Value, D1= Genotypic stability.

LITERATURE CITED

Akçura, M., Y. Kaya, and S. Taner, 2009. Evaluation of durum wheat genotypes using parametric and nonparametric stability statistics. Turkish Journal of Field Crops, 14(2): 111-122.

Allard, R.W., and A.D. Bradshaw, 1964. Implications of genotype-environmental interactions in applied plant breeding. Crop Science, 4: 503-508.

Annicchiarico, P. 1997. Joint regression vs AMMI analysis of genotype-environment interactions for cereals in Italy. Euphytica, 94: 53-62.

Arshad, M., A. Bakhsh, M. Zubair, and A. Ghafoor, 2003. Genetic variability and correlation studies in chickpea (*Cicer arietinum* L). Pakistan Journl of Botany, 35(4): 605-611.

Baxevanos, D., C. Goulas, S. Tzortzios, and A. Mavromatis, 2008. Interrelationship among and repeatability of seven stability indices estimated from commercial cotton variety evaluation trials in three Mediterranean countries. Euphytica, 161(3): 371-382.

Bernardo, R., 2002. Quantitative traits in plants. Stemma Press, 1938 Bowsens Lanne, Woodbury, MN 55125.

Bever, J.S., and R.R. Johnson, 1981. Yield stability of determinate and indeterminate soybeans adapted to the northern United States. Crop Science, 21: 449–454.

Blanche, S.B., 2005. New methods to assess cotton varietal stability and identify discriminating environments. PhD dissertation, Louisiana state university and agricultural and mechanical college.

Comstock, R.F., and R.H. Moll, 1963. Genotype – environment interactions. In: Hanson WD, Robinson HF (eds) Statistical genetics and plant breeding. NAS-NCR Publ. 982, Washigton, DC, pp 164–196.

Dehghani, H., S.H. Sabaghpour, and N. Sabaghnia, 2008. Genotype × environment interaction for grain yield of some lentil genotypes and relationship among univariate stability statistics. Spanish Journal of Agricultural Research, 6(3): 385-394.

Dehghani, H., S.H. Sabaghpour, and A. Ebadi, 2010. Study of genotype × environment interaction for chickpea yield in Iran. Agronomy Journal, 102: 1-8.

Eagles, H.A., and K.J. Frey, 1977. Repeatability of stability variance statistics in oats. Crop Science, 6: 253-256.

Eberhart, S.A., and W.A. Russell, 1966. Stability parameters for comparing varieties. Crop Science, 6: 36-40.

FAO, 2008. Data stat year 2008, Rome, Italy United Nations Food and Agriculture Organization, Rome.

Fatunla, T., and K.J. Frey, 1976. Repeatability and regression stability indexes for grain yield in oats (*Avena sativa* L.). Euphytica, 25: 21-28.

Finlay, K.W., and G.N. Wilkinson, 1963. The analysis of adaptation in a plant breeding programme. Australian Journal of Agricultural Research, 14: 742-754.

Francis, T.R., and L.W. Kannenberg, 1978. Yield stability studies in short–season maize Canadian Journal of Plant Science, 58: 1025-1034.

Gauch, H.G. 1992. Statistical Analysis of Regional Yield Trials: AMMI Analysis of Factorial. Designs Elsevier, Netherlands, Amsterdam 256 pp.

Gauch, H.G., and R.W. Zobel, 1996. AMMI analysis of yield trials In: Genotype by environment interaction. In: Kang, M.S., H.G. Gauch, (eds) pp 85-122.

Genstat, 2010. Genstat for Windows. 12th ed. VSN Int., Hemel Hempstead, UK.

Gollob, H.F. 1968. A statistical model which combines features of factor analytic and analysis of variance techniques. Psychometrika, 33: 73-115.

Helms, T.C., 1993. Selection for yield and stability among oat lines. Crop Science, 33: 423-426

Ilker, E., H. Geren, R. Unsal, I. Sevim, F. A. Tonk and M. Tosun. 2011. AMMI-biplot analysis of yield performances of bread wheat cultivars grown at different locations. Turkish Journal of Field Crops, 16(1): 64-68.

Jalaluddin, M.D., and S.A. Harrison, 1993. Repeatability of stability statistics for grain yield in wheat. Crop Science, 33: 720–725.

Kang, M.S., 1993. Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. Agronomy Journal, 85: 754-757.

Karimizadeh, R., M. Mohammadi, and M.K. Shefazadeh, 2011. Evaluation of reliability and stability of lentil (*Lens culinaris*. Medik) genotypes in dryland areas of Iran. Journal of Food Agriculture and Environment, 9(1): 432-437.

Karimizadeh, R., B. Vaezi, T. Hoseinpour, A. Mehraban, and H. Ghojogh, 2009. Study on correlation and repeatability of parametric and multivariate statistics of grain yield stability in rainfed barley. Journal of Science and Technology of Agriculture and Natural Resources, 13(48): 53-63.

Karimizadeh, R., M. Safikhani, M. Mohammadi, F. Seyyedi, A. Mahmoodi, and B. Rostami, 2008. Determining rank and stability of lentil in rainfed condition by nonparametric statistics. Journal of Science and Technology of Agriculture and Natural Resources, 43(1): 93-103.

Leon, J., and H.C. Becker, 1988. Repeatability of some statistical measures of phenotypic stability–Correlations between single year results and multi-year results. Plant Breeding, 100: 137–142.

Lin, C.S., and M.R. Binns, 1988. A superiority measure of cultivar performance for cultivar × location data. Canadian Journal of Plant Science, 68: 193–198.

Lin, C.S., and M.R. Binns, 1991. Genetic properties of four types of stability statistic. Theoretical and Applied Genetics, 82: 505-509.

Lin, C.S., M.R. Binns, and L.P. Lefkovitch, 1986. Stability analysis: where do we stand? Crop Science, 26: 894-900.

Mekbib, F., 2003. Yield stability in common bean (*Phaseolus vulgaris* L.) genotypes Euphytica, 130:147-153.

Ntare, B.R., and M. Aken'Ova, 1985. Yield stability in segregating populations of cowpea. Crop Science, 25: 208–211

Pham, H.N., and M.S. Kang, 1988. Interrelationship among and repeatability of several stability statistics estimated from international maize trials. Crop Science, 28:925-928.

Pinthus, J.M., 1973. Estimate of genotype value: a proposed method. Euphytica, 22: 121-123.

Purchase, J.L., 1997. Parametric analysis to describe genotype × environment interaction and yield stability in winter wheat. PhD Thesis, Department of Agronomy, Faculty of Agriculture of the University of the Free State, Bloemfontein, South Africa.

Rajput, M.A., and P. Sarwar, 1989. Genetic variability, correlation studies and their implications in selection of high yielding genotypes in lentil. Lens newsletter 16: 5-8.

Sabaghnia, N., H. Dehghani, and S.H. Sabaghpour, 2006. Nonparametric methods for interpreting genotype × environment interaction of Lentil genotypes. Crop Science, 46: 1100-1106.

Sabaghnia, N., H. Dehghani, and S.H. Sabaghpour, 2008. Graphic analysis of genotype × environment interaction of lentil yield in Iran. Agronomy Journal, 100: 760–764.

Sarker, A., W. Erskine, and M. Singh, 2003. Regression models for lentil seed and straw yields in Near East. Agriculture and Forestry Meteorology, 116: 61-72.

SAS Institute, 1996. SAS/STAT users guide. v. 6, 4th ed. SAS Inst., Cary, NC.

Shukla, G.K. 1972. Some statistical aspects of partitioning genotype × environmental components of variability. Heredity, 29: 237-245.

Sneller, C.H., L. Kilgore-Norquest, and D. Dombek, 1997. Repeatability of yield stability statistics in soybean. Crop Science, 37: 383-390.

Steel, R.G.D., and J.H. Torrie, 1980. Principles and procedures of statistics. McGraw Hill Book Co., New York.

Virk, D.S., S.S. Chahal, and H.S. Pooni, 1985. Repeatability of stability estimators for downy mildew incidence in pearl millet. Theoretical and Applied Genetics, 70: 102-106.

Wricke, G., 1962. Uber eine methode zur refassung der okologischen streubretite in feldversuchen. Flazenzuecht, 47: 92-96.

Yan, W., and M.S. Kang, 2003. GGE Biplot analysis. A graphical toll for breeders, geneticists, and agronomists. CRC Press

Zavala-Garcia, F., P.J. Bramel-Cox, and J.D. Eastin, 1992. Potential gain from selection for yield stability in ten grain sorghum populations. Theoretical and Applied Genetics, 85: 112-119.

Zobel, R.W., and H.G. Gauch, 1988. Statistical analysis of a yield trial. Agronomy Journal, 80: 388-393.