Australian Journal of Crop Science AJCS

AJCS 6(6):1017-1023 (2012) ISSN:1835-2707

Using different aspects of stability concepts for interpreting genotype by environment interaction of some lentil genotypes

Rahmatollah Karimizadeh[1]*, Mohtasham Mohammadi[1], Naser Sabaghnia[2] and Mohammad Kazem Shefazadeh[3]

[1]**Dryland Agricultural Research Institute (DARI), Gachsaran, Iran**
[2]**Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Maragheh, Maragheh, Iran**
[3]**Department of Agronomy, Yasooj Branch, Islamic Azad University, Yasooj, Iran**

***Corresponding author: Karimizadeh_ra@yahoo.com**

Abstract

Multi-environmental tests were done for variety recommendation in the final stages of breeding programs for awareness of the importance of genotype × environment (GE) interactions. Sixteen genetically improved lentil genotypes and two cultivars were grown in 12 semiarid environments in Iran during 2007 to 2009. Results of combined ANOVA showed there were significant GE interactions and that genotypes varied significantly for seed yield. According to environmental variance and coefficient of variation statistics Type I, genotypes G7, G8 and G11 were the most stable genotypes while based on four parameters, which used GE magnitude, genotypes G5, G13 and G18 were the most stable. Results of the principal component (PC) analysis and correlation analysis of different stability concepts (Type I to Type IV) and seed yield indicated that only the Type II stability method would be useful for simultaneous selection for high yield and stability. The most favorable genotypes for a given environment were assessed by considering high mean yield, Type II stability and variance of years within a location for each test location, so genotypes G5 and G12 for Gorgan, genotypes G1 and G12 for Moghan, genotypes G2 and G12 for Lorestan and genotypes G1, G5, G14 and G15 for Gachsaran could be recommended for commercial release in rain-fed areas.

Keywords: adaptation, multi-environmental trials, regression analysis.

Abbreviations: METs = multi-environmental trials, AMMI = additive main effects and multiplicative interaction, EV = environmental variance, CV = coefficient of variation, Wi = ecovalence, PP = mean variance component, P = GE variance component of Plaisted, SH = stability variance, FW = slope of simple regression model, PJ = slope of adjusted regression model of Perkins and Jinks.

Introduction

Lentil (*Lens culinaris* Medik.) has been cultivated as a pulse crop for a long time; it may have been one of the first agricultural products. It is a cool season crop cultivated in Asia and Europe among other areas of world (Erskine, 2009). The crop grows well in conditions with limited rainfall in arid or semi-arid areas. Lentil is a crop that provides a good source of protein (22 to 35%) and it is an excellent supplement to cereal grain diets. Iran is an important lentil producer in global terms, together with Canada, Turkey and India. It produces remarkable amounts of legumes mainly comprising chickpeas, dry beans and lentils; production in year 2009 was about 209000 tones for chickpeas, 181000 tones for dry beans and 84000 tones for lentils (FAO, 2009). Like most plant breeding programs, the majority of lentil breeders' efforts are directed toward yield improvement and other targets such as resistance to disease and quality (Materne and McNeil, 2007). It is essential to grasp the genetic basis for yield before applying any breeding strategy. The basic strategy in a lentil-breeding program is to use operating resources to screen breeding lines for important and favorable characters (Sarker et al., 2009). The Dry-Land Agricultural Research Institute (DARI) of Iran has performed important lentil-breeding programs in recent years with support from the International Center for Agricultural Research in Dry Areas (ICARDA). Increasing the genetic potential of yield is the main objective of lentil breeding programs in Iran (Sabaghnia et al., 2006). These improved lentil genotypes must be evaluated in multi-environmental trials (METs) to test performance across different locations and over several years. In tests observe the interaction genotype × environment (GE), complicating selection for improved yield. The focus on GE interactions can hinder a selection process by masking genotypic effects (Annicchiarico, 2002). Different yield stability statistics proposed to characterize GE interactions in METs and several methods have been proposed to evaluate stability. These methods could be in the form of a linear regression (Eberhart and Russell, 1966), clustering procedures (Lin and Butler, 1990), multiplicative approaches such as Additive Main Effects and Multiplicative Interaction (AMMI; Zobel et al., 1988), or nonparametric methods (Huehn, 1979). Most stability statistics relate to one or other of the four types of stability. Lin et al. (1986) classified stability statistics into three distinct groups (Types I, II, and III). Type I involves models that benefit from environmental or GE interaction variance. Types II and III are related to linear slope and deviation from linear regression analysis, respectively. Lin et al. (1986) interpreted Type III stability as an indicator of the goodness of a fit to a regression model and concluded that poor fit indicates Type II stability statistics. Furthermore, Lin and Binns (1988a) introduced a Type 4 stability, which relates to stability in time (across years). Becker and Léon (1988) introduced two concepts of stability, static and dynamic. Static or biological stability relates to Type I stability and can be described in terms of homeostasis, that is, a stable genotype that tends to maintain a constant yield across different environments and shows minimum environmental sensitivity (Dyke et al., 1995). The study of dynamic concepts needs a specific set of tested genotypes, unlike the criterion of static stability (Lin et al., 1986). In this concept, a stable genotype has a varying yield response according to environment, which is parallel to the mean response of the tested genotypes. This dynamic concept of stability relates to Type II stability with high goodness of fit. Evaluations of yield stability of a genotype may reveal major differences between them depending on these various stability concepts. For using regression slopes as stability parameters, regression demands that heterogeneity of genotype regression accounts for a high portion of a GE interaction (Annicchiarico, 1997). However, a favorable genotype is one that combines both high mean yield and performance stability making it acceptable over a wide range of environmental conditions (Allard and Bradshaw, 1964). This idea for identifying favorable genotypes reflects a dynamic concept of stability. However, each stability statistic reflects different aspects of yield stability and as such no single method can adequately explain performance across different environments (Kang, 1998; Flores et al., 1998). Therefore it seems that for a reliable GE interaction and effective selection of favorable genotypes, it is better that a MET's dataset is evaluated through different aspects of yield stability. The objectives of this investigation were (i) to identify lentil genotypes with both high yield and stable performance across different environments for semiarid areas of Iran and similar regions in the Middle East as well as the other similar areas and (ii) to study different aspects of stability in this dataset.

Table 1. ANOVA analysis of lentil performance trial yield data.

Source	DF	MS
Year (Y)	2	8400774^{ns}
Location (L)	3	3962077^{ns}
Y×L	6	4579496^{**}
R (Y×L)	36	38152
Genotype (G)	17	320003^{**}
Y×G	34	80769^{ns}
L×G	51	134137^{*}
Y×L×G	102	84021^{**}
Error	612	31713

**, * and ^{ns} significant at the 0.01 and 0.05 probability level and no significant, respectively.

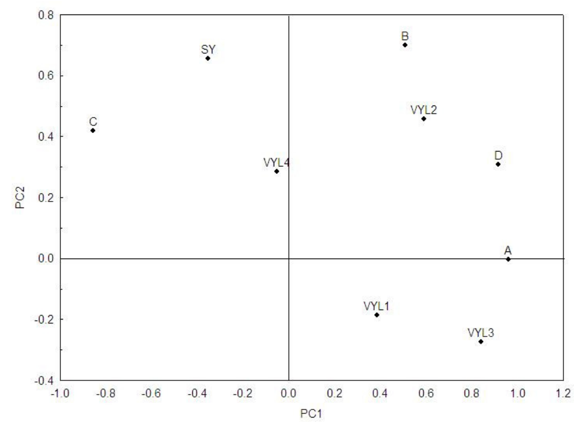

Fig 1. Principle component analysis (PC1 and PC2) plot of genotypic ranks based on various stability statistics (each stability statistic produced unique ranks for genotypes), for 18 durum wheat genotypes grown in 12 environments and showing interrelationships among stability concepts. Group A, EV and CV; group B, W, PP, P and SH; group C, regression slopes; group D, deviation from regression (EB and PJ); four VYL (VYL1 to VYL4); and MY, mean yield.

Results and discussion

Analysis of variance

Variances of homogeneity from results of the Bartlett test revealed that the mean squares of individual environments were homogenous and so a combined ANOVA could be done (results are not shown). This analysis was conducted to determine the main effects of year, location, genotype, and interactions among these factors, on grain yield of the lentil genotypes in this study (Table 1). The main effect of year (Y) and location (L) were not significant ($P > 0.05$), but their interactions (Y × L) were highly significant ($P < 0.01$). The main effect of genotype was significant ($P < 0.01$), the genotype by year interaction (G × Y) was not significant ($P > 0.05$), the genotype by location interaction (G × L) was significant ($P > 0.05$) and three way interactions (G × Y × L) or GE were highly ($P < 0.01$) significant (Table 1). The high significance of GE interaction indicates that the studied genotypes exhibited both crossover and non-crossover types of GE interaction. Analyses of quantitative traits such as yield indicated important sources of genetic variation attributed to GE interactions (Gauch and Zobel, 1996). Complexity of these traits is a result of diverse processes that occur during plant development. However, GE interaction arising from lack of genetic correlation among test environments can be relevant if the result for a given data set is used to understand the nature of GE interaction in a breeding program (Cooper and Byth, 1996). The relative large contributions of GE interaction in grain yield of lentil demonstrated in this study were similar to those found in other MET studies of lentil in rain-fed conditions (Mohebodini et al., 2006; Sabaghnia et al., 2008a).

Stability analysis

The economic importance of yield stability was investigated through environmental variance (EV) and coefficient of variation (CV). According to these statistics, genotypes G7, G8 and G11 were the most stable (Table 2). The other group of stability parameters used GE magnitude to identify favorable genotypes and all of these methods consisted of the following; PP mean variance component (Plaisted and Peterson, 1959), P: GE variance component (Plaisted, 1960), W: ecovalance (Wricke, 1962) and SH: stability variance (Shukla, 1972) that identified the genotypes G5, G13 and G18 as the most stable. The two mentioned groups reflect Type I stability. According to Lin and Binns (1991b), Type I stability is heritable and its genetic mode is additive and consistent. Among the following stable genotypes; G5, G7, G8, G11 G5,

Table 2. Seed yield, six stability parameters which performance Type I stability concept (EV, CV, W, PP, P and SH) and two stability parameters which performance Type II stability concept (FW and PJ).

	SY	EV ($\times10^{-3}$)	CV	W ($\times10^{-3}$)	PP ($\times10^{-3}$)	P ($\times10^{-3}$)	SH ($\times10^{-3}$)	FW	PJ
G1	1418.7	137.7	26.2	320.0	27.5	23.9	31.2	1.27	0.27
G2	1365.6	92.6	22.3	156.9	19.7	24.8	14.5	1.05	0.05
G3	1287.3	65.6	19.9	220.9	22.8	24.5	21.1	0.82	-0.18
G4	1272.1	116.8	26.9	237.0	23.5	24.4	22.7	1.17	0.17
G5	1324.5	114.8	25.6	86.1	16.3	25.3	7.3	1.25	0.25
G6	1096.5	63.7	23.0	152.1	19.5	24.9	14.0	0.85	-0.15
G7	1304.2	56.2	18.2	315.9	27.3	23.9	30.8	0.69	-0.31
G8	1191.1	49.1	18.6	179.8	20.8	24.7	16.9	0.73	-0.27
G9	1329.5	108.1	24.7	535.3	37.9	22.6	53.2	0.92	-0.08
G10	1188.0	73.6	22.8	437.1	33.2	23.2	43.2	0.74	-0.26
G11	1374.1	54.7	17.0	174.3	20.5	24.7	16.3	0.77	-0.23
G12	1334.8	92.0	22.7	217.5	22.6	24.5	20.7	1.01	0.01
G13	1292.2	76.5	21.4	138.8	18.8	25.0	12.7	0.95	-0.05
G14	1401.9	134.2	26.1	299.2	26.5	24.0	29.1	1.25	0.25
G15	1307.4	126.8	27.2	231.2	23.3	24.4	22.1	1.25	0.25
G16	1272.4	109.5	26.0	257.1	24.5	24.2	24.8	1.11	0.11
G17	1203.3	132.7	30.3	509.8	36.7	22.7	50.6	1.11	0.11
G18	1314.6	137.7	22.1	320.0	27.5	23.9	31.2	1.05	0.05

SY, seed yield; EV, environmental variance; CV, coefficient of variation; W, ecovalance; PP, mean variance component of Plaisted and Peterson (1959); P, GE variance component of Plaisted (1960); SH, stability variance; FW, slope of simple regression model (Finlay and Wilkinson, 1963); PJ, slope of adjusted regression model (Perkins and Jinks, 1968).

Table 3. Two stability parameters which performance Type III stability concept (ER, DPJ and R), four stability parameters which performance Type IV stability concept (VYL1 to VYL4) and priority index (PI).

	ER ($\times10^{-3}$)	DPJ ($\times10^{-3}$)	R	VYL1 ($\times10^{-3}$)	VYL2 ($\times10^{-3}$)	VYL3 ($\times10^{-3}$)	VYL4 ($\times10^{-3}$)	PI ($\times10^{-3}$)	MSGE ($\times10^{-3}$)
G1	146.0	26.5	0.807	78.4	23.1	450.5	9.1	36.6	20088.31
G2	101.6	15.5	0.833	82.7	29.2	291.2	19.7	43.3	15767.40
G3	69.6	19.6	0.701	41.7	32.8	139.7	11.6	59.2	10295.11
G4	126.2	21.4	0.816	46.9	8.2	378.3	28.6	63.2	9370.38
G5	121.2	3.6	0.969	33.6	49.4	415.7	2.3	46.2	8170.10
G6	68.3	13.5	0.807	36.7	32.1	202.3	5.7	135.7	8905.15
G7	54.5	24.3	0.607	74.3	0.7	90.8	15.5	60.2	16430.42
G8	48.4	12.3	0.772	11.5	1.7	166.0	15.8	95.5	11809.72
G9	118.4	53.0	0.554	49.3	93.7	388.6	22.9	71.6	34989.11
G10	75.6	38.4	0.526	29.9	76.0	66.1	5.8	110.4	25464.57
G11	56.1	13.4	0.777	16.9	5.2	215.9	7.4	40.4	14890.71
G12	101.2	21.7	0.785	36.5	20.0	205.7	11.8	47.5	12232.13
G13	84.0	13.7	0.837	82.0	6.9	214.4	12.3	58.3	10816.51
G14	142.6	24.9	0.832	51.3	26.0	391.1	8.1	33.6	13954.23
G15	134.7	18.4	0.868	123.0	71.0	336.9	0.5	60.5	17619.84
G16	119.6	24.8	0.794	22.5	94.3	344.2	18.1	73.3	19629.55
G17	145.1	50.1	0.657	33.2	99.5	574.8	6.2	113.7	34978.11
G18	92.9	6.8	0.927	2.0	10.5	339.4	3.6	48.7	7942.36

The yearly variance within location; VYL1 for Gorgan, VYL2 for Moghan, VYL3 for Lorestan, VYL4 for Gachsaran.

G13 and G18, most of them had low mean yield except for genotype G11 (Table 2). Although, this condition (having both high yield and Type I stability concept) occurs rarely in METs, it was evident in this investigation. Thus, the new released cultivar Gachsaran (G11) had good yield performance in all locations and years. It is interesting that Gachsaran was identified as a favorable genotype according to EV and CV parameters. The regression strategy for investigation of GE interaction was first used by Yates and Cochran (1938); the idea was then taken up by Finlay and Wilkinson (1963) who rediscovered this method and used it extensively. According to the line slope of a linear regression (FW; Finlay and Wilkinson, 1963) and the line slope of an adjusted linear regression (PK; Perkins and Jinks, 1968), genotypes G1, G5, G14 and G15 were the most responsive (Table 2) and were thus regarded as the most favorable. Lin and Binns (1991b) reported Type II stability as a non-consistent heritable and that its genetic mode was therefore additive. The most favorable genotypes G1 and G14 had higher mean yields, while the other favorable genotypes G5 and G15 were less high yielding. A linear regression is the most popular method due to its simple application and the fact that results are easily applicable to locations other than chosen test locations (Romagosa and Fox, 1993). According to Annicchiarico (1997), the linear regression model and AMMI (Additive Main effects and Multiplicative Interaction) procedures are more likely to result in similar performance for small grain cereals such as durum wheat and they provide similar results in regions where cold stress is limited. Regarding rain-fed and relatively warm conditions of most lentil producing areas, it seems that the linear regression approach could be useful for stability analysis. The other concept of stability, Type III was used via application of the method of Eberhart and Russel (1966), in which a genotype was considered stable if it had a coefficient of regression of approximately 1.0 and deviation from regression as small as possible. Therefore, genotypes G5, G6 and G18 followed by genotypes G2, G11, G13 and G14 could be identified as the most stable (Table 3). A similar idea was introduced for the adjusted linear regression (Perkins and Jinks, 1968); genotypes G5, G8 and G18 were the most stable while only genotype G5 was the most responsive. Lin et al. (1986) described variance of genotype deviations from linear regression to Type III stability and interpreted it as an indicator of the goodness to a linear regression model. Type III stability was based on residual GE that is not predictable and so permits for GE provided it is predictable (Gauch and Zobel, 1997). Type IV stability involves consistency of yield across years within test sites. Thus, genotypes G8, G11 and G18 were the most favorable in the location of Gorgan while genotypes G7, G8 and G18 were the most favorable genotypes in the location of Moghan (Table 3). Also, genotypes G3, G7 and G10 were the most favorable genotypes in the location of Lorestan and genotypes G5, G15 and G18 were the most favorable genotypes in the location of Gachsaran based on mean squares of years within a location. Assessment of this procedure could be summarized as the variance of years within location averaged over all locations. Considering all locations, genotypes G8, G11 and G18 followed by genotypes G6, G7 and G10 were the most favorable. Lin and Binns (1991) reported that Type IV stability is strictly related to the static concept of stability. The Type IV concept of stability is related to the idea of removing predictable components of interactions and finding genotypes that minimize residual components (Gauch and Zobel, 1997). In METs, plant breeders treat location as a predictable effect under the control of the breeder, while yearly variation within a location is not. Therefore, under Type IV stability, plant breeders seek to find those lines showing the best response to a particular location while minimizing yearly variation at that location. The priority index (PI) and MSGE statistics measure a genotype's general adaptability and could be used as a supplementary approach in a regression model. According to PI statistics, genotypes G2, G11 and G4 were the most stable genotypes while based on MSGE properties, genotypes G5, G6 and G18 were the most favorable. Simultaneous consideration of PI and MSGE statistics showed that genotypes G5, G14 and G18 were the most favorable. The priority index measurement can be used if data do not fit the linear regression model. Pinthus (1973) proposed use of the coefficient of determination (R^2) in linear regression for its goodness of fit property. According to Table 3, all lentil genotypes had high amounts coefficient of determination except genotypes G7, G9 and G10, which indicated goodness of linear regression fit. Although, PI and MSGE statistics can be used for completing linear regression models, these genotypes (G7, G9 and G10) were not the most stable genotypes according to these supplementary statistics.

Associations among stability statistics

Each of the stability statistics produced a unique genotype ranking and Spearman's rank correlations between each pair of stability statistics were calculated (Table 4). The results demonstrated that there were not any significant positive or negative correlations between mean yield and stability statistics except for PI. Environmental variance indicated significant positive correlation with CV, EB and yearly variance within locations of Moghan and Lorestan. Also, EV had significant negative correlation with both regression slopes FW and PJ (Table 4). The stability statistics W, PP, P and SH were positively correlated to each other and deviation from PJ regression and MSGE index. These parameters benefited from GE variation and reflected Type I stability. Slope of FW linear regression model showed significant positive correlation with slope of PJ linear regression model while it had a significant negative correlation with deviation from the FW regression (EB) and variance of years within location for the Lorestan site (Table 4). EB indicated significant negative correlation with variance of years within location for locations of Moghan and Lorestan. Deviation from the PJ regression had significant positive correlation with MSGE and variance of years within location for Moghan. None of the variance of years within locations for the four studied sites had any significant positive or negative correlation with each other (Table 4). It seems that each test site had different environmental properties and showed different results for GE interaction. To better reveal associations among types of stability, the two-way rank data was analyzed further using a principle component (PC) analysis. Mean ranks of EV and CV were used as group A; parameters W, PP, P and SH as group B; regression slopes as group C; deviation from regression (EB and PJ) as group D as well as four VYL which showed Type IV stability and seed yield (SY). The two first PCs explained 63.1% (45.4 and 17.7% by PC1 and PC2, respectively) of the total variance. In plot of PC1 versus PC2, the PC1 axis mainly distinguished the methods of group C and VYL4 (Gachsaran) from the other methods (Fig. 1). Also, seed yield (SY) groups near these statistics, and we referred to these as Class 1 (C1) stability statistics. The second PC axis separated VYL of locations Gorgan and Lorestan from the other remaining stability concepts. However, stability methods of groups A, B and D besides VYL2 (Moghan) indicated similar behavior in stability analysis of this dataset. Static stability concept, Type I stability concept (groups A, B), Type III stability concept (groups D) and VYL of Moghan were grouped together. It seems that linear regression slopes (group C) could be useful for detecting the most stable genotypes, which had high mean yields. The VYL index indicated different concepts of stability in each test location. However, the priority index and MSGE or Type II stability concept could be used as a supplementary procedure in a regression model when the coefficients of determinations are low. Finally, the results of this investigation showed that there are some genotypes that are stable for seed yield. Comparable results have been reported in other research on studies on lentil (Sabaghnia et al., 2008b) and other crops such as maize (Dehghani et al., 2009). Similar to the other research, identifying genotypes that are simultaneously stable and high mean yielding is somewhat challenging. However, it is reasonable to choose the most favorable genotypes for a given environment.

Materials and methods

Plant materials and experiments

The investigation was carried out in complete randomized block design with 4 replications. Evaluations were done on sixteen improved genotypes with two cultivars (Gachsaran and Cabralia). Sowing was carried out manually in rows that were 25 cm apart. Seeds were sown in 1 × 4 m plots consisting of 4 rows. Plot size was 4 m^2 and the harvested plot size was 1.75 m^2 (two 3.5 m rows at the center of each plot). Weed control was done by hand, carried out twice when weed density was highest at the pre-flowering and post-flowering stages. All

Table 4. Spearman's correlation coefficients among ranks of 18 lentil genotypes at 12 environments.

	SY	EV	CV	W	PP	P	SH	FW	PJ	EB	DPJ	VYL1	VYL2	VYL3	VYL4	PI
EV	-0.36¶															
CV	0.02	0.90														
W	0.03	0.37	0.43													
PP	0.03	0.37	0.43	1.00												
P	0.03	0.37	0.43	1.00	1.00											
SH	0.03	0.37	0.43	1.00	1.00	1.00										
FW	0.41	-0.93	-0.81	-0.03	-0.03	-0.03	-0.03									
PJ	0.43	-0.94	-0.80	-0.05	-0.05	-0.05	-0.05	1.00								
EB	-0.35	1.00	0.90	0.36	0.36	0.36	0.36	-0.93	-0.93							
DPJ	-0.03	0.45	0.46	0.94	0.94	0.94	0.94	-0.11	-0.13	0.44						
VYL1	-0.34	0.38	0.25	0.17	0.17	0.17	0.17	-0.32	-0.33	0.35	0.25					
VYL2	0.19	0.48	0.62	0.40	0.40	0.40	0.40	-0.34	-0.34	0.51	0.47	-0.01				
VYL3	-0.42	0.85	0.73	0.20	0.20	0.20	0.20	-0.83	-0.85	0.87	0.23	0.10	0.37			
VYL4	-0.02	-0.08	-0.17	0.27	0.27	0.27	0.27	0.21	0.19	-0.10	0.29	0.19	-0.23	-0.06		
PI	0.91	-0.25	0.16	0.27	0.27	0.27	0.27	0.38	0.40	-0.23	0.20	-0.29	0.38	-0.27	0.04	
MSGE	-0.11	0.29	0.30	0.84	0.84	0.84	0.84	0.00	-0.01	0.30	0.81	0.21	0.46	0.17	0.20	0.19

¶ Critical values of correlation $P<0.05$ and $P<0.01$ (D.F. 16) are 0.46 and 0.50, respectively.

EV, environmental variance; CV, coefficient of variation; W, ecovalance; PP, mean variance component of Plaisted and Peterson (1959); P, GE variance component of Plaisted (1960); SH, stability variance; FW, slope of simple regression model (Finlay and Wilkinson, 1963); PJ, slope of adjusted regression model (Perkins and Jinks, 1968); EB, deviation from simple regression model (Eberhart and Russell, 1966); DPJ, deviation from simple regression model (Perkins and Jinks, 1968); VYL1 to VYL4, variance within location; PI, the priority index; MSGE, PI related GE mean squares.

Table 5. Geographical properties of test locations.

Location	Longitude Latitude	Altitude (m)	Soil Texture	Soil Type¶	Rainfall (mm)
Gorgan	54° 16´E 36° 51´N	13.3	Sandy-Loam	Cambisols	701.2
Moghan	48° 03´E 39° 01´N	1100	Sandy-Loam	Cambisols	271.2
Lorestan	23˚ 26´ E 48˚ 17ό´ N	1148	Silt-Loam	Regosols	433.1
Gachsaran	50ȯ 50´ E 30ȯ 20ό´ N	710	Silty Clay Loam	Regosols	460.8

plots were fertilized with 20 kg N ha^{-1} and 80 kg P_2O_5 ha^{-1} at the time of planting. These experiments were performed over three growing seasons (2007-2009) and at four different locations: Gorgan, Moghan, Lorestan and Gachsaran. Gorgan (north-eastern Iran) was categorized as having a semi-arid climate and sandy loam soil. Moghan in northwestern Iran was characterized as having an arid and semi-arid climate with sandy loam soil. Lorestan, in western Iran, had moderate rainfall and silt loam soil. Gachsaran, in southern Iran, is relatively arid and has silt loam soil. Some properties of test locations are given in Table 5.

Statistical procedure

Evaluations used nine univariate parametric procedures representing three different stability concepts (Types I, II and III). These methods were as follows; Group (A); environmental variance (Roemer 1918 cited in Becker, 1981), coefficient of variation (Francis and Kannenberg, 1978), Group (B); mean variance component (Plaisted and Peterson, 1959), GE variance component (Plaisted, 1960) ecovalance (Wricke, 1962), stability variance (Shukla, 1972), group (C); slope of simple regression model (Finlay and Wilkinson, 1963), slope of adjusted regression model (Perkins and Jinks, 1968), Group (D); deviation from simple regression model (Eberhart and Russell, 1966), deviation from simple regression model (Perkins and Jinks, 1968). The priority index (PI) measurement and its related GE mean squares (Lin and Binns, 1988b) were used as supplementary methods to the regression procedure. Also, variance within a location as Type IV stability concept (Lin and Binns, 1991) was used in analysis of three-way data (genotype × location × year). Hussein et al. (2000) developed SAS codes which are known as SASG × ESTAB that compute statistics in terms if stability.

Conclusions

Considering the properties of high mean yield, Type II stability and VYL (variance of years within a location) for each test location were identified as suitable measurements for stability. Furthermore, genotypes G5 and G12 for Gorgan, genotypes G1 and G12 for Moghan, genotypes G2 and G12 for Lorestan and genotypes G1, G5, G14 and G15 for Gachsaran can be recommended for commercial release in rain-fed areas.

Acknowledgements

Sincere gratitude goes to Iran's Research and Education Organization (AREO) and its Agricultural Research Stations for providing plant materials, experimental sites, and technical assistance.

References

Allard RW, Bradshaw AD (1964) Implications of genotype-environmental interactions in applied plant breeding. Crop Sci 4:503–508.

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

Annicchiarico P (2002) Defining adaptation strategies and yield stability targets in breeding programmes. In: Kang, M.S. Ed. Quantitative genetics, genomics, and plant breeding, p. 365–383. Wallingford, UK, CABI.

Becker HC (1981) Correlations among some statistical measures of phenotypic stability. Euphytica 30:835–840.

Becker HC, Leon J (1988) Stability analysis in plant breeding. Plant Breed 101:1–23.

Cooper M, Byth DE (1996) Understanding plant adaptation to achieve systematic applied crop improvement - A fundamental challenge. *In* M. Cooper and G.L. Hammer, eds. Plant adaptation and crop improvement, p. 5-23. Wallingford, UK, CABI.

Dehghani H, Sabaghnia N, Moghaddam M (2009) Interpretation of genotype-by-environment interaction for late maize hybrids' grain yield using a biplot method. Turk J Agric Fores 33:139–148

Eberhart SA, Russell WA (1966) Stability parameters for comparing varieties. Crop Sci 6:36–40.

Erskine W (2009) Global production, supply and demand. pp: 4-13 In: The Lentil: Botany, Production and Uses. (ed) Erskine W, Muehlbauer F, Sarker A, Sharma B. 480 pp. CABI. UK.

FAO (2009) Data stat year 2009. Food Agriculture Organization, Rome, Italy.

Finlay KW, Wilkinson GN (1963) The analysis of adaptation in a plant breeding programme. Aust J Agric Res 14:742–754.

Flores F, Moreno MT, Cubero JI (1998) A comparison of univariate and multivariate methods to analyze environments. Field Crops Res 56:271–286.

Francis TR, Kannenberg LW (1978) Yield stability studies in short-season maize: I. A descriptive method for grouping genotypes. Can J Plant Sci 58:1029–1034.

Gauch HG, Zobel RW (1996) AMMI analysis of yield trials. In M.S. Kang and H.G. Gauch, H.G (ed.) Genotype by environment interaction. CRC Press, Boca Raton, FL.

Gauch HG, Zobel RW (1997) Identifying mega-environments and targeting genotypes. Crop Sci 37:311–326.

Huehn VM (1979) Beitrage zur erfassung der phanotypischen stabilitat. EDV Med Biol 10:112–117.

Hussein MA, Bjornstad A, Aastveit AH (2000) SASG x ESTAB, A SAS program for computing genotype x environment stability statistics. Agron J 92:454–459.

Kang MS (1998) Using genotype-by-environment interaction for crop cultivar development. Advan Agron 62:199–252.

Lin CS, Binns MR (1988a) A method for analyzing cultivar x location x year experiments: a new stability parameter. Theor Appl Genet 76:425-430.

Lin CS, Binns MR (1988b) A priority measure of cultivar performance for cultivar × location data. Can J Plant Sci 68:193–198.

Lin CS, Butler G (1990) Cluster analysis for analyzing two way classification data. Agron J 82:344-348.

Lin CS, Binns MR (1991) Genetic properties of four types of stability parameter. Theor Appl Genet 82:505-509.

Lin CS, Binns MR, Lefkovitch LP (1986) Stability analysis: where do we stand? Crop Sci 26:894–900.

Materne M, McNeil DL (2007) Breeding Methods and Achievements. pp: 241-253 In: Lentil: an ancient crop for modern times. (ed) Yadav SS, McNeil D, Stevenson PC 461 pp. Springer.

Mohebodini M, Dehghani H, Sabaghpour SH (2006) Stability of performance in lentil (*Lens culinaris* Medik) genotypes in Iran. Euphytica 149:343–352.

Perkins JM, Jinks JL (1968) Environmental and genotype-environmental components of variability. Heredity 23:339–356.

Pinthus JM (1973) Estimate of genotype value: a proposed method. Euphytica 22:121–123.

Plaisted RI, Peterson LC (1959) A technique for evaluating the ability of selection to yield consistently in different locations or seasons. Am Potato J 36:381–385.

Plaisted RL (1960) A shorter method for evaluating the ability of selections to yield consistently over locations. Am Potato J 37:166–172.

Sabaghnia N, Dehghani H, Sabaghpour SH (2006) Nonparametric methods for interpreting genotype × environment interaction of lentil genotypes. Crop Sci 46:1100–1106.

Sabaghnia N, Dehghani H, Sabaghpour SH (2008a) Graphic analysis of genotype by environment interaction for lentil yield in Iran. Agron J 100:760–764.

Sabaghnia N, Sabaghpour SH Dehghani H (2008b) The use of an AMMI model and its parameters to analyse yield stability in multi-environment trials. J Agric Sci 146:571–581.

Sarker A, Aydogan A, Chandra S, Kharrat M, Sabaghpour S, (2009) Genetic enhancement for yield and yield stability. pp: 102-120 In: The Lentil: Botany, Production and Uses. (ed) Erskine W, Muehlbauer F, Sarker A, Sharma B. 480 pp. CABI. UK.

Shukla GK (1972) Some statistical aspects of partitioning genotype-environmental components of variability. Heredity 29:237–245.

Wricke G (1962) Über eine Methode zur Erfassung derökologischen Streubreite in Feldversuchen. Z Pflanzenz 47:92–96.

Yates F, Cochran WG (1938) The analysis of groups of experiments. J Agric Sci 28:556–580.

Zobel RW, Wright MJ, Gauch HG (1988) Statistical analysis of a yield trial. Agron J 80:388–393.