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Araştırma Makalesi/Research Article (Original Paper)

Grain Yield Stability Analysis of Lentil Genotypes by Additive Main Effects and Multiplicative Interactions Model

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Abstract: This paper presents the yields and several stability parameters of additive main effects and multiplicative interactions (AMMI) model in ten improved lentil genotypes which tested in very diverse environmental conditions in Iran. The F-Gollob indicated that first three interaction principle component analysis (IPCA) axis of AMMI model was significant while cross validation procedure through RMSPD (root mean square prediction difference) values indicated only first an IPCA axis of AMMI model was adequate for GE interaction interpretation. According to EV1, D1, AMGE1, SIPC1 and ASV parameters, genotypes ILL 6037, ILL6199 and cultivar Gachsaran were the most stable genotypes. Based on EVF parameter, genotypes FLIP 96-9L, FLIP 96-4L and ILL 7946 and according to DF parameter genotypes FLIP 96-9L, ILL 7946 and ILL 6199 were the most stable genotypes. Genotypes FLIP 92-12L, ILL 7946 and ILL 6199 based on SIPCF parameter and genotypes FLIP 82-1L, FLIP 96-9L and ILL6199 based on AMGEF parameter were the most stable genotypes. According to the rank correlation coefficients, mean yield did not has any positive significant correlation with AMMI model parameters but showed negative significant correlation with EV1, D1, AMGE1, SIPC1 and ASV parameters. The results of factor analysis of AMMI stability parameters and mean yield indicated that only SIPCF following to EVF parameters would be useful for simultaneously selecting for high yield and stability. A scatter plot of the rotated scores of the first two factors indicated the AMMI stability parameters classified as two distinct classes that corresponded to different static and dynamic concepts of yield stability.

Key words: Dynamic, Factor analysis, Lentil, Stability, Static, Yield

Eklemeli Ana Etkiler ve Çarpımsal Etkileşim Modeli ile Mercimek Genotiplerinin Tane Verimi Stabilite Analizi

Özet: Bu makalede İran'ın çok farklı çevre koşullarında test edilmiş on adet geliştirilmiş mercimek genotiplerinde eklemeli ana etkiler ve çarpımsal etkileşim (AMMI) modelinin verim ve bazı stabilite parametreleri sunulmaktadır. RMSPD (ortalama karekök tahmin farkı) değerleri vasıtasıyla çapraz doğrulama prosedürünün sadece AMMI modelinin ilk ICA ekseninin GE etkileşimi yorumlanması için yeterli olduğunu gösterirken, F-Gollob, AMMI modelinin ilk üç etkileşimi temel bileşen analizi (IPCA) ekseninin önemli olduğunu göstermiştir. EV1, D1, AMGE1, SIPC1 ve ASV parametrelerine göre, ILL 6037, ILL6199 ve Gachsaran çeşidi en stabil genotipler olarak bulunmuştur. EVF parametresine bağlı olarak FLIP 96-9L, FLIP 96-4L ve ILL 7946 genotipleri; DF parametresine bağlı olarak FLIP 96-9L, ILL 7946 ve ILL 6199 genotipleri en istikrarlı genotipler olarak belirlenmiştir. FLIP 92-12L, ILL 7946 ve ILL 6199 genotipleri SIPCF parametresine göre; AMGEF parametresi temelinde ve FLIP 82-1L, FLIP 96-9L ve ILL6199 genotipleri ise AMGEF parametresine göre en istikrarlı genotipler olarak bulunmuştur. Sıra korelasyon katsayılarına göre, ortalama verim AMMI model parametreleri ile herhangi bir pozitif anlamlı bir korelasyon göstermemiş, fakat EV1, D1, AMGE1, SIPC1 ve ASV parametreleri ile negatif anlamlı korelasyon göstermiştir. AMMI stabilite parametreleri ve ortalama verimin faktör analizi sonuçları sadece EVF'yi izleyen SIPCF parametrelerinin yüksek verim ve stabilitenin aynı zamanda seçilmesi için faydalı olabileceğini göstermiştir. İlk iki faktörün döndürülmüş puanlarının bir serpilme diyagramı, AMMI stabilite parametrelerinin verim istikrarının farklı statik ve dinamik kavramlarına karşılık gelen iki ayrı sınıf olarak sınıflandırıldığını göstermiştir.

Anahtar kelimeler: Dinamik, Faktör analizi, Mercimek, İstikrar, Statik, Verim,

Introduction

Lentil (*Lens culinaris* Medik.) is an annual herbaceous legume better adapted to cool climate and is the second most cultivated food legume after chickpea in Iran which is yielding from 457 to 774 kg ha^{-1} (Sabaghnia et al. 2006). Lentil is grown in a wide range of environments and hence, yield of several improved genotypes tested across locations and over years differed due to high genotype × environment (GE) interactions. The GE interactions structure is an important aspect of both plant breeding programs and the introductions of new improved crop cultivars (Sabaghnia et al. 2008b). Several statistical methods have been proposed for analysis yield stability with the aim of explaining the information contained in the GE interaction data matrix (Lin et al. 1986; Flores et al. 1998). These range from univariate parametric, such as linear regression slope (Final and Wilkinson 1963), to multivariate methods such as additive main effects and multiplicative interactions (AMMI) model analysis which introduced by Gauch and Zobel (1988) and Zobel et al. (1988).

Analysis of variance (ANOVA) which is an additive model is effective in partitioning the whole sum of squares into the genotype main effect (G), the environment main effect (E) and GE interaction, but it does not provide insight into GE interaction structure. To study the underlying interaction component, more advanced techniques such as principle component analysis (PCA) are required (Kang 1998). The AMMI model is a hybrid model involving both additive and multiplicative component of two-way data structure (Zobel et al. 1988; Crossa 1990). The AMMI model separates the additive variance from the multiplicative variance and then applies PCA to the GE interaction portion to a new set of coordinate axis which explain in more detail the GE interaction pattern and the estimation performed via the least squares principle (Gauch 2006). AMMI analysis has been shown to be effective because it captures a large portion of the GE sum of squares, it cleanly separates main and interaction effects that present agricultural researchers with different kinds of opportunities, and the model often provides meaningful interpretation from agronomical aspect of the data (Gauch et al. 2008).

Determination of the significant or adequate numbers of GE interaction PCA axis in AMMI model is very important. An F-test devised by Gollob (1968) for the assessment of GE interaction PCA axis proved too liberal both on theoretical grounds and following simulation results. Also, cross validation procedure and its related root mean square prediction difference (RMSPD) values are tabulated for a family of AMMI models or sufficient GE interaction PCA axis (Gauch and Zobel 1988). The RMSPD expected for dataset according to statistical theory and the error mean squares is compared with the empirical value. The RMSPD prediction error of the best AMMI model is estimated, and this result is interpreted in terms of the number of free observations (Gauch 1992; Gauch and Zobel 1996). According to significant number of IPCAs, different AMMI parameters could be computed for stability analysis. These parameters are including EV1 and EVF (Zobel 1994) as the averages of the squared eigenvector values, AMGE1, AMGEF, SIPC1 and SIPCF which describe the contribution of environments to GE interaction (Sneller et al. 1997), D1 and DF as the Euclidean distance from the origin of significant interaction IPCAs axis as D parameter (Annicchiarico 1997) and AMMI stability value (ASV) that derived from first two IPCAs of AMMI model to quantify and rank genotypes according their yield stability (Purchase 1997).

This investigation explored the GE interaction effects on the yield of 10 lentil genotypes grown under several environments in Iran. The different parameters of AMMI model were used to explore desirable genotypes and recommending cultivar release through various concepts of yield stability.

Materıal and Methods

Trials: Nine improved lentil genotypes from International Center for Agricultural Research in the Dry Areas (ICARDA) consisting FLIP 97-1L (FLIP 97-1L), FLIP 82-1L (FLIP 82-1L), FLIP 92-15L (FLIP 92-15L), FLIP 96-9L (FLIP 96-9L), FLIP 92-12L (FLIP 92-12L), FLIP 96-4L (FLIP 96-4L), ILL 7946 (ILL 7946), ILL 6037 (ILL 6037) and ILL6199 (ILL6199) were tested along with the long term check cultivar (Gachsaran) in the yield trials in five research station locations from rain-fed conditions of Iran's lentil producing areas across two growing seasons. The properties and the location of the experimental environments are given in Table 1.

Table 1. Geographical properties and mean yield of the 10 lentil genotypes, studied in 5 locations.

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
5	Shirvan	1131	58 07 E 37 19 N	Loam	267	384

In each location × year, experiment was sown in the February month and a randomized complete block design with four replications was used. The grains were planted with hand according to local practice with planting rate of about 50 grains m^{-2}. Each experimental plot contained four 4 m long rows with 25 cm between rows and plot size was 4 m^2. Control by hand weeding was carried out twice when the weed density was high, in the pre-flowering and post-flowering stages. The plots were fertilized with 20 kg N ha^{-1} and 80 kg P_2O_5 ha^{-1} at planting. Also fighting with yellow rust was done in Kermanshah and Gachsaran using sulfur dust as Wettable Powder form. The harvested plot size was 1.75 m^2 (two 3.5^{-m} rows at the center of each plot). Mean grain yield was estimated for each genotype at each environment. The grain yield dataset was balanced because all genotypes were present in all environments.

Statistical analysis: Analyses of variance were done for each environment (location × year) to plot residuals and identify outliers. Homogeneity of residuals variance was determined by Bartlett's homogeneity test. Effect of year was assumed to be random but the genotype and location effects were assumed to be fixed. A combined analysis of variance was performed on the original dataset to partition out environment (E), genotype (G) and GE interaction. The equation of AMMI model for GE interaction analysis is:

$$Y_{ij} = \mu + g_i + e_j + \sum_{n=1}^{N} \lambda_n \gamma_{in} \delta_{jn} + \rho_{ij}$$

where Y_{ij} is the yield of the *i*th genotype in the *j*th environment; μ is the grand mean; g_i and e_j are the genotype and environment deviations from the grand mean, respectively; λ_n is the eigenvalue of the IPC analysis axis n; γ_{in} and δ_{jn} are the genotype and environment eigenvectors for axis n; n is the number of principal components retained in the model and ρ_{ij} is the error term. F-test Gollob (1968) and RMSPD procedure of (Gauch and Zobel, 1988) were used for the identification of proper numbers of GE interaction PCA axis in AMMI model. The AMMI parameters EV (Zobel 1994), AMGE and SIPC (Sneller et al. 1997), D parameter (Annicchiarico 1997) and ASV (Purchase 1997) were calculated according to equations of Table 2. The associations among different AMMI stability parameters were studied using their Spearman's rank correlation and plot of varimax rotated scores of two first factors obtained Factor Analysis. For each genotype and environment, genotypic and environmental scores were obtained by PROC IML of SAS as well as extraction of significant IPC axis via F-test Gollob (1968) procedure (Burgueno et al. 2001). The RMSPD values calculation for AMMI were performed by the open source software MATMODEL 3.0 (Gauch 2007).

Table 2. Equations of AMMI stability parameters.

Parameters	Equation	Author(s)
EV	$\sum_{n=1}^{N}\gamma_{In}^{2}/n$	Zobel (1994)
AMGE	$\sum_{n=1}^{N}\sum_{g=1}^{M}\lambda_n\gamma_{in}\delta_{jn}$	Sneller et al. (1997)
SIPC	$\sum_{n=1}^{N}\lambda_n^{0.5}\gamma_{in}$	Sneller et al. (1997)
D	$\sqrt{\sum_{n=1}^{N}(\lambda_n\gamma_{in})^2}$	Annicchiarico (1997)
ASV	$\sqrt{\frac{SSIPC1}{SSIPC2}(PC1)^2+(PC2)^2}$	Purchase (1997)

n, the number of significant IPC axis from 1 to N

SSIPC1 and SSIPC2, sum of squares of interaction PC1 and IPC2, respectively

Results

The grain yield of lentil genotypes varied from 128.5 kg ha^{-1} in genotype FLIP 97-1L grown at Shirvan in 2008 to 2715.0 kg ha^{-1} at Kermanshah in genotype FLIP 82-1L grown in 2009 (Table 3). Maximum mean yields varied from 2715 kg ha^{-1} in FLIP 82-1L to 1832.5 kg ha^{-1} in FLIP 97-1L0, while minimum men yield varied from only 128.5 kg ha^{-1} in genotype FLIP 97-1L to 412.8 kg ha^{-1} in FLIP 96-4L. Average yield was not correlated with maximum and minimum mean yield. Yield amplitudes were very large, from 1601.0 kg ha^{-1} to 2442.3 kg ha^{-1} and were correlated with average yield, but not with minimum and maximum mean yield. The mean grain yield of Gachsaran in year 2008 (1752.8 kg ha^{-1}) and Kermanshah at year 2009 (2093.0 kg ha^{-1}) were the highest while the mean grain yield of Gonbad in year 2008 (476.5 kg ha^{-1}) and Shirvan in year 2009 (249.2 kg ha^{-1}) were the lowest. Regarding both mean yields of two years, the mean grain yield of Kermanshah and Gachsaran were high and the mean grain yield of Shirvan was low (Table 3). These variations among test locations show considerable differences among these locations for lentil production.

Table 3. The mean yield of lentil genotypes at five locations across two years (2008–2009).

Genotype	The first year					The second year				
	Gonbad	Kermanshah	Ilam	Gachsaran	Shirvan	Gonbad	Kermanshah	Ilam	Gachsaran	Shirvan
FLIP 97-1L	563.8	1705.0	876.0	2100.0	501.3	1186.3	1865.0	1248.5	1703.0	128.5
FLIP 82-1L	462.5	1915.0	621.0	1650.0	539.8	1070.0	2715.0	508.5	1696.5	272.8
FLIP 92-15L	375.0	1580.0	678.5	1490.0	465.8	1051.3	2162.5	267.0	1469.5	351.5
FLIP 96-9L	402.5	1495.0	593.3	1730.0	516.0	892.5	2210.0	315.3	1521.3	295.8
FLIP 92-12L	566.3	1317.5	1008.5	2040.0	518.8	1305.0	1632.5	1512.8	1577.3	208.5
FLIP 96-4L	465.0	1985.0	886.8	1640.0	503.8	1070.0	2477.5	659.5	1429.0	412.8
ILL 7946	473.8	1582.5	696.8	1911.3	418.0	1296.3	1772.5	1019.5	1746.3	159.8
ILL 6037	485.0	2170.0	649.3	2060.0	484.0	1116.3	2230.0	769.0	1822.5	216.3
ILL6199	518.8	1945.0	774.0	2150.0	531.8	1193.8	2375.0	946.0	2029.8	214.3
Gachsaran	452.5	1832.5	637.3	1750.0	388.3	1157.5	1490.0	671.0	1412.5	231.5
Mean	476.5	1752.8	742.1	1852.1	486.7	1133.9	2093.0	791.7	1640.8	249.2

Combined ANOVA (Table 4) showed that, main effect of year (Y) was not significant while main effect of location (L) was significant ($P< 0.05$). The genotype main effect, YL interaction, GL interaction and GLY interaction were highly significant ($P< 0.01$). Locations had the largest effect, as the location explained 92% of environment variations while years and YL interaction explained 1 and 7% of total environment sum of squares, respectively. Relatively similar results were seen for GE interaction variations, as the GL interaction explained 71% of GE (GL+GY+GLY) interaction sum of squares while GY and GLY explained 3 and 27% of total GE variations, respectively. Finally, environment (Y+L+YL) had the largest effect, as the environment explained 89% of E+G+GE variations while genotype and GE interaction explained 2 and 9% of total E+G+GE sum of squares, respectively.

Table 4. Combined analysis of variance and AMMI analysis of lentil performance trial yield data from five research station locations from rain-fed conditions of Iran.

Source of variation	Df	Sum Squares	Mean Squares	% of GE	F_{Gollob}	RMSPD
Year (Y)	1	1431612.3	1431612.3^{ns}			
Location (L)	4	146111233.6	36527808.4^{*}			
Y × L	4	11598206.0	2899551.5^{**}			
Replication / YL (Error I)	30	3619650.0	120655.0			
Genotype (G)	9	3326339.7	369593.3^{**}			
G × L	36	10861880.4	301718.9^{**}			
G × Y	9	423161.1	47017.9^{ns}			
G × L × Y	36	4068799.2	113022.2^{**}			
IPC1	17	10446892.7	614523.1	68.04	10.53^{**}	298.17
IPC2	15	2178861.0	145257.4	14.19	2.49^{**}	<u>268.79</u>
IPC3	13	1550551.6	119273.2	10.10	2.04^{*}	275.43
Error II	270	13827780.0	51214.0			

* = Significant at 5% level of probability
** = Significant at 1% level of probability
^{ns} = Non significant at > 5% level of probability
RMSPD, the root mean square prediction differences in cross validation, the minimum value of RMSPD is underlined.

F-test Gollob (1968) indicated first three IPCA axis of AMMI model was significant and reminded in the model (Table 2). In contrast, the AMMI model was validated through MATMODEL RMSPD values between AMMI model's estimates and their respective validation observations indicated only first IPCA axis of AMMI model was adequate for GE interaction interpretation (Table 2). Therefore, two types of AMMI parameters were calculated as RMSPD parameters (EV1, AMGE1, SIPC1 and D1) and F-test parameters (EVF, AMGEF, SIPCF and DF). Considering explained variation due to each IPCs, RMSPD based parameters benefits 68.04% of GE interaction sum of squares while F-test based parameters benefits 92.33% of GE interaction variations (Table 2).

According to minimum values EV1 and D1 parameters, and minimum absolute values of AMGE1 and SIPC1 parameters, genotypes ILL 6037, ILL6199 and cultivar Gachsaran were the most stable genotypes (Table 5). Fortunately, some of these stable genotypes (ILL 6037 and ILL6199) indicated high mean yield across test locations and over years which could be regarded as the most favorable genotypes. In other word, these genotypes showed static or biologic concept of stability which equal to homeostasis phenomena in quantitative genetics. Most plant breeders have used the stability as the above similar propose to determine a genotype which shows a relatively constant yield in various environmental conditions but this genotype does not necessarily respond to improved growing conditions with increased yield (Becker, 1981).

Table 5. Mean yields in kg ha^{-1} (MY) and AMMI stability parameter estimates for lentil yields of 10 genotypes tested in 10 environments from five research station locations from rain-fed conditions of Iran.

Genotype	MY	EV1	D1	SIPC1	AMGE1	EVF	DF	SIPCF	AMGEF	ASV
FLIP 97-1L	1187.73	0.1134	544.18	13.54	0.000158	0.1513	561.25	15.32	0.000215	29.97
FLIP 82-1L	1145.10	0.1902	704.86	-17.53	-0.000204	0.2806	730.40	-21.82	-0.000053	38.49
FLIP 92-15L	989.10	0.0741	439.90	-10.94	-0.000128	0.2790	552.04	-21.91	-0.000154	26.90
FLIP 96-9L	997.15	0.0578	388.49	-9.66	-0.000113	0.1411	438.26	-20.21	-0.000025	22.12
FLIP 92-12L	1168.70	0.3625	973.08	24.21	0.000282	0.5823	1022.13	7.18	0.000482	53.56
FLIP 96-4L	1152.93	0.0828	465.05	-11.57	-0.000135	0.1389	496.84	-18.03	-0.000134	26.14
ILL 7946	1107.65	0.0763	446.31	11.10	0.000129	0.0802	448.68	13.05	0.000124	24.37
ILL 6037	1200.23	0.0125	180.74	-4.50	-0.000052	0.3706	462.75	17.00	-0.000210	17.24
ILL6199	1267.83	0.0014	59.75	-1.49	-0.000017	0.3125	407.65	7.35	0.000094	14.42
Gachsaran	1002.30	0.0290	275.22	6.85	0.000080	0.6635	570.57	22.08	-0.000338	15.58

Based on minimum values EVF parameter, genotypes FLIP 96-9L, FLIP 96-4L and ILL 7946 were the most stable genotypes which have moderate mean yield across environments (Table 5). Genotypes FLIP 96-9L, ILL 7946 and ILL6199 were the most stable genotypes regarding minimum values DF parameter while genotypes FLIP 92-12L, ILL 7946 and ILL6199 were the most stable genotypes regarding minimum absolute values SIPCF parameter (Table 5). The mentioned most stable genotypes have relatively moderate or low mean yield. The minimum absolute values of AMGEF showed that genotypes FLIP 82-1L, FLIP 96-9L and ILL6199 were the most stable genotypes. Among these most stable genotypes, only FLIP 82-1L (FLIP 82-1L) was as the high mean yield (1145.1 kg ha^{-1}) genotype. Agronomists would prefer an agronomic (dynamic) concept of stability instead of static (biologic) concept of stability (Becker and Leon 1988). In this concept it is not required that the genotypic response to environmental conditions should be equal for all genotypes.

AMMI stability value (ASV) which uses the first two IPCAs of AMMI model, benefits 82.23% of GE interaction variation. According to ASV, genotypes ILL 6037, ILL6199 and cultivar Gachsaran were the most stable genotypes (Table 5). In other word, its results were in good agreement with EV1, D1, AMGE1 and SIPC1 parameters. Therefore, ASV parameter introduced some of the high mean yielding genotypes (ILL 6037 and ILL6199) as the most stable ones. It should be noticed that the ASV parameter uses IPCA1 and IPCA2 scores as well as magnitude of their sum of squares and so is different from the other AMMI parameters which use only genotypic or environmental IPCs scores or their modifications. Dehghani et al. (2010) in analyzing of multi-environmental trials of some chickpea (*Cicer arietinum* L.) genotypes, reported similar results for the power of ASV and AMMI model parameters which are computed the first IPCA for GE interaction investigation. These authors emphasized that ASV and EV1, D1, AMGE1 and SIPC1 parameters have static concept of stability.

Each one of the AMMI model parameters produced a unique genotype ranking and the Spearman’s rank correlation coefficients between each pair of stability parameters and mean yield were calculated (Table 6). According to rank correlation coefficients, mean yield (MY) did not have any positive significant correlation with AMMI model parameters but showed negative significant correlation with EV1, D1, AMGE1, SIPC1 and ASV parameters. The AMMI model parameters which are calculated from the first IPC (EV1, D1, AMGE1 and SIPC1) were positively significant correlated with each other and with ASV (Table 6). Furthermore, these parameters indicated positive significant correlation with DF parameter. Sabaghnia et al. (2008a) reported no positive or negative association for mean yield with the AMMI stability parameters expects significant negative correlation for EVF. None of the EVF, AMGEF and SIPCF parameters was correlated significantly with the other parameters of AMMI model (Table 6).

Table 6. Spearman's rank correlation coefficients among ranks of 10 lentil genotypes at 10 environments from five research station locations from rain-fed conditions of Iran.

	MY	EV1	D1	SIPC1	AMGE	EVF	DF	SIPCF	AMGE
EV1	-0.95^{**}								
D1	-0.95^{**}	0.99^{**}							
SIPC1	-0.95^{**}	0.99^{**}	0.99^{**}						
AMGE1	-0.95^{**}	0.99^{**}	0.99^{**}	0.99^{**}					
EVF	0.14^{ns}	-0.20^{ns}	-0.20^{ns}	-0.20^{ns}	-0.20^{ns}				
DF	-0.71^{*}	0.71^{*}	0.71^{*}	0.71^{*}	0.71^{*}	0.45^{ns}			
SIPCF	0.12^{ns}	-0.16^{ns}	-0.16^{ns}	-0.16^{ns}	-0.16^{ns}	0.07^{ns}	0.20^{ns}		
AMGE	-0.21^{ns}	0.20^{ns}	0.20^{ns}	0.20^{ns}	0.20^{ns}	0.55^{ns}	0.60^{ns}	-0.13^{ns}	
ASV	-0.99^{**}	0.95^{**}	0.95^{**}	0.95^{**}	0.95^{**}	-0.14^{ns}	0.71^{*}	-0.12^{ns}	0.21^{ns}

**, * and ns significant at the 0.01 and 0.05 probability level, respectively and non-significant.

For better understanding the relationships among the AMMI stability parameters, a FA exploration based on the rank correlation matrix was performed. When applying the PC analysis, the two first PCs explained 84.3% (65.3 and 19.0% by Factor 1 and Factor 2, respectively) of the variance of the original variables. The relationships among the different AMMI stability parameters are graphically displayed in a graph by plotting varimax rotated scores of Factor 1 versus Factor 2 (Figure 1). In this scatter plot, the Factor 1 axis mainly distinguishes the methods of SIPCF and EVF from the other methods which mean yield (MY) also groups near these statistics. Although these stability parameters seem to reflect dynamic stability concept but they are far from mean yield. Other AMMI stability parameters could represent static or biologic stability concept. Like to our findings, Dehghani et al. (2010) reported dynamic stability concept for SIPCF and EVF parameters but they found similar nature for AMGEF parameter.

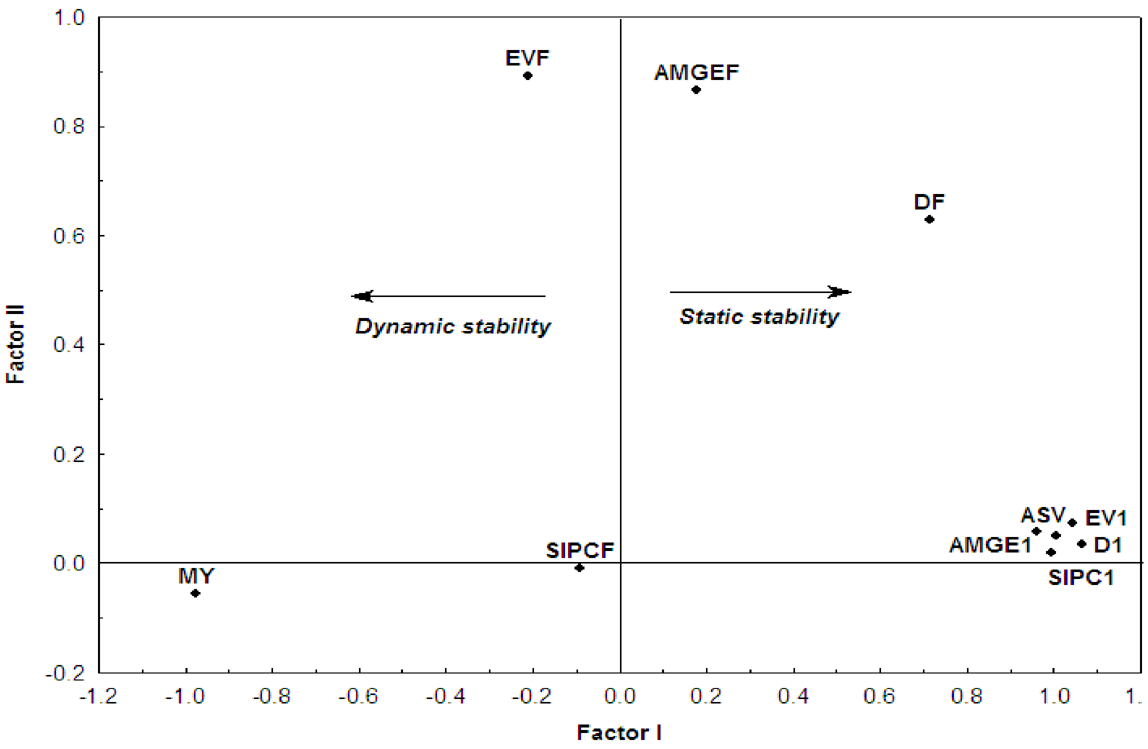

Figure 1. Plot of the first Factor versus the second Factor of mean yield and AMMI stability parameters using yield data from 10 lentil genotypes grown in 10 environments five research station locations from rain-fed conditions of Iran.

In this study, we found that environment (Y, L and YL) had large effect on grain yield performance of lentil genotypes and its contribution is about 89% of total variations (E+G+GE). Among environmental sources, location was important than other components as explained 92% of environment variations. Therefore it is possible to find genotype(s) which are well adapted to specific environment. Also evaluation of GE interaction indicated that GL interaction was important than GY and GLY interactions and explained 71% of GE (GL+GY+GLY) interaction. These findings demonstrated the high affect of location in comparison to year. According to Annicchiarico (1997) and Piepho et al. (1998) only GL interaction instead of all kinds of GE interaction, is useful for investigation adaptation patterns, as only this interaction can be exploited by selecting for specific adaptation. The remaining interactions of genotype (GY and GLY) should be considered with yield stability.

According to F-Gollob, three IPCAs are required for interpreting of GE interaction via AMMI model; but based on cross validation procedure and minimum RMSPD, only one IPCA can describe GE interaction. According to Gauch (2006), higher AMMI models with many IPCs axis are complicated and may failure in detecting significant information. In contrast using the first IPC could explain 68.04% of GE interaction sum of squares while three IPCs could explain 92.33% of GE interaction variations. However, according to our results, AMMI parameters which are computed from three IPCs, were more useful and introduced relatively the high yielding genotypes as the most stable genotypes. Although, cross validation as a statistical method for estimating the performance of AMMI predictive model had many advantages but it would not be useful in all situations specially in agriculture field. It seems that for reliable decision, it is better to examine various procedures in GE interaction study and yield stability analysis, comparing their results and conclude a comprehensive result. Although, Sabaghnia et al. (2008b), Dehghani et al. (2010) and Sabaghnia et al. (2012) used some of the AMMI stability parameters in analyzing of multi-environmental trials but they did not compare cross validation versus F-test strategies in GE interaction investigation.

Different AMMI stability parameters reflect various aspects of GE interaction and so introduce different genotypes as the most stable or unstable candidates. Our results revealed that ASV, EV1, D1, AMGE1 and SIPC1 parameters identified similar genotypes as the most stable ones but F-test based parameters identified different genotypes as the most stable candidates. It maybe due to three involved IPCs which are independent and show different aspect of GE interaction. Although simultaneous assessment of several IPCs of the AMMI model for studied lentil genotypes may facilitate the identification of superior genotypes but in this investigation the ability of ASV, EV1, D1, AMGE1 and SIPC1 parameters for detection of the most favorable genotypes was acceptable. Sabaghnia et al. (2008b) mentioned that SIPCF stability parameter clearly influenced by high mean yield. The GE interaction is complex phenomenon and performs in different ways in various multi-environmental trials. According to Zobel et al. (1988) GE interactions are associated with the nature of the crop, environmental conditions or diverse genetic background of tested genotypes which obtained from different sources and based on Flores et al. (1998), GE interaction was overshadowed by genetic effects.

The AMMI stability parameters could be considered from well known stability concepts (static and dynamic). We found that none of the AMMI stability parameters benefit dynamic concept of stability and most of them had static concept of stability. Although, there are relatively comparable and distinct results about the nature of the AMMI stability parameters (Flores et al., 1998; Annicchiarico, 2002; Sabaghnia et al., 2008b; Dehghani et al., 2010), but is seems that F-test based parameters are more meaningful in most satiations especially when complex GE interaction is observed. In past decades, plant breeders since Roemer (1917, cited by Becker 1981) have used the static concept of stability, but simultaneous selection of both mean yield and stability as dynamic concept of stability have used in recent decades. In this stability concept, it is not needed that the genotypic response to environmental conditions should be equal for all genotypes (Becker and Leon, 1988).

Conclusions

The SIPCF following to EVF parameters are indispensable, as agronomists would prefer to use a high-yielding genotype that performs consistently across environments. The best recommended genotypes according to this investigation are FLIP 92-12L following to ILL6199, which had high mean yield and was the most stable based on SIPCF parameter. Finally, SIPCF stability parameter of AMMI model was useful in detecting the phenotypic stability of the genotypes and genotype FLIP 92-12 is recommended for release as a cultivar by the Dry Land Agricultural Research Institute of Iran.

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