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Genotype by environment interaction and stability analysis for grain yield of lentil genotypes

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Abstract

The lentil (*Lens culinaris* Medik.) is an important cool-season crop and a valuable source of dietary protein and ranks seventh among grain legumes. Genotype by environment (GE) interaction is considered to be among the major factors limiting the efficiency of breeding programs. Eight improved lentil genotypes from the International Centre for Agricultural Research in the Dry Areas (ICARDA), one commercial cultivar ('Gachsaran'), and one local landrace were evaluated at five locations in two growing seasons. The combined analysis of variance for grain yield of the 10 lentil genotypes showed mean squares of location, genotype, year × location, genotype × location and genotype × year × location were significant. According to coefficient of variation (CV) and stability variance (SHUK) parameters, genotype G7 was the most stable one while based on priority index (PI), desirability index (DI) and regression linear model, genotypes G8 and G9 were the most stable ones. The partitioning general pattern of relationships among stability parameters and lentil genotypes through principle component (PC) analysis indicated that the first two PCs explained 79% (PC1 = 55% and PC2 = 24%) of the total variation. Plotting the scores of the first two PCs in one graph indicated that DI and PI stability parameters were grouped with mean yield and showed dynamic stability. Therefore, these statistics are acceptable for agronomists who prefer to use a high-yielding genotype. Finally, the best genotypes in this study were G8 (ILL 6037) and G9 (ILL 6199) which produced high mean yield and were the most stable based on the most stability statistics and therefore recommended for release as commercial cultivars.

Key words: adaptation *ANOVA*, biplot, principle component analysis.

Introduction

Lentil (*Lens culinaris* Medik.) is the fourth most important legume crop in the world. Its grain is rich in protein for human consumption and the straw is a valued animal feed. Sowing legumes in a rotation with cereals has been shown to be beneficial in many semi-arid areas of the Middle East. In most lentil production areas yields seem to be no more than one-half of potential yields while improved genotypes contribute to increased lentil production and yields (Erskine, 2009). Selecting genotypes for high mean yield and yield stability has been a challenge for lentil breeders. The requirement for stable genotypes that perform well over a wide range of environments becomes increasingly important as farmers need reliable production quantity (Gauch et al., 2008). Therefore, identifying most stable genotypes is an important objective in many plant breeding programs for all crops, including lentil. The performance of a genotype is determined by three factors: genotypic main effect (G), environmental main effect (E) and their interaction (Yan et al., 2007). Understanding genotype by environment (GE) interactions is necessary to accurately determine stability in lentil genotypes and help breeding programs by increasing efficiency of selection (Sabaghnia et al., 2008). The GE interactions structure is an important aspect of both plant breeding programs and the introductions of new improved crop cultivars as yield stability analysis (Neacşu, 2011).

Stability has been classified into two main concepts: static and dynamic (Becker, 1981). The static concept of stability is characterized by constant genotype performance over different environmental conditions while the dynamic concept of stability is characterized by the performance of a given genotype compared with the environmental mean (Becker, Leon, 1988). Cotes et al. (2002) reported that breeding for stable mean yields has overshadowed the goal for increased yield. The ability to select for most stable genotypes based on these two concepts has been facilitated by using proper statistical methods. The two static procedures to be used in this study, coefficient of variation (Francis, Kannenberg, 1978) and the stability variance (Shukla, 1972), are similar as discussed by Lin et al. (1986). Also, the two dynamic procedures to be used in this investigation are the slope of linear regression (Finlay, Wilkinson, 1963) and the desirability index (Hernández et al., 1993).

Eberhart and Russell (1966) further developed linear regression and suggested the use of mean squares of deviation from linearity as stability parameter when describing the performance of one genotype across environments. Lin and Binns (1988 a) introduced a new stability concept as yearly variance within test locations (YV) which relates to stability in time (across years). Also, Lin and Binns (1988 b) defined the superiority index (PI) as the genotype general superiority and defined it as the distance mean square between the genotype's response and the maximum response over environments. The issue of defining genotype reaction to environmental variation is a very complex problem. However, additive (G and E) and multiplicative (GE interaction) nature of variation sources needs the combination of additive and multiplicative models. That is a general idea in combined models commonly consisting of *ANOVA* and linear regression or principal components analysis (PCA) as multiplicative models (Brady, Gabriel, 1978). Considering the results of these different stability methods could be useful for identification of the most favourable genotype. Anyhow after regarding of these procures results separately, biplot presentation of these methods and studied genotypes is considered.

The biplots are drawn according to the PC analysis to visual display stability indices and genotypes simultaneously that has become a valuable tool in determining the data patterns (Gabriel, 1971; Yang et al., 2009). The relevant components are graphically displayed to permit for a number of inferences to be made including (i) clearly distinguishing which genotype has the best performance based on a specific stability index, (ii) which stability index is the best for differentiating genotype performance and (iii) which genotypes are considered stable due to all stability indices. The objective of this investigation was to evaluate ten lentil genotypes (one commercially available cultivar, one local landrace and eight advanced breeding lines) grown in ten environments for grain yield using several statistical stability methods.

Materials and methods

One commercial cultivar ('Gachsaran'), one local landrace (FLIP 82-1L) and eight advanced breeding lines from the lentil breeding program at the International Centre for Agricultural Research in the Dry Areas (ICARDA) were evaluated in this investigation. The name, pedigree and origin of parental lines of the studied genotypes are given in Table 1. The study was conducted during two growing seasons of 2007–2008 and 2008–2009 at the Gonbad (silty clay loam soil), the Kermanshah (clay loam soil), the Ilam (clay loam soil), the Gachsaran (silty clay loam soil) and Shirvan (loam soil) Research Stations.

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

Code	Location	Year	Altitude m	Longitude, latitude	Soil texture	Rainfall mm	Yield kg ha^{-1}
E1	Gonbad	2008	45	55° 12′ E	silty clay loam	294	477
E2		2009		37° 6′ N		440	1753
E3	Kermanshah	2008	1351	47° 19′ E	clay loam	391	742
E4		2009		34° 20′ N		519	1852
E5	Ilam	2008	975	46° 36′ E	clay loam	313	487
E6		2009		33° 47′ N		387	1134
E7	Gachsaran	2008	710	50° 50′ E	silty clay loam	535	2093
E8		2009		30° 20′ N		385	792
E9	Shirvan	2008	1131	58° 07′ E	loam	347	1641
E10		2009		37° 19′ N		187	249

The properties and the location of the experimental environments are given in Table 2. The test locations, selected to sample climatic and edaphic conditions, vary in latitude, rainfall, soil types, temperature and other agro-climatic factors.

Table 2. Origin of the 10 lentil genotypes studied in 10 environments

Code	Name	Pedigree	Origin of parents
G1	FLIP 97-1L	ILL 5989 × ILL6199	ICARDA × ICARDA
G2	FLIP 82-1L	landrace	ICARDA
G3	FLIP 92-15L	ILL 5588 × ILL5714	ICARDA × ICARDA
G4	FLIP 96-9L	ILL 6199 × ILL 6198	ICARDA × ICARDA
G5	FLIP 92-12L	ILL 5582 × ILL 707	Jordan × Cyprus
G6	FLIP 96-4L	ILL 467 × ILL 45	Chile × Syria
G7	ILL 7946	ILL 6209 × ILL5671	ICARDA × ICARDA
G8	ILL 6037	ILL 4349 × ILL 4605	Canada × Argentina
G9	ILL6199	ILL 5746 × LL 975	ICARDA × Chile
G10	'Gachsaran'	cultivar	Iran

In each location and each year, the trial was sown in February, which is the optimal sowing time for lentil. The experimental design used at each test location was a randomized complete block design with four replications. The grains were planted according to local practice with a planting rate of about 50 grains m^{-2}. Plot size was 4 m^2; each plot contained four 4 m long rows with 25 cm between rows. Appropriate pesticides were used to control insects, weeds and diseases, and appropriate fertilizers were applied (at recommended rates) for the location × year. The harvested plot size was 1.75 m^2 (two 3.5 m rows at the centre of each plot). Mean grain yield was estimated for each genotype at each site × year.

The grain yield dataset was balanced because all genotypes were present in all environments. 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 E, G and GE interaction. The main effect of year, location and their interaction were tested against the replication within environment (R/E) as Error I. The main effect of G was tested against the GE interaction and the GE interaction was tested against Error II.

Eight stability parameters were applied for stability analysis. These parameters were computed using the IML procedure of *SAS 9.1* (SAS/STAT User's Guide, 2004). The economic importance of stability was recognized by using the variance across environments. Francis and Kannenberg (1978) proposed the use of the coefficient of variation (CV) for improving of this stability concept. For calculating the stability variance of Shukla (1972), an unbiased estimate of the variance of a genotype across environments was computed. The PI of Lin and Binns (1988 b) was calculated as the distance mean square between the genotype's response and the maximum response over environments. For fitting regression model, the observations are regressed on environmental indices (the difference between the grand mean of the environments and the overall mean). According to Eberhart and Russell (1966), mean squares of deviations from regression as stability parameter were used to describe the performance of one genotype across a range of environments. The DI of Hernández et al. (1993) and YV of Lin and Binns (1988 a) were computed according to original papers. A comprehensive *SAS* program *SASG × ESTAB*, which calculates different stability methods (Hussein et al., 2000) was used to calculate different stability statistics.

Results

Environments. The mean performance of grain yield over environments indicated the relative performance of the genotypes tested across environments (Table 1). The environment mean yield ranged from 249 (E10, Shirvan 2009) to 2093 kg ha^{-1} (E7, Gachsaran 2008) indicating subseasonal differences among the test environments. This yield range reflects the different climatic conditions across locations and years (Dehghani et al., 2008). Mean environment yield was positively related to seasonal rainfall ($r = 85.7\%$, $P < 0.01$) (Table 1). Shirvan 2003 and Gonbad 2008, and Ilam 2008 reported that the lowest yielding environments had little seasonal rainfall, whereas Gachsaran 2008 and Kermanshah 2009 indicated that the highest yielding environments had much seasonal rainfall.

Analysis of GE interaction. Analysis of variance was conducted to determine the effects of year, location, genotype, and interactions among these factors on grain yield of lentil genotypes (Table 3). Effect of year was not significant while effect of location was significant ($P < 0.05$). The genotype main effect, year by location (YL) interaction, genotype by location (GL) interaction and genotype, location and year (GLY) interaction were highly significant ($P < 0.01$). The general pattern of genotype by environment (GE) interaction could be seen in Figure 1 which represents both additive and crossover interaction. A significant GE interaction for grain yield can limit efforts in selecting superior genotypes for both new cultivar introduction and improved genotype development. GE interaction is an important aspect of plant breeding programs and it is important for plant breeders to identify specific genotypes adapted or stable to environment (Flores et al., 1998; Yan, Kang, 2003). Also, achieving genetic gain through screening of genotypes for high yield stability under different environmental conditions is necessary before their release.

Stability analysis. The results of the different stability statistics are given in Table 4. According to CV parameter, genotypes G1, G5 and G7 were the most stable ones. Genotypes G7, G8 and G9 were the most stable ones based on stability variance of Shukla (1972). These two stability statistics represent static stability concept and so it seems that genotype G7 could be regarded as the most stable one. Considering both PI and its MSGE statistics of Lin and Binns (1988 b), genotypes G1, G8 and G9 were the most favourable ones (Table 4). Genotypes G8 and G9 were the most responsive ones according to slope of linear regression. Simultaneous regarding of slope of linear regression and mean squares of deviations from regression, genotypes G3, G8 and G9 were the most favourable ones. The linear regression model for analyzing the stability of the lentil genotypes showed that G2, G8 and G9 were stable because of a high regression coefficient and had specific adaptability to favourable environments.

Table 3. Combined analysis of variance of the 10 lentil genotypes' performance, trial yield data

Source of variation	df	Mean squares
Year (Y)	1	1431612.3^{ns}
Location (L)	4	36527808.4^{*}
Y × L	4	2899551.5^{**}
Replication / YL (Error I)	30	120655.0
Genotype (G)	9	369593.3^{**}
G × L	36	301718.9^{**}
G × Y	9	47017.9^{ns}
G × L × Y	36	113022.2^{**}
Error II	270	51214.0

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

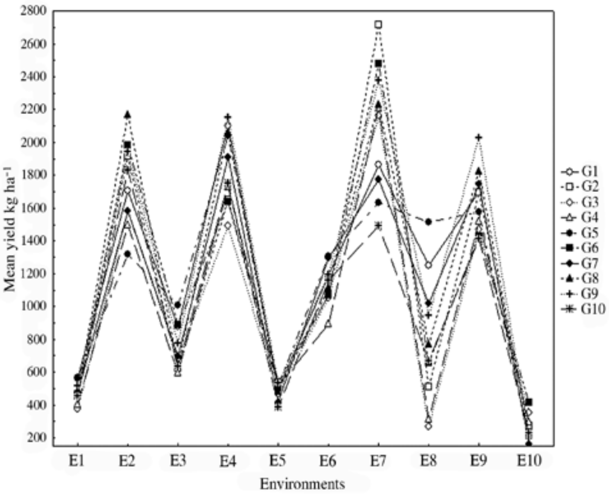

Figure 1. Plot of the 10 lentil genotypes versus the environment mean yield to visually assess genotype by environment (GE) interaction and genotype stability

According to DI parameter, genotypes G1, G8 and G9 were the most stable ones which had high mean yield. This stability statistic indicates dynamic or agronomic concept of stability. The yearly variance within test locations (YV) introduced genotypes G6, G8 and G10 as the most stable ones. The YV parameter benefits Type IV stability concept (Lin et al., 1986), and involves yield stability exclusively across years within test sites. Lin and Binns (1991) reported the Type IV concept of stability that is strictly related to the static concept of stability. The Type IV concept of stability is relating with the idea of removing predictable components of interactions and trying to find genotypes that minimize the residual components (Gauch, Zobel, 1997). In multi-environmental trials (MET), plant breeders treat locations as being predictable effects under the control of the breeder, while yearly variations within a location are not. Therefore, under Type IV stability concept, plant breeders seek to find those lines showing the largest response to particular locations while minimizing their yearly variation at those locations.

Table 4. Stability parameters for 10 lentil genotypes which show different aspects of stability concepts

Code	MY	CV	SHUK	PI	MSGE	Slope	SD	DI	YV
G1	1187.7	55.48	39621.5	61588.2	29520.4	0.95	487180.4	1281.2	115914.2
G2	1145.1	70.68	71061.7	83517.2	39746.2	1.17	722327.7	1260.4	169370.5
G3	989.1	66.44	39390.1	158691.1	56595.6	0.95	484507.5	1082.3	140175.5
G4	997.2	68.89	31535.2	148164.2	49673.9	1.00	530845.0	1095.5	145955.9
G5	1168.7	49.67	139880.2	107878.9	70812.1	0.75	347901.2	1242.4	105567.1
G6	1152.9	61.50	42914.2	76063.2	34576.8	1.02	565208.5	1253.7	135420.6
G7	1107.7	57.96	27041.7	89939.2	34386.5	0.94	461637.7	1199.8	117432.8
G8	1200.2	65.82	24400.1	52622.5	23642.3	1.18	686247.8	1316.2	152766.0
G9	1267.8	62.27	18652.3	29826.0	14835.5	1.18	684532.8	1384.2	146116.0
G10	1002.3	59.45	39387.2	154619.9	58402.0	0.86	389698.7	1087.0	120761.7

Note. MY – mean yield, CV – coefficient of variation, SHUK – stability variance, PI – priority index, MSGE – mean squares of genotype by environment interactions, Slope – regression coefficient, SD – deviation from regression, DI – desirability index, YV – yearly variance within test locations.

Biplot analysis. When the PC analysis was fitted, the first two PCs explained 79% (PC1 = 55% and PC2 = 24%) of total variation for lentil multi-environmental trials. The genotypes which were farthest from the origin of biplot (G1, G2, G3, G4, G5, G8, and G9) used as corners of a polygon when these genotypes were connected with straight lines. The lines that started from the biplot origin and were perpendicular to the sides of the polygon classified the biplot into seven sectors (Fig. 2). These seven genotypes were the best in the stability statistics that are in their respective sectors. Therefore, genotype G3 was the highest performer according to DI, PI and YV statistics. Also, MY was in this sector and so it could be concluded that DI, PI and YV stability statistics indicate dynamic stability concept. Genotype G5 was the highest performer according to slope of regression (B) and stability variance (SHUK) statistics (Fig. 2). Finally, genotype G2 was the highest performer according to CV statistics while genotype G8 was the highest performer according to mean squares of SD statistics (Fig. 2). Genotypes G1, G4 and G9 did not give the stable yield based on any stability parameters. The above inferences about polygon patterns are mostly, but not totally, validated from the original data. Some contrasts (genotype G9 was the most stable one according to some stability parameters) originate from the incomplete fitting (79% instead of 100%) of the PC model to the original data. Figure 2 suggests that there exist four possible stability statistics. However, this pattern needs verification through other multi-environment trials for other crops.

In Figure 3, a vector is drawn from the biplot origin to each marker of the stability statistics to facilitate visualization of the relationship among different stability statistics. The correlation coefficient between any two stability statistics is approximated by the cosine of the angle between the vectors. Therefore, the most prominent relations according to Figure 3 are: (i) strong positive association between PI with DI and mean yield as indicated by the small angles between their vectors ($r = \cos 0° = +1$), (ii) near zero correlation between MY with CV, between MY with regression coefficient, between MY with PI and DI stability statistics as indicated by the near

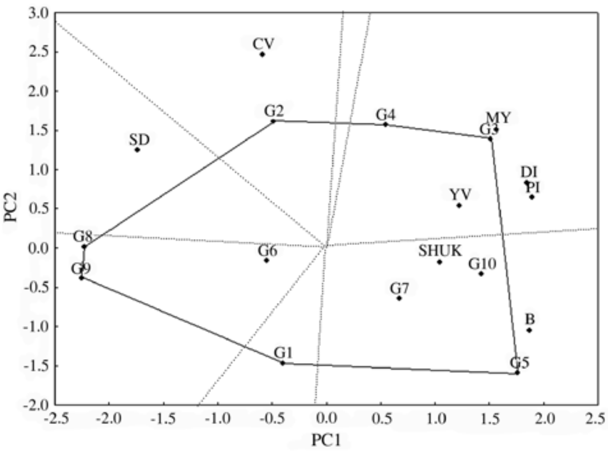

Figure 2. Polygon view of the biplot for the genotype by stability statistics two-way data, showing which genotypes were the most stable ones according to stability statistics

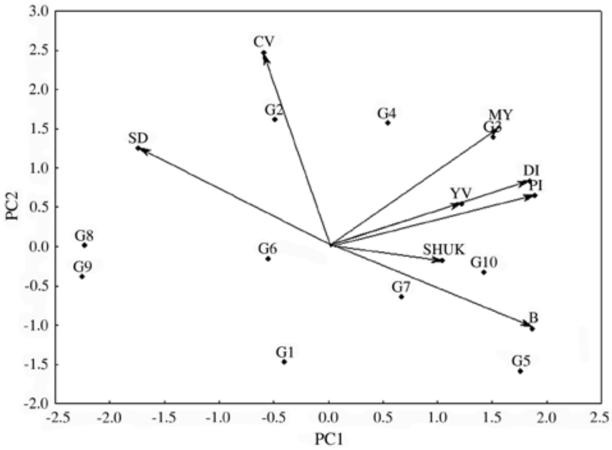

Figure 3. Vector view of the biplot for the genotype by stability statistics two-way data, showing relationships between stability statistics

perpendicular vectors ($r = \cos 90° = 0$), and (iii) strong negative association between regression coefficient with mean squares of SD as indicated by the large obtuse angles between their vectors ($r = \cos 180° = -1$).

Although, multi-environment trials are used for genotype evaluation, they can also be used in stability statistics evaluations. Ideal stability statistics should be highly differentiating of the genotypes and at the same time identifying high yield genotypes. In Figure 4, the stability statistics are ranked based on both discriminating ability and representativeness. The centre of the concentric circles is where an ideal stability statistics should be; its projection on the average tester coordinate x-axis was designed to be equal to the longest vector of all stability statistics; therefore, it is the most discriminating; its projection on the average tester coordinate y-axis was obviously zero, meaning that it is absolutely representative of the average stability statistics. Therefore, the closer stability statistics are to this mean yield, the better it is as stability statistics. Thus, PI, DI and YV stability statistics were a relatively favourable stability statistics and CV and SD stability statistics were unfavourable stability statistics (Fig. 4).

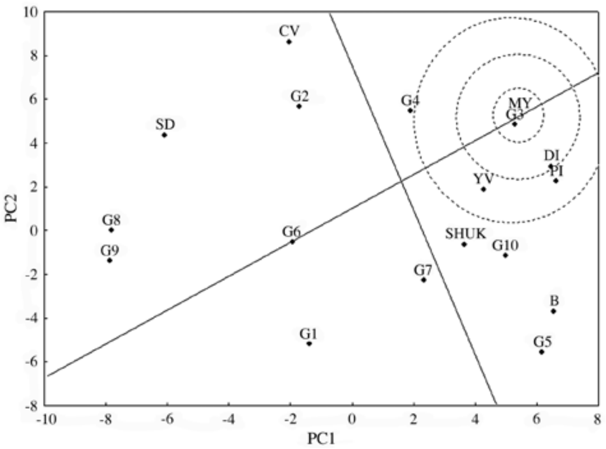

Figure 4. The biplot for the genotype by stability statistics two-way data, showing stability statistics positions due to mean yield

An ideal genotype, which is located at the centre of the concentric circles in Figure 5, is one that has both high mean yield and high stability. Ideal genotype projection on the average tester coordinate x-axis is designed to be equal to the longest vector of all the genotypes. The ideal genotype is stable because its projection on the average tester coordinate y-axis is zero. Genotypes are ranked based on the average yield and stability of the ideal genotype. A genotype is more favourable if it is closer to the ideal genotype. Therefore, G3 was more reliable followed by G4 and G10. Ranking of other genotypes based on the ideal genotype was G3 > G4 > G10 > G7 > G5 > G2 > G6 > G1 > G8 > G9.

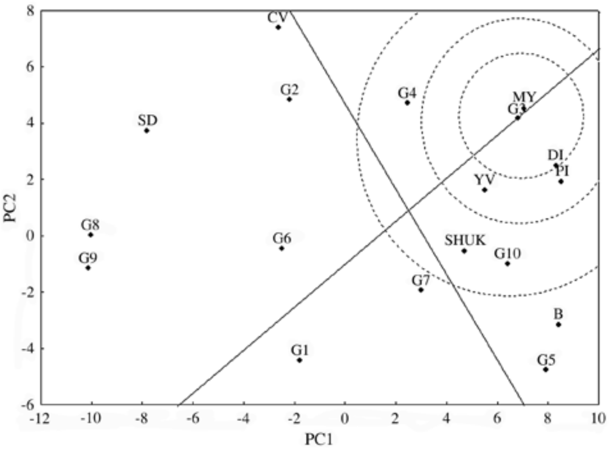

Figure 5. The biplot for the genotype by stability statistics two-way data, showing the favourable genotype position

Discussion

Lentil is becoming increasingly popular in developed countries due to its healthy component of the diet. Lentil is adapted to less-favourable areas, which would provide rotational benefits (such as nitrogen fixation) and alleviation of monoculture insect, disease and weed problems (Sarker et al., 2009). Lentil is grown in a wide-range of environmental conditions and so the yield of several genotypes tested across locations and over years differed due to high GE interactions (Sabaghnia et al., 2008). In this investigation both additive (non-crossover) and crossover GE interaction would be presented in Figure 1. This GE interaction is combines from years, locations and genotypes and so was three-way interaction. Understanding the causes of GE interaction is important at all stages of plant improvement process and can be used to establish breeding objectives, identify ideal test conditions and formulate recommendations for areas of optimal genotype adaptation.

We found that according to the static concept of stability (CV and SHUK), genotype G7 was the most stable one, while based on the dynamic concept of stability (linear regression coefficient and DI) genotypes G8 and G9 were the most stable ones. Most plant breeders have used the stability to introduce a genotype which indicates a relatively constant yield, independent of environmental conditions. This concept of stability is similar to homeostasis concept which is widely used in quantitative genetics (Becker, Leon, 1988). This concept of yield stability may be considered as a biological or static concept of stability. In contrast, agronomists would prefer an agronomic or dynamic concept of yield stability. In this concept of stability, it is not needed that the genotypic response to environmental conditions should be equal for all genotypes (Becker, 1981).

Our findings based on biplot figures of PC analysis indicated that DI, PI and YV stability statistics were grouped with MY and so reflect dynamic stability concept. These results are in good agreement with the results of Mohebodini et al. (2006) and Karimizadeh et al. (2012). Also, slope of regression (B) and stability variance (SHUK) statistics as one group, CV statistics as one group and SD statistics as the other group. These results indicated that the static and dynamic concepts of yield stability are relatively right. According to polygon of biplot, genotype G3 was identified as the most stable one. It seems that the desirability index (Hernández et al., 1993) and two suggested procedures of Lin and Binns (1988 a; b) were the most proper methods for evaluation of genotypes in multi-environmental trials. Dehghani et al. (2008) have reported that the DI benefit from dynamic concept of stability and could be selected high yielding genotypes as the most stable ones. Selection of genotypes for stability or high mean yield is required in most dry-land conditions, where the environment is variable and unpredictable (Sabaghnia et al., 2008; Annicchiarico et al., 2011). Thus, genotype evaluation under variable environmental conditions and simultaneous selection for yield and stability is the most valuable selection index that can be used in any plant breeding program.

The present investigation demonstrated the advantage of univariate parametric statistics for the analysis of the GE for grain yield in lentil. Our findings do not permit these methods to be widely recommended for assessing GE interactions. However, using these stability statistics appears particularly useful for depicting static and dynamic responses of legumes and especially lentil grain over the lentil-producing areas in arid and semi-arid conditions. In conclusion, various stability statistics which have been used in this study quantified stability of genotypes with or with no respect to mean yield. Both yield and stability should be considered to investigation of GE interaction and to make selection of the most favourable genotypes. Therefore, the DI, PI and YV statistics are acceptable for agronomists who prefer to use a high-yielding genotype. Thus, the best recommended genotypes according to the this study are G8 (ILL 6037) and G9 (ILL 6199) which had high mean yield and were the most stable based on the most stability statistics. These genotypes had the highest grain yield among the lentil genotypes studied (G8, 1200.23 and G9, 1267.83kg ha^{-1}) and therefore were recommended for release as commercial cultivars by the Dry Land Agricultural Research Institute.

Conclusion

The following findings can be summarized from this investigation: (i) G8 (ILL 6037) and G9 (ILL 6199) were found to be the most stable genotypes and therefore were recommended for national release; (ii) the desirability index (DI), priority index (PI) and yearly variance (VY) within test locations statistic of the univariate parametric procedures were found to be useful in detecting the stability as well as high yielding of the genotypes studied; (iii) various stability statistics reflect different types of stability (static or dynamic) and differ in stability nature and (iv) the significant genotype by environment (GE) interactions and the changes in ranks of genotypes across environments suggest a breeding strategy of specifically adapted genotypes in homogeneously grouped environments.

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Genotipo bei aplinkos sąveikos įtaka lęšių derliui ir jo stabilumo analizė

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Santrauka

Valgomasis lęšis (*Lens culinaris* Medik.) yra svarbus vėsiojo sezono augalas ir vertingas maistinių baltymų šaltinis, tarp pupinių grūdų užimantis septintą vietą. Genotipo ir aplinkos sąveika yra vienas iš pagrindinių veiksnių, ribojančių selekcinių programų efektyvumą. Lęšio aštuoni pagerinti genotipai iš Tarptautinio sausų regionų žemės ūkio tyrimų centro, viena komercinė veislė ‘Gachsaran’ ir viena senoji vietinė veislė du vegetacijos sezonus buvo vertinami penkiose vietovėse. Lęšio dešimties genotipų grūdų derliaus duomenų dispersinė analizė parodė, kad vietos, genotipo, metų × vietos, genotipo × vietos ir genotipo × metų × vietos sąveikos buvo esminės. Pagal variacijos koeficientą ir stabilumo dispersijos parametrus stabiliausias buvo genotipas G7, o pagal prioriteto indeksą (PI), pageidaujamumo indeksą (DI) ir regresijos linijinį modelį stabiliausi buvo genotipai G8 bei G9. Bendrojo ryšių tarp stabilumo parametrų modelio ir lęšio genotipų suskirstymas pagal pagrindinio komponento (PC) analizę parodė, kad pirmieji du PC paaiškino 79 % (PC1 = 55 %, PC2 = 24 %) bendrosios variacijos. Pirmųjų dviejų PC taškai, atidėti vienoje diagramoje, atskleidė, kad PI ir DI stabilumo parametrai buvo sugrupuoti su vidutiniu derliumi ir parodė dinamišką stabilumą. Tyrimo duomenys yra svarbūs selekcininkams, teikiantiems pirmenybę genotipams, kurie duoda didelį derlių. Pagal tyrimo rezultatus geriausi genotipai yra G8 (ILL 6037) ir G9 (ILL 6199), kurių vidutinis derlius buvo didžiausias ir pagal stabilumo statistinius rodiklius buvo stabiliausi, todėl yra rekomenduotini registruoti kaip komercinės veislės.

Reikšminiai žodžiai: adaptacija, *ANOVA*, *biplot* analizė, pagrindinio komponento analizė.