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Full Length Research Paper

Evaluation of the performance and stability of genotype x environment interaction and stability analysis for yield and its components in lentil

Hassan ElBradei

Department of Agronomy, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt.

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The objective of this investigation is to determine the performance and stability of 24 lentil (*LENS CULINARIS* Medik.) genotypes under a wide range of variable environments. The regression model and ecovalence (W_i) were used to analyze the response of the lentil genotypes to variable environmental conditions for yield and some of its components in six experiments in three seasons under two locations. Results indicated that both environmental conditions (E) and studied genotypic accessions (G) influenced significantly on the performance of yield and yield components. Moreover, the performance of genotypes varied highly significantly from environment to another for all traits, except 100 seed weight as proved by significance of G x E. Therefore, further stability analyses were performed for traits that recorded significant G x E. Four genotypes were stable for pods plant^{-1} either measured by W_i or S^2_d. For this trait, all genotypes were non responsive to environmental conditions except PL81-17 which may behave positively to pod bearing conditions. For seed yield plant^{-1} only Sinai 1 was significantly unstable measured by W_i and S^2_d, respectively. The significance of b's for seed yield feddan^{-1} proved that only 3 genotypes were responsive to environments. Two of them (XG88-17 and Giza 51) may behave better under good environments and the third (Giza 4) may be recommended under poor ones. It may be concluded in lentil breeding programs, which the performance of genotypes under each location should be evaluated firstly and those reliable ones will be tested for stability across various environmental conditions prior to recommendations.

Key words: Lentil, *Lens culinaris*, G x E interaction, regression, stability analyses, ecovalence.

INTRODUCTION

Lentil (*Lens culinaris* Medik.) is one of the most important food legume crops grown in the Mediterranean region and Middle East. According to FAO statistics of 2010, the acreage of lentil in Egypt is 1380 ha and yielded 2178 tons, which represents 2% of the national annual need.

The self-insufficiency of lentil may be attributed to several constraints that limit lentil production and cultivars potentiality. These factors include mainly the sensitivity of cultivars to various biotic and abiotic stresses such as weeds, fungal pathogens and other pests (Sarker et al., 2009), in addition to drought and salinity (Saxena et al., 1993; Hamdi et al., 2004).

In Egypt, several investigations were conducted to develop promising lentil cultivars using local and exotic accessions. The resultant materials were evaluated under variable conditions of Egyptian environments. The outcomes of these investigations were several cultivars, that is, Giza 9, Sinia 1 (Precoz) and Giza 370 which were recommended due to resistance to root rot and wilt, rainfed cultivation and multi-locations stability (Hamdi et al., 2003).

The evaluation of genotypes is the key to utilization in

breeding programs and is a continuous process. However, lentil genotypes suffered from narrow adaptability (due to long-day sensitivity performance) and susceptibility to less favorable environments (Erskine and Saxena, 1993). Thus, the most important goal of lentils improvement programs not only high yield, biotic and abiotic stresses tolerant cultivars, but also wide adaptability and stability (Hamdi et al., 2002; Dehghani et al., 2008).

Several scientists studied the stability of various genetic resources of lentils across variable environmental conditions (Hassan et al., 1988; Hamdi and Rabeia, 1991; Hamdi et al., 1995; Abd El-Gawad et al., 1997; Selim, 2000; Hamdi et al., 2003; Ezzat et al., 2005; Mehdi et al., 2006; Dehghani et al., 2008; El-Kadi et al., 2011).

The genotype x environment interactions could be attributed to predictable and non-predictable effects as reported by Allard and Bradshaw (1964). The first one may be due to macro-environmental conditions, but the second is mainly caused by climatic and micro-environmental conditions.

Several methods were proposed to analyze G x E interaction to determine the stability of performance (Becker and Léon, 1988). The most frequently utilized two methods for detecting the stability are partitioning of G x E interaction of evaluated genotypes (Wricke, 1962) and the regression model (Eberhart and Russell, 1966). Eberhart and Russell (1966) considered two parameters for measuring the varietal phenotypic stability: the regression coefficient (b_i) and deviation from regression (S^2_d). The variety with a (b_i) value not significantly different from unity (b_i = 1) and (S^2_d) value not significantly different from zero would be described as a stable variety. Therefore, the aim of the present investigation is to evaluate different genotypes and selections of lentil for yield and its components a n d to determine the G x E of these lentil genotypes under six variable environments of Upper and Lower Egypt during three seasons.

MATERIALS AND METHODS

Twenty four lentil genotypes were evaluated during 2009/10, 2010/11 and 2011/12 seasons at two locations (El-Gemmeiza and El-Mataana Research Stations), ARC, Egypt. El-Gemmeiza located at El-Gharbia Governorate (30° 57' E Latitude, 30° 57' N Longitude and Altitude 8.30 m), while El-Mataana is at Luxor Governorate (26° 10' E Latitude and 32° 43' N Longitude, Altitude 72.60 m). The code number and pedigree of the studied genotypes are presented in Table 1. The randomized complete blocks design (RCBD) with four replications was used in each experiment.

The experimental plot consisted of 10 rows, each was 30 cm apart and 3 m long (=9 m^2). Fertilizers were applied during seed bed preparation at the rate of 30 kg P_2O_5 and 15 kg N/fed. At harvest, number of pods/plant, number of seeds/pod, 100-seed weight and seed yield/plant were recorded using a random sample of 10 guarded plants from each plot. Seed yield/plot was used to calculate seed yield in ardab/fed (One ardab=160 kg and one fed = 4200 m^2).

Statistical analysis

The regular analysis of variance of RCBD as outlined by Gomez and Gomez (1984) was applied on the obtained data of each trial. The Bartelett's test of the homogeneity of error variances adopted indicated the validity of applying combined analysis of variance for the six environments.

To detect the differences among genotypes across all the studied environments (Ei), least significant difference (LSD) test was used.

Stability analysis

ECOVALENCE

Ecovalence parameter (W_i) proposed by Wricke (1962) was used to calculate the ecovalence of each genotype as follows:

$$SS = \sum r\left(\bar{x}_{ij} = x_{i.} - x_{.j} + x_{..}\right)^2$$

SS refer to the summation of squares; x_{ij} = the mean performance of character on the i^{th} variety in the j^{th} environment; $x_{i.}$ = mean of i^{th} variety across all environments; $x_{.j}$ = mean of j^{th} environment across all varieties; x.. Grand mean and r = No. of replicates

$$df = \frac{(t-1)(p-1)}{t}$$

df is degrees of freedom; t signifies genotypes and p, environments.

Regression analysis

The performance of an individual genotype was regressed on the environmental index (deviation of the mean yield at that environment from the overall mean yield of all environments) as outlined by Eberhart and Russell (1966). In this model, the regression coefficient, b_i and the deviation from regression mean squares (S^2_d) were considered as parameters of response and stability, respectively.

RESULTS AND DISCUSSION

Significance of mean squares

The mean squares and their significance of each environment and combined across environments are presented in Table 2. Variances due to genotypes (G) were highly significant in all environments for all studied traits, except for seed/pod in 2009/2010 and 2010/2011 seasons at El- Gemmeiza and in 2010/2011 and 2011/2012 seasons at El- Mataana location. However, lentil genotypes varied highly significantly across all environments for all studied traits.

Environments as a source of variation in combined analysis affected highly significantly all the investigated lentil traits.

These results indicated that both environmental conditions and studied genotypic accessions influenced significantly on the performance of yield and yield components of lentil. Moreover, the performance of

Table 1. Code and pedigree of the studied lentil genotypes.

S/N	Genotype	Origin	Pedigree
1	FLIP 95-51L	ICARDA	Accession No. ILL7707
2	FLIP 95-67L	ICARDA	Land race
3	FLIP 96-19L	ICARDA	ILL245x ILL883
4	FLIP 97-31L	ICARDA	UJ88 286Lx ILL6205
5	FLIP 98-34L	ICARDA	ILL223x ILL19
6	FLIP 200-18L	ICARDA	ILL5588x ILL7010
7	FLIP 2003-37L	ICARDA	ILL723xILL7163
8	FLIP 2003-38L	ICARDA	ILL723x ILL7554
9	PL81-17	India	Land race
10	Line 88522	Pakistan	Accession No.ILL9836
11	Line 89503	Pakistan	Accession No.ILL7723
12	XG88-17	Egypt	Selection from hybrid family
13	XG88-1-1	Egypt	Selection from hybrid family
14	XG88-3-2	Egypt	Selection from hybrid family
15	XG88-6-1	Egypt	Selection from hybrid family
16	XG88-9-1	Egypt	Selection from hybrid family
17	Sinai 1	Egypt	Selection from Argentinian cultivar "Preccoz"
18	Giza 9	Egypt	Wide spread cultivar
19	Giza 370	Egypt	Wide spread cultivar
20	Giza 4	Egypt	Family 119 x Family 174
21	Giza 51	Egypt	Selection from hybrid family
22	Fam. 29	Egypt	Land race
23	Fam. 300-Preccoz	Egypt	Selection from Precoz
24	ILL4403	Pakistan	Land race

Source: Food Legume Crops Res. Dep., FCRI, ARC, Egypt. ICARDA = International Center for Agricultural Research in the Dry Areas.

genotypes varied highly significantly from one environment to another for all traits except 100 seed weight, as proved by the significance of G x E interaction. From combined analysis, the magnitudes of variances due to environments were larger compared to those of genotypes, particularly for pods/plants (17 fold), seeds/pod and seed yield/plant (10 fold) and seed yield/fed (43 fold).

Therefore, further stability analysis could be performed for traits that recorded significant G x E interaction.

Mean effects of environments

The mean performance and environmental index (I) of the investigated lentil genotypes in each environment are presented in Table 3. The environmental index used in this table is the deviation of each environment from the grand mean of all environments.

The prevailing conditions of 2009/2010 at El-Gemmeiza (1^{st} Env.) and 2011/2012 at El-Mataana (6^{th} Env.) recorded significantly the highest number of pods/plant, which was reflected in the highest positive environmental indices. Seeds per pod under 1^{st}, 3^{rd} and 5^{th} environments were significantly higher corresponded to the positive I's compared to those negative of other three environments.

Seed index for all seasons under El-Gemmeiza location was lighter with negative environmental indices, whereas those at El-Mataana were heavier with positive I's.

The plant seed yield was performed similar to number of pods per plant, which was only positive under 1^{st} and 6^{th} environments. Regarding the outcome product as seed yield per feddan in the 1st, 3rd, 4th and 6th environments was higher product ones with positive environmental indexes. The 1st and 6th environments showed these effects may be due to the positive effects of pods and seed yield per plant.

However, such positive effects on the seed yield per feddan due to other two environments (3^{rd} and 4^{th}), may be due to the compensation of other yield components, that is, seeds per pod and seed index. Similar environmental effects on the performance of lentil genotypes and the G x E interactions were previously detected by several authors (Hamdi and Rabeia, 1991; Hamdi et al., 1995; Selim, 2000; Hamdi et al., 2002; Dehghani et al., 2008).

Table 2. Mean squares due to different sources of variation of each individual environment and combined across environments for seed yield and its components of 24 genotypes under El-Gemmeiza and El-Mataana locations during 2009/2010 through 2011/2012 season.

Location	Season	S.V.	d.f.	Mean squares				
				Pods/plant	Seeds/pod	100-seed weight	Seed yield/plant	Seed yield/fed
El-Gemmeiza	2009/2010 (1st environment)	Genotypes	23	3180.14**	0.252ns	1.076**	2.192**	2.402**
	2010/2011 (2nd environment)	Genotypes	23	440.62**	0.119ns	0.300**	0.317**	0.606**
	2011/2012 (3rd environment)	Genotypes	23	2124.48**	0.214**	0.853**	1.307**	3.779**
El-Mataana	2009/201) (4th environment)	Genotypes	23	313.96**	0.116**	0.419**	1.733**	3.946**
	2010/2011 (5tn environment)	Genotypes	23	393.95**	0.019ns	0.262**	0.583**	0.609**
	2011/2012 (6tn environment)	Genotypes	23	854.04**	0.010ns	7.683**	1.123**	6.699**
Combined across six environments		Environments (E)	5	40732.65**	1.274**	5.610*	32.134**	261.652**
		Genotypes (G)	23	2439.05**	0.132**	3.319**	3.192**	6.138**
		G x E	115	973.63**	0.120**	1.455ns	0.813**	2.380**

ns, * and ** indicate insignificant, significant at 0.05 and 0.01 levels of probability, respectively.

Table 3. Mean performance and environmental index (I) of investigated lentil genotypes in each environment for studied characters from combined analysis.

Location	Season	Pods/plant		Seeds/pod		100-seed weight (g)		Seed yield/plant (g)		Seed yield/Fed (ardab)	
		Mean	I_i	Mean	I_i	Mean	I_i	Mean	I_i	Mean	I_i
El-Gemmeiza	2009/2010 (1st environment)	84.3a	23.33	1.33b	0.01	2.55bc	-0.05	2.65b	0.47	3.99c	0.41
	2010/2011 (2nd environment)	31.8d	-29.20	1.26b	-0.01	2.29c	-0.31	1.27e	-0.91	1.70f	-1.88
	2011/2012 (3rd environment)	58.1b	-2.85	1.43a	0.16	2.59bc	-0.01	2.17c	-0.01	4.29b	0.71
El-Mataana	2009/2010 (4th environment)	47.8c	-13.20	1.18c	-0.08	2.71ab	0.11	1.92d	-0.26	3.82d	0.23
	2010/2011 (5tn environment)	59.7b	-1.31	1.32b	0.06	2.66abc	0.07	2.15cd	-0.03	2.84e	-0.74
	2011/2012 (6th environment)	84.2a	23.24	1.11c	-0.15	3.03a	0.19	2.93a	0.75	4.85a	1.27

Means in the same column followed by the same letters are not significantly different.

Stability analysis

The stability parameters and mean performance is the investigated lentil genotypes are presented in Table 4. The analysis of stability was performed only for pods and seed yield/plant and per fed using ecovalence and regression analysis was performed. The ecovalence (Wi) as a parameter of stability proposed by Wricke (1962) as outlined by Becker and Léon (1988), measures the G x E of each genotype.

The significance of Wi means instability of performance across targeted environments and/or the stable genotype records Wi = 0.0 or possesses high ecovalence. The regression model of stability proposed by Ebarhart and Russell (1966), considered that b as a parameter of response and S2d indicates instability due to the deviation from zero. However, the significance of the coefficient of regression (b) means responsiveness either to favorable environment (b is more than unity) or poor ones (b is less than unity).

Accordingly, 4 genotypes (FLIP 96-19L, FLIP

Table 4. Mean performance and stability parameters of studied 24 lentil genotypes across the six environments.

Genotype	Pods/plant				Seed yield/plant (g)				Seed yield/fed (ardab)			
	Mean	W_i [1]	S^2d [2]	b_i [3]	Mean	W_i [1]	S^2d [2]	b_i [3]	Mean	W_i [1]	S^2d [2]	b_i [3]
FLIP 95-51L	61.6	3140.2**	939.9**	1.00^{ns}	2.45	2.72^{ns}	0.70**	1.51^{ns}	3.65	4.37**	1.26**	1.13^{ns}
FLIP 95-67L	59.7	396.0**	116.9**	0.94^{ns}	1.72	0.31^{ns}	0.04^{ns}	0.65*	3.55	0.37^{ns}	0.10*	1.06^{ns}
FLIP 96-19L	57.8	208.4^{ns}	62.3^{ns}	0.99^{ns}	2.22	0.62^{ns}	0.14*	1.33^{ns}	3.63	0.44*	0.07^{ns}	1.14^{ns}
FLIP 97-31L	70.7	2627.9**	729.1**	1.30^{ns}	2.25	1.40^{ns}	0.37**	1.33^{ns}	3.85	5.74**	1.64**	1.15^{ns}
FLIP 98-34L	66.2	1505.6**	448.9**	0.94^{ns}	2.11	0.51^{ns}	0.14*	1.17^{ns}	3.80	1.33**	0.31**	1.16^{ns}
FLIP 200-18L	68.3	130.1^{ns}	23.0^{ns}	1.17^{ns}	2.28	0.17^{ns}	0.04^{ns}	0.83^{ns}	4.13	2.14**	0.38**	1.28^{ns}
FLIP 2003-37L	61.4	321.9*	70.7*	1.22^{ns}	2.07	0.19^{ns}	0.04^{ns}	1.18^{ns}	3.73	1.99**	0.54**	1.13^{ns}
FLIP 2003-38L	48.8	467.7**	129.6**	1.10^{ns}	1.45	0.24^{ns}	0.05^{ns}	0.79^{ns}	2.31	2.35**	0.36**	0.68^{ns}
PL81-17	59.6	138.3^{ns}	11.0^{ns}	1.2*	2.12	0.38^{ns}	0.10^{ns}	1.19^{ns}	3.27	0.45*	0.12*	0.93^{ns}
Line 88522	62.2	471.8**	137.1**	1.09^{ns}	2.38	0.35^{ns}	0.09^{ns}	1.19^{ns}	3.73	0.85**	0.25**	1.02^{ns}
Line 89503	65.5	686.2**	170.6**	1.30^{ns}	2.38	0.27^{ns}	0.02^{ns}	0.62**	3.98	1.77**	0.52**	1.05^{ns}
XG88-17	67.5	281.4*	84.2*	0.99^{ns}	2.65	0.37^{ns}	0.05^{ns}	1.38*	4.29	1.68**	0.21**	1.29*
XG88-1-1	51.2	1236.4**	316.9**	0.68^{ns}	1.88	0.26^{ns}	0.08^{ns}	0.99^{ns}	3.15	0.69**	0.14**	0.86^{ns}
XG88-3-2	47.6	1254.9**	285.9**	0.59^{ns}	1.87	0.52^{ns}	0.15*	0.86^{ns}	3.12	5.13**	1.34**	0.76^{ns}
XG88-6-1	49.1	227.5^{ns}	64.4^{ns}	0.92^{ns}	1.87	0.26^{ns}	0.05^{ns}	0.77^{ns}	2.90	1.60**	0.35**	0.81^{ns}
XG88-9-1	59.8	562.2**	156.5**	0.85^{ns}	2.08	0.50^{ns}	0.14*	1.13^{ns}	3.73	1.90**	0.51**	1.13^{ns}
Sinai 1	80.1	3237.3**	909.5**	1.34^{ns}	3.05	4.31*	1.28**	1.18^{ns}	4.23	0.39*	0.11*	0.96^{ns}
Giza 9	83.2	1882.8**	472.5**	1.41^{ns}	2.84	1.82^{ns}	0.45**	1.49^{ns}	4.43	2.72**	0.79**	1.09^{ns}
Giza 370	61.9	844.9**	184.5**	0.64^{ns}	2.45	0.24^{ns}	0.07^{ns}	1.02^{ns}	3.55	2.26**	0.59**	0.84^{ns}
Giza 4	60.9	449.1**	116.6**	0.82^{ns}	2.09	1.03^{ns}	0.22**	0.55^{ns}	3.59	4.22**	1.24**	0.92*
Giza 51	70.5	470.1**	90.5**	1.31^{ns}	2.33	0.26^{ns}	0.08^{ns}	1.01^{ns}	3.64	2.05**	0.61**	1.01*
Fam. 29	58.4	766.4**	205.3**	0.79^{ns}	2.11	0.53^{ns}	0.14*	0.76^{ns}	3.69	2.47**	0.74**	1.00^{ns}
Fam. 300-Preccoz	53.0	460.0**	128.2**	0.87^{ns}	2.06	0.79^{ns}	0.22**	0.79^{ns}	3.39	7.43**	2.17**	0.88^{ns}
ILL4403	38.8	1607.8**	330.6**	0.47^{ns}	1.63	1.47^{ns}	0.22**	0.28^{ns}	2.61	2.84**	0.58**	0.72^{ns}
$LSD_{0.05}$	6.13	-	-	-	0.26	-	-	-	0.22	-	-	-

[1] * and ** indicate unstable genotype at 5 and 1%, respectively; ^{ns} means stable genotype; (2) ^{ns}, * and ** indicate insignificant, significant at 5 and 1% of deviation regression from zero; [3] ^{ns}, * and ** = insignificant, significant at 5 and 1% of regression coefficient from unity.

200-18L, PL81-17 and XG88-6-1) were stable for pods/plant measured by Wi and S2d. For this trait, all genotypes were non-responsive to environmental conditions, except PL81-17 which may behave positively to pod bearing conditions. For seed yield per plant, only FLIP 95-51L and XG88-17 accessions were significantly unstable measured by Wi and S2d, respectively. Another two genotypes (FLIP 95-67 L and XG88-17) and one genotype (XG88-1-1) may perform better for yield per plant under favorable and less favorable environments, respectively. This is due to the significant estimated b which is lesser than unity in the first case and more than one in the second situation. Regarding the seed yield per feddan, all genotypes recorded significant W_i (except FLIP 95-67L) and S^2_d (except FLIP 96-19L). This indicates that out of 24 accessions, 23 were instable across the studied environments either measured by W_i or S^2_d for seed yield per

feddan. The significance of b's for seed yield per feddan proved that only 3 genotypes were responsive to environments. Two of them (XG88 17 and Giza 51) behaved better under good environments and the remaining one (Giza 4) may be recommended under poor ones.

The variability of lentil genotypes for stability across different environmental conditions was reported in Egypt by Hamdi and Rabeia (1991), Hamdi et al. (1995), Selim (2000), El-Kadi et al. (2011) and Hamdi et al. (2002).

To elucidate the interrelationship between mean performance and estimated stability parameters (W_i and S^2_d), the rank correlation was calculated for all studied traits. The obtained rank correlation coefficients were small in magnitude and insignificant (-0.10 and 0.13 for pods/plant, 0.19 and 0.31 for seed yield per plant and 0.34 and 0.38 for seed yield per feddan between mean and each of W_i and S^2_d, respectively.

Such insignificant correlations proved that the performance of the tested lentil genotypes was not related to the extent of stability measured either by W_i or S^2_d. Thus, it may be concluded in lentil breeding programs that the performance of genotypes under each location should be evaluated firstly and those showing reliable means will be tested for stability across environmental conditions prior to recommendations.

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