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Graphic analysis of yield stability in new improved lentil (*Lens culinaris* Medik.) genotypes using nonparametric statistics

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ABSTRACT

Yield stability is an interesting feature of today's lentil breeding programs, due to the high annual variation in mean yield, particularly in the arid and semi-arid areas. The genetic effects including genetic main and genotype × environment (GE) interaction effects for grain yield of eighteen lentil (*Lens culinaris* Medik.) genotypes were studied with fourteen nonparametric stability statistics. Results of five distinct nonparametric tests of GE interaction and combined ANOVA showed there were both additive and crossover interaction types and genotypes varied significantly for grain yield. According to most of the nonparametric stability statistics, genotypes G5, G6, G8 and G18 were the most stable genotypes. Considering mean yield versus stability values via their plotting, indicates that genotypes G2, G11 and G14 following to G5, G16 and G18 were the most favorable genotypes. None of the nonparametric stability statistics were correlated with mean yield and so had static concept of stability. Our results confirmed that rankings of genotypes within environments and using mean yield information permit ease of interpretation of nonparametric results. Finally genotypes G2 (FLIP 92-12L), G11 (Gachsaran) and G14 (ILL 6206) were found to be the most stable and high mean yielding genotype and thus recommended for commercial release. Such an outcome could be used to delineate predictive, more rigorous recommendation strategies as well as to help define stability concepts for lentil and other crops.

Key words: adaptability, dynamic stability, genotype × environment interaction

IZVLEČEK

GRAFIČNA ANALIZA STABILNOSTI PRIDELKA NOVIH IZBOLJŠANIH GENOTIPOV LEČE (*Lens culinaris* Medik.) Z UPORABO NEPARAMETRIČNE STATISTIKE

Stabilnost pridelka je zaradi velikih letnih nihanj, še posebej v aridnih in semi-aridnih območjih, zanimiva lastnost v današnjih žlahtniteljskih programih pri leči (*Lens culinaris* Medik.). Pri 18 genotipih leče smo s 14 neparametričnimi statističnimi testi, ki vrednotijo stabilnost pridelka, preučevali glavne vplive genotipa in interakcije med genotipom in okoljem (GO) na pridelek zrnja. Rezultati petih neparametričnih testov GO interakcij, ter parametrične ANOVA so pokazali, da so se genotipi značilno razlikovali v pridelku zrnja tako v povezanjih kot prekrižanih interakcijah. Gleda na večino neparametričnih testov stabilnosti pridelka so se genotipi G5, G6, G8 in G18 izkazali kot najbolj stabilni. Primerjava povprečnih pridelkov in stabilnosti je pokazala, da so genotipi G2, G11, G14 in G5, G16 ter G18 najbolj primerni. Nobeden izmed neparametričnih testov stabilnosti ni koreliral s povprečnim pridelkom, kar kaže na njihov statičen značaj. Naši rezultati potrjujejo, da rangiranje genotipov po povprečnem pridelku za vsake okoljske razmere posebej omogoča uporabo rezultatov neparametričnih testov. Na koncu so bili genotipi G2 (FLIP 92-12L), G11 (Gachsaran) in G14 (ILL 6206) prepoznani kot najbolj stabilni, z velikim povprečnim pridelkom in priporočeni za komercialno uporabo. Takšni izsledki bi lahko bili uporabljeni za ponazoritev napovedovanj in resnejših priporočil kot tudi pomoč pri določanju stabilnost pridelave leče in drugih poljščin.

Ključne besede: prilagodljivost, dinamična stabilnost, interakcije med genotipom in okoljem

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1 INTRODUCTION

Iran is one of the foremost countries in terms of lentil (*Lens culinaris* Medik.) production and sowing area in the world, and is followed by Canada, Turkey and India. Although, the lentil is the second grain legume crop after the chickpea in Iran but its average yield (489 kg ha^{-1}) is not acceptable for many local farmers (Sabaghnia et al., 2008). According to the latest statistics from The Food and Agricultural Organization of the United Nations, 162000 ha were used for lentil production and 79000 t of production were obtained in 2000 (FAOSTAT, 2010). This low yield performance of the cultivated lentil cultivars in comparison to the highest global yields (14580 kg ha^{-1}, produced in Canada; FAOSTAT, 2010), encouraged Dryland Agricultural Research Institute (DARI) of Iran for performing an important lentil-breeding program in recent years, supported by the International Center for Agricultural Research in Dry Areas (ICARDA).

Like to the other crops, increasing the potential of yield is an important target of lentil breeding programs. The new improved genotypes are evaluated in multi-environment trials to test their performance across different environmental conditions. In most trials, crop yield fluctuates due to suitability of genotypes to different conditions which is known as genotype × environment (GE) interaction (Kang, 1998). In presence of GE interaction, a genotype does not exhibit the same phenotypic characteristics under test environments and various genotypes respond differently to a specific environment. GE interaction exploration and yield stability is an area of current interest and the success of plant breeding efforts depend on the identification of superior genotypes from stability and yield aspects. Exploring, measurement and interpretation of GE interaction can be aided by different statistical modeling and a number of statistics, parametric as well as nonparametric have been proposed for the study of yield stability (Huehn, 1996). These statistical models can be linear formulations (Eberhart and Russell, 1966), multiplicative formulations such as additive main effects and multiplicative interaction (Zobel et al., 1988), or nonparametric procedures (Huehn, 1979).

The use of nonparametric statistics in the assessment of yield stability had several benefits. In this approach, no assumptions about the observations are needed and there is less sensitivity to measurement errors or to outliers (Huehn, 1990a). Also, additions or deletions a few genotypes do not cause distortions and these statistics are useful in situations where parametric statistics fail due to the presence of large non-linear GE interaction (Huehn, 1990b). In most cases the plant breeder is concerned with non-additive (crossover) GE interaction and so yield stability measuring based on rank-information, seems more relevant and usefulness. Therefore, the nonparametric statistics are widely used in the selection of favorable genotypes especially when the interest lies in crossover GE interaction (Nassar and Huehn, 1987; Huehn, 1996; Mut etal., 2009). Although, it is demonstrated that the nonparametric procedures are less powerful than their parametric methods but Raiger and Prabhakaran (2000) have shown that when the number of genotypes is large, the power efficiency of the nonparametric statistics will be quite close to the parametric statistics.

According to both GE interaction types, additive (non-crossover) and crossover (non-additive), several nonparametric tests based on ranks were proposed by different authors. These methods of Bredenkamp (1974), Hildebrand (1980) and Kubinger (1986) for testing of additive GE interaction and methods of de Kroon and van der Laan (1981) and, Azzalini and Cox (1984) for testing of crossover GE interaction were introduced. Also, several nonparametric stability statistics proposed by Huehn (1979), Kang (1988), Ketata et al. (1989), Fox et al. (1990), and Thennarasu (1995) which are identifying genotypes with similar ranking across environments as the most stable genotypes. Nassar and Huehn (1987) developed two distinct statistical tests as Z1 and Z2 for the two first nonparametric stability statistics of Huehn (1979) which known as $S_i^{(1)}$ and $S_i^{(2)}$.

The objectives of present study were to (1) test presence of GE interaction through different nonparametric tests, (2) interpret GE interaction via ranks obtained by nonparametric stability statistics of 18 lentil genotypes over twelve environments, (3) visually assess how to vary rank statistics versus yield performances based on the plot, (4) determine promising favorable genotype(s) with high mean yielding and good stability, and (5) investigate interrelationships among different nonparametric stability statistics in lentil dataset.

2 MATERIALS AND METHODS

2.1 Plant Material and Field Conditions

The study included 18 lentil genotypes (16 new improved lines and 2 cultivars) that were grown in 4 different locations under rainfed conditions during the 2007-2009 growing seasons. The names of studied lentil genotypes are given in Table 1.

Table 1. Geographical properties and mean yield of the 18 lentil genotypes, studied in 4 locations

Code	Location	Altitude (meter)	Longitude Latitude	Soil Texture	Rainfall (mm)	Yield (kg ha^{-1})
1	Gorgan	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
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

All trials were arranged in accordance with a randomized complete block design with 4 replicates. The experimental plots consisted of 4 rows, each 4 m in length with 25 cm row spacing. The planted plot size was 4 m^2 and the harvested plot size was about two 3.5 m rows with 1.75 m^2. All trials were fertilized with 20 kg of N ha^{-1} and 80 kg of P_2O_5 during sowing stage. Weeds were controlled by hand twice in the high weed density (pre-flowering and post-flowering stages).

The test locations (Gorgan, Gachsaran, Kermanshah and Shirvan) were selected as sample of lentil growing areas of Iran and to vary in latitude, rainfall, soil types, temperature and other agro-climatic factors. Gorgan in the north-east of Iran is characterized by semi-arid conditions with sandy loam soil. Gachsaran, in southern Iran, is relatively arid and has silt loam soil. Kermanshah in the west of Iran is characterized by semi-arid conditions with clay loam soil. Gachsaran, in southern Iran, is relatively arid and has silt loam soil. Shirvan in the north-east of Iran is characterized by moderate conditions, relatively high rainfall and have clay loam soil. Some of the important properties and the location of the experimental environments are given in Table 2.

Table 2: The name and yield (kg ha $^{-1}$) of 18 lentil genotypes studied in multi-environmental trials

Code	Name	Type	Yield	Code	Name	Type	Yield
G1	FLIP 96-7L	Line	1418.73	G10	ILL 6030	Line	1187.98
G2	FLIP 92-12L	Line	1365.64	G11	Gachsaran	Cultivar	1374.14
G3	FLIP 96-13L	Line	1287.29	G12	ILL 7523	Line	1334.75
G4	FLIP 96-8L	Line	1272.07	G13	ILL 6468	Line	1292.16
G5	FLIP 96-4L	Line	1324.46	G14	ILL 6206	Line	1401.88
G6	FLIP 96-14L	Line	1096.53	G15	ILL 62-12	Line	1307.35
G7	ILL 5583	Line	1304.15	G16	FLIP 82-1L	Line	1272.40
G8	FLIP 96-9L	Line	1191.14	G17	CABRALIA	Cultivar	1203.28
G9	ILL 6002	Line	1329.48	G18	FLIP 92-15L	Line	1314.63

2.2 Nonparametric Statistical Methods

Conventional combined analysis of variance as well as nonparametric tests for presence of GE interaction was done. Three nonparametric tests including Bredenkamp (1974), Hildebrand (1980) and Kubinger (1986) procedures were applied for additive GE interaction and two nonparametric tests including de Kroon and van der Laan (1981) and Azzalini and Cox (1984) procedures were applied for crossover GE interaction. These nonparametric tests have been described in detail by Huehn and Leon (1995) and Truberg and Huehn (2000). For computing of the above mentioned statistics, a SAS-based computer program was used.

Huehn (1979) developed six nonparametric stability statistics, which Kang and Pham (1991) and Kaya and Taner (2002) described only four $S_i^{(1)}$, $S_i^{(2)}$ $S_i^{(3)}$ and $S_i^{(6)}$ statistics. The two other nonparametric statistics are expressed as follows:

$$S_i^{(4)} = \sqrt{\frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_{i.})^2}{n}}$$

$$S_i^{(5)} = \frac{\sum_{j=1}^{n}| r_{ij} - \bar{r}_{i.} |}{n}$$

for *k* genotypes and *n* environments, the value of *i*th genotype in *j*th environment is x_{ij}, where $i = 1,2,...,k$, $j = 1,2,...,n$, r_{ij} as the rank of the *i*th genotype in the *j*th environment, and $\overline{r_{ij}}$ as the mean rank across all environments for the *i*th genotype. Ketata et al. (1989) proposed plotting mean rank across environments against standard deviation of ranks for all genotypes (σ_r) or plotting mean yield across environments against standard deviation of yields for all genotypes (σ_{my}). The formula for calculating both standard deviations are expressed as:

$$\sigma_r = \sqrt{\frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_{i.})^2}{n-1}}$$

$$\sigma_{my} = \sqrt{\frac{\sum_{j=1}^{n}(r_{ij} - \bar{x}_{i.})^2}{n-1}}$$

Nonparametric stability statistics as Top, Mid and Low were introduced by Fox et al. (1990) as nonparametric superiority measure (NSM) using stratified ranking of the genotypes and their ranking was done at each environment separately and the number of environment at which the genotype occurred in the top, middle, and bottom third of the ranks was computed. Kang's (1988) rank-sum is another nonparametric stability statistics where both mean yield and Shukla's (1972) stability variance are used as selection criteria. Thennarasu (1995) proposed the use of the four nonparametric statistics based on the corrected ranks. In other word, the ranks of genotypes in each environment were determined according adjusted values ($x_{ij}^{*} = x_{ij} - \overline{x_{i.}}$). For calculation of these nonparametric stability statistics, SAS-based computer programs of Lu (1995) and Hussein et al. (2000) were used.

3 RESULTS

The residuals mean squares were not correlated to environment mean yield (r = 0.12, $P > 0.05$) thus the data were not transformed. Variances homogeneity test via Bartlett procedure ($\chi^2 = 25.1$, $P < 0.05$) showed that the mean squares of individual environments were homogeny and so the combine analysis of variance could be done. Analysis of variance was conducted to determine the effects of year, location, genotype, and their interactions on grain yield of lentil genotypes (Table 3).

Table 3: Combined ANOVA of lentil performance trial yield data

Source	DF	Mean Squares
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

Genotypes and locations were regarded as fixed effects, while years were regarded as random effects. The main effect of Y, L and Y × L were tested against the replication within environment (R/Y×L). The main effect of G was tested against the G × Y × L interaction and the G × Y × L interaction was tested against error term. The main effects of year (Y) and location (L) were not significant ($P > 0.05$), but their interactions (YL) were highly significant ($P < 0.01$). The main effect of genotypes was significant ($P < 0.01$), the genotype × year interaction (GY) was not significant ($P > 0.05$), the genotype × location interaction (GL) was significant ($P > 0.05$) and three way interactions (GYL) or GE were highly ($P < 0.01$) significant (Table 3). The GE interaction, which arising from the lack of genetic correlation among environments, must be used to understand in breeding program. Analyses of the quantitative traits like grain yield indicate important sources of genetic variation attributed to GE interactions (Gauch et al., 2008). The relative large contributions of GE interaction in grain yield of lentil which found in this study is similar to those found in other multi-environmental trials studies of lentil in rain-fed conditions (Mohebodini et al., 2006; Sabaghnia et al., 2008).

Table 4: Analysis of GE interaction using different non-parametric tests on 18 durum lentil genotypes grown in 12 environments

Nonparametric tests	Nonparametric tests	df	χ^2	P-value
Additive	Bredenkamp	187	894.05	0.00 <
	Hidebrand	187	364.21	0.00 <
	Kubinger	187	385.67	0.00 <
Crossover	de Kroon-van der Laan	187	368.46	0.00 <
	Azzalini-Cox	187	305.31	0.00 <

The results of various nonparametric tests verified the results combined ANOVA. According to chi-squares statistics of Bredenkamp (1974), Hildebrand (1980) and Kubinger (1986) producers, the existence of additive (non-crossover) GE interaction; and based on de Kroon and van der Laan (1981) and Azzalini and Cox (1984) producers, the existence of crossover (non-additive) GE interaction were demonstrated (Table 4). The high significance of GE interactions for lentil grain yield via combined ANOVA and five nonparametric tests indicated the genotypes exhibited both crossover and non-crossover types of GE interaction. In other word, results of nonparametric tests are in agreement with the ANOVA, but provide more specific information about the nature of GE interactions from additive and crossover aspects. Cooper and Byth (1996) explained that the large magnitude of GE interaction due to the more dissimilarity of the genetic systems controlling the physiological processes conferring adaptation to different environments.

The values of the first two nonparametric stability statistics of Huehn (1979), $S_i^{(1)}$ and $S_i^{(2)}$, indicated that genotype G18, followed by G5 and G11 were the most stable genotypes (Table 5). Nassar and Huehn (1987) and Flores et al. (1998) pointed out that the $S_i^{(1)}$ and $S_i^{(2)}$ are associated with the static or biological concept of stability and define stability in the sense of homeostasis. However, the stability property alone is of limited use and for a successful genotype testing program, both stability and mean yield must be considered simultaneously.

Table 5: Nonparametric stability statistics for grain yield of 18 lentil genotypes evaluated in 12 environments

	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(4)}$	$S_i^{(5)}$	$S_i^{(6)}$	Top	Mid	Low	RS	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	σ_r	σ_{my}
G1	7.61	42.00	73.75	18.81	4.83	12.08	58.33	25.00	16.67	16	5.42	1.806	0.919	0.525	5.67	420.82
G2	6.52	31.24	44.24	15.79	4.30	9.16	58.33	33.33	8.33	9	5.21	1.157	0.743	0.385	4.76	401.19
G3	6.18	28.09	32.99	15.90	3.99	6.24	33.33	25.00	41.67	21	4.54	0.454	0.527	0.290	4.80	375.57
G4	6.15	26.82	39.44	17.69	4.58	6.93	25.00	41.67	33.33	25	4.04	0.385	0.434	0.320	5.33	376.62
G5	4.83	16.57	23.75	12.89	3.29	5.64	33.33	66.67	0.00	9	3.96	0.396	0.388	0.259	3.89	391.36
G6	5.92	25.36	5.58	8.38	2.00	1.90	0.00	25.00	75.00	22	4.46	0.262	0.282	0.087	2.53	319.74
G7	5.86	24.81	34.02	16.26	4.04	6.24	25.00	50.00	25.00	24	4.21	0.411	0.478	0.300	4.90	379.45
G8	6.03	25.55	18.57	14.29	3.63	3.95	8.33	33.33	58.33	23	3.71	0.239	0.335	0.179	4.31	345.34
G9	7.45	41.18	57.60	19.74	5.03	8.93	41.67	33.33	25.00	24	6.04	0.863	0.615	0.414	5.95	392.23
G10	7.74	43.54	38.19	19.35	4.83	5.92	16.67	25.00	58.33	33	5.63	0.388	0.516	0.268	5.83	347.71
G11	5.02	18.27	29.75	12.60	3.22	7.25	41.67	58.33	0.00	9	3.63	0.483	0.533	0.339	3.80	399.98
G12	6.56	30.45	33.77	15.52	3.92	6.59	41.67	33.33	25.00	13	4.58	0.509	0.506	0.310	4.68	391.93
G13	5.26	19.90	30.38	15.26	3.85	6.02	25.00	41.67	33.33	14	3.88	0.456	0.406	0.284	4.60	378.08
G14	6.85	34.42	26.97	11.69	2.83	6.71	50.00	50.00	0.00	15	4.88	0.750	0.792	0.330	3.52	415.54
G15	6.08	27.66	38.11	16.75	4.29	6.99	33.33	41.67	25.00	19	4.71	0.523	0.534	0.325	5.05	387.68
G16	5.76	23.91	31.48	15.74	3.56	5.42	25.00	58.33	16.67	25	3.71	0.371	0.416	0.284	4.75	375.91
G17	7.98	49.30	51.59	21.31	5.83	7.95	41.67	8.33	50.00	32	6.96	0.535	0.549	0.333	6.42	358.98
G18	4.53	14.81	20.64	11.67	2.92	5.30	41.67	50.00	8.33	9	2.88	0.338	0.435	0.254	3.52	385.67

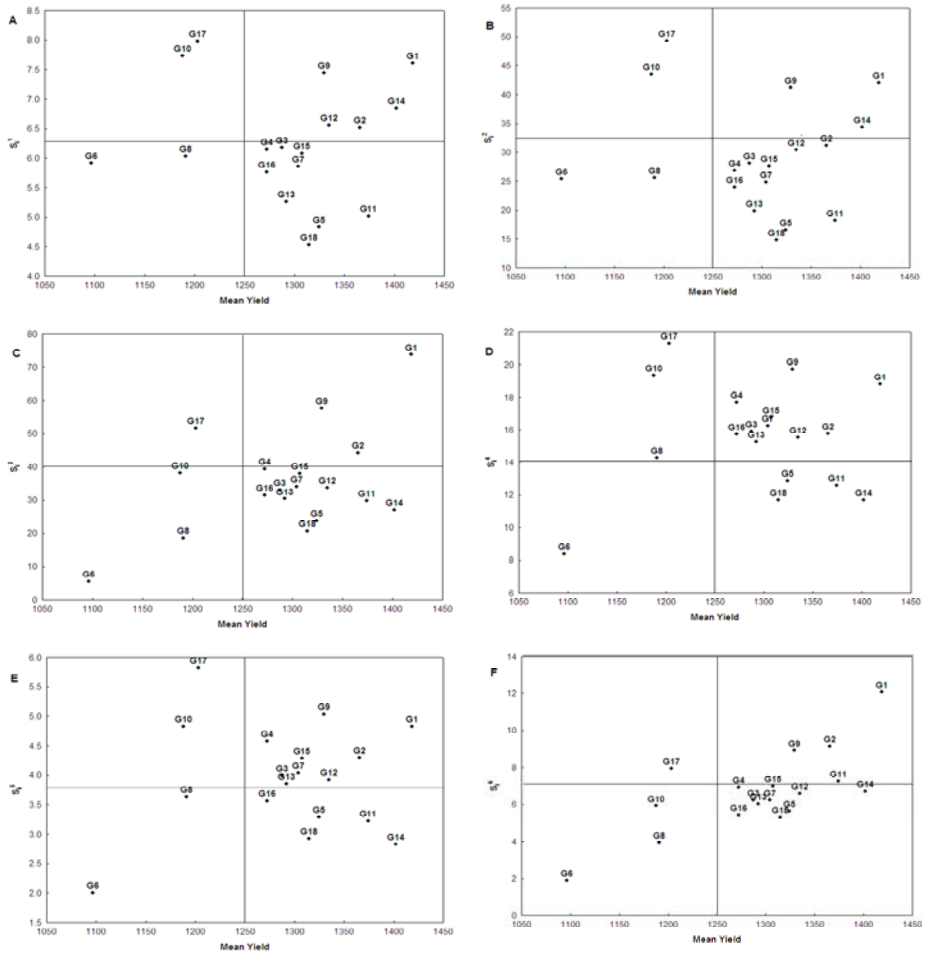

Figure 1: Plot of the mean yield versus Huehn's (1979) nonparametric stability statistics (A) $S_i^{(1)}$, (B) $S_i^{(2)}$, (C) $S_i^{(3)}$, (D) $S_i^{(4)}$, (E) $S_i^{(5)}$ and (F) $S_i^{(6)}$.

Figure 1A represents plot portrayed by mean yield values and $S_i^{(1)}$ nonparametric stability statistic. This figure is divided by grand mean yield and average $S_i^{(1)}$ values into four sections. Therefore studied lentil genotypes are classified as Group I, with stable low yield characteristics; Group II, with high yield stable genotypes; Group III, with unstable low yield properties; Group IV, with unstable high yielding genotypes (Table 6). Among these groups, only Group II is acceptable for recommending as the most favorable genotypes which are consist on G3, G4, G5, G7, G11, G13, G15, G16 and G18 (Table 6). According to Figure 1A, genotypes G2, G3, G4, G5, G7, G11, G12, G13, G15, G16 and G18 were identified as the most stable genotypes regarding both mean yield and $S_i^{(2)}$ nonparametric stability statistic.

Table 6: Grouping of 18 lentil genotypes based on mean yield and nonparametric stability statistics

	Group I	Group II	Group III	Group IV
$S_i^{(1)}$	G6, G7	Remained genotypes	G10, G17	G1, G2, G9, G12, G14
$S_i^{(2)}$	G6, G8	Remained genotypes	G10, G17	G1, G9, G14
$S_i^{(3)}$	G6, G8, G10	Remained genotypes	G17	G1, G2, G9
$\mathrm{S_i^{(4)}}$	G6	G5, G11, G14, G18	G8, G10, G17	Remained genotypes
$\mathrm{S_i^{(5)}}$	G6, G8	G5, G11, G14, G16, G18	G10, G17	Remained genotypes
$S_i^{(6)}$	G6, G8, G10	Remained genotypes	G17	G1, G2, G9, G11
$NP_i^{(1)}$	G6, G8	Remained genotypes	G10, G17	G1, G2, G9
$NP_i^{(2)}$	G6, G8, G10, G17	Remained genotypes	----	G1, G2
$NP_i^{(3)}$	G6, G8, G10, G17	Remained genotypes	----	G1, G2, G9, G14
$NP_i^{(4)}$	G6, G8, G10	G3, G5, G13, G16, G18	G17	Remained genotypes
σ_r	G6, G8	G5, G11, G14, G18	G10, G17	Remained genotypes
σ_{my}	G6, G8, G10, G17	----	----	Remained genotypes
RS	G5, G12, G13, G18	G2, G11, G14	----	G1, G9, G12
NSM	G17	Remained genotypes	G6, G8, G10	G3, G4, G7, G13, G16

Group I, Stable and low yield; Group II, Stable and high yield; Group III, Unstable and low yield; Group IV, Unstable and high yield

According to $S_i^{(3)}$ and $S_i^{(6)}$ nonparametric statistics, genotypes G6, G8 and G18 were the most stable genotypes while based on $S_i^{(4)}$ and $S_i^{(5)}$ nonparametric statistics, genotypes G6, G14 and G18 were the most stable genotypes (Table 5). Kang and Pham (1991) found that the $S_i^{(3)}$ and $S_i^{(6)}$ nonparametric statistics would be useful tools for selecting simultaneously for yield and yield stability while Ebadi-Segherloo et al. (2008) pointed out that the $S_i^{(4)}$ and $S_i^{(5)}$ nonparametric statistics were similar to the $S_i^{(1)}$ and $S_i^{(2)}$ statistics, and explore GE interaction with the biological concept of stability. Figure 1C showed that all genotypes expect G1, G2, G6, G8, G9, G10 and G17 were the most favorable genotypes based on $S_i^{(3)}$ and mean yield. According to Fig. 1D, genotypes G5, G11, G14 and G18 and according to Fig. 1E, genotypes G5, G11, G14, G16 and G18 were identified as the favorable genotypes with high mean yield and stability. Also, Figure 1F indicated that all genotypes expect G1, G2, G6, G8, G9, G10, G11 and G17 were the most favorable genotypes based on $S_i^{(6)}$ and mean yield. Finally, according to the most of the nonparametric stability statistics of Huehn (1979), genotypes G5, G6 and G18 were the most stable genotypes while based on the related figures and considering mean yield, genotypes G5, G11, G14, G15, G16 and G18 were the most favorable genotypes. It seems that using graphic presentation of the nonparametric statistics of Huehn (1979) which usually reflect static concept of stability could aid in detecting the most favorable genotypes with high mean yield and stability. Thus, genotypes G11 and G14 following to genotypes G5, G15 and G14 are recommended as the most favorable genotypes.

The nonparametric statistic $NP_i^{(1)}$ showed that genotypes G8, G11, G16 and G18 were the most stable genotypes while based on the nonparametric statistic $NP_i^{(2)}$, genotypes G6, G8, G16 and G18 were the most stable genotypes (Table 5). Many lentil genotypes (except G1, G2, G6, G8, G9, G10 and G17) were grouped in Group II and the most favorable genotypes considering $NP_i^{(1)}$ and mean yield (Figure 2A). Relatively, similar results were observed in Fig. 2B which identified the most favorable genotypes based on $NP_i^{(2)}$ and mean yield. According to the nonparametric statistic $NP_i^{(3)}$, genotypes G5, G6 and G8 were identified the most stable genotypes while the nonparametric statistic $NP_i^{(4)}$ indicated genotypes G6, G8 and G18 as the most stable genotypes (Table 5). Regarding mean yield and $NP_i^{(3)}$ (Figure 2C), all genotypes except G1, G2, G6, G8, G9, G10, G14 and G17 were as the most favorable genotypes while considering $NP_i^{(4)}$ and mean yield (Figure 2D), genotypes G3, G5, G13, G16 and G18 were detected as the most favorable genotypes.

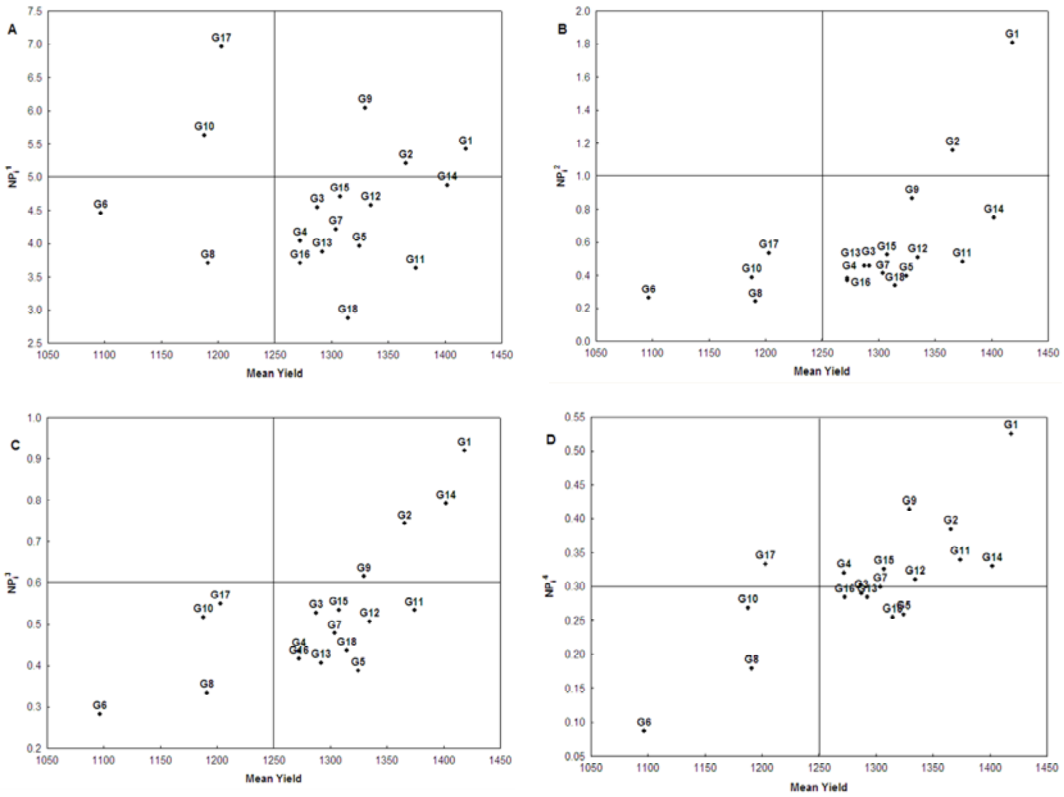

Figure. 2: Plot of the mean yield versus Thennarasu's (1995) nonparametric stability statistics (A) $NP_i^{(1)}$, (B) $NP_i^{(2)}$, (C) $NP_i^{(3)}$ and (D) $NP_i^{(4)}$

According to σ_r statistic of Ketata et al. (1989), genotypes G6, G14 and G18 were the most stable genotypes while based on σ_{my} statistic of Ketata et al. (1989), genotypes G6, G8 and G10 were the most stable genotypes (Table 5). Also, simultaneous considering of mean yield and σ_r statistic (Figure 3A), genotypes G5, G11, G14 and G18 were the most favorable genotypes while based on both mean yield and σ_{my} statistic (Fig. 3B), none of the studied genotypes were the most stable ones. Kang's (1988) rank-sum (RS) uses mean yield and Shukla's (1972) stability variance. According to the rank-sum statistic, G2, G5, G11 and G18 were the most stable genotypes (Table 5). Based on the plot of mean yield versus RS (Figure 3C), genotypes G2, G11 and G14 were the favorable stable genotypes. According to Fox et al. (1990), genotypes G1 and G2 were the most stable because they ranked in the top third of genotype in a high percentage of environments (58.3%), which were the high yield genotypes in this study with 1418.7 and 1365.6 kg ha^{-1}, respectively (Table 2). Considering all Top, Mid and Low statistics of nonparametric superiority measure (NSM), G1, G2 and G14 were the most stable genotypes.

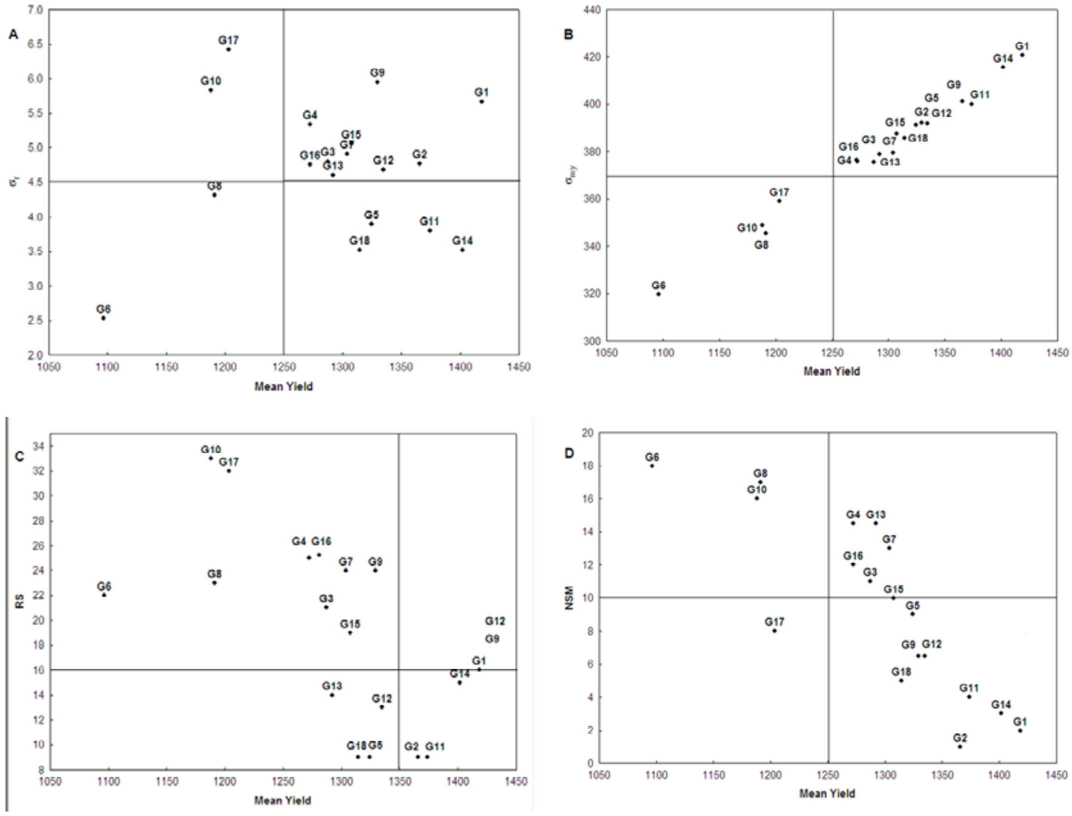

Figure 3: Plot of the mean yield versus nonparametric stability statistics (A) σ_r , (B) σ_{my} , (C) RS and (D) NSM

According to Figure 3D, genotypes G1, G2, G5, G9, G11, G12, G14, G15 and G18 were the favorable stable genotypes due to mean yield as well as Top, Mid and Low statistics of Fox et al. (1990). The rank correlation among the nonparametric stability statistics may indicate if more estimates should be obtained to improve confidence in the prediction of genotype behavior. The nonparametric stability statistics were compared using their ranks for each genotype (Table 7) via calculating Spearman's rank correlation. The rank correlation between the NSM and RS statistics with mean yield (Y) was positive and significant. Selecting the most stable genotypes based on these stability statistics result in high yielding genotypes were selected as the stable genotypes. In contrast, rank correlation between the $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and σ_{my} with mean yield (Y) were negative and significant. Therefore, the above mentioned procedures could not introduce the high mean yield genotypes as the most stable genotypes.

Table 7: Spearman's rank correlation coefficients between the nonparametric stability statistics for grain yield of 18 lentil genotypes

NSS¶	MY	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$\mathrm{S}_{\mathrm{i}}^{(4)}$	$\mathrm{S}_{\mathrm{i}}^{(5)}$	$S_i^{(6)}$	NSM	RS	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	σ_r
$S_i^{(1)}$	-0.02*													
$S_i^{(2)}$	-0.04	1.00												
$S_i^{(3)}$	-0.21	0.70	0.71											
$\mathrm{S}_{\mathrm{i}}^{(4)}$	0.12	0.69	0.69	0.91										
$\mathrm{S}_{\mathrm{i}}^{(5)}$	0.06	0.70	0.71	0.93	0.97									
$S_i^{(6)}$	-0.60	0.56	0.58	0.81	0.59	0.64								
NSM	0.89	-0.19	-0.21	-0.33	-0.01	-0.08	-0.68							
RS	0.69	0.47	0.45	0.36	0.63	0.51	-0.07	-0.07						
$NP_i^{(1)}$	-0.10	0.91	0.93	0.73	0.69	0.71	0.61	0.61	0.36					
$NP_i^{(2)}$	-0.71	0.56	0.59	0.68	0.43	0.49	0.90	0.90	-0.23	0.68				
$NP_i^{(3)}$	-0.64	0.65	0.68	0.68	0.47	0.49	0.86	0.86	-0.08	0.68	0.89			
$NP_i^{(4)}$	-0.66	0.53	0.55	0.76	0.53	0.56	0.98	0.98	-0.07	0.56	0.90	0.88		
σ_r	0.12	0.68	0.68	0.91	1.00	0.97	0.58	0.58	0.62	0.68	0.42	0.46	0.52	
σ_{my}	-0.98	0.08	0.09	0.30	-0.03	0.03	0.66	0.66	-0.62	0.17	0.75	0.67	0.71	-0.04

NSS, Nonparametric Stability Statistics

* Critical vales of correlation P<0.05 and P<0.01 (D.F. 16) are 0.47 and 0.59, respectively

According to Table 7, the rank correlations among the six nonparametric stability statistics ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(4)}$, $S_i^{(5)}$ and $S_i^{(6)}$) of Huehn (1979) with each other were positive and significant. Similar results were obtained in maize (*Zea mays* L.) by Scapim et al. (2010) and in wheat (*Triticum aestivum* L.) by Kaya and Taner (2002). Also, $S_i^{(1)}$ $S_i^{(2)}$ $S_i^{(3)}$ and statistics show high significant and positive correlations with the other remained nonparametric stability statistics expect NSM, RS, $NP_i^{(4)}$ and σ_{my}. It is interesting that these statistics had positive significant correlations with NSM and RS. The, $S_i^{(4)}$ $S_i^{(5)}$ and $S_i^{(6)}$ stability statistics showed positive significant correlation with $NP_i^{(4)}$ and σ_r (Table 7). In agreement with our results, Flores et al. (1998) found high correlations between $S_i^{(3)}$ and $S_i^{(6)}$ in faba bean (*Vicia faba* L.) and pea (*Pisum sativum* L.) multi environmental trials.

The NSM nonparametric superiority statistic of Fox et al. (1990) had significant positive correlation with mean yield, σ_r and all NP_i s (Table 7). Kang's (1988) rank-sum (RS) statistics indicated significant positive correlation with mean yield, $S_i^{(4)}$ and σ_r. In contrast, Ebadi-Segherloo et al. (2008) found no significant correlations among RS and the other nonparametric procedures. This opposite finding could be result of the different nature of the studied crops, environmental conditions (climatic and edaphic factors) or diverse genetic background obtained from different sources. All four NP_i s except $NP_i^{(4)}$ had significant positive correlation with each other but σ_{my} of Ketata et al. (1989) had significant positive correlation with, $S_i^{(6)}$ NSM, $NP_i^{(1)}$, $NP_i^{(2)}$ and $NP_i^{(3)}$ (Table 7). Sabaghnia et al. (2006) found high correlations between $NP_i^{(2)}$ and $NP_i^{(4)}$ in multi environmental trials of lentil.

4 DISCUSSION

In this investigation, interpretation of the GE interaction was based on nonparametric statistical procedures. The former method (ANOVA) had shown certain deficiencies for determining GE interaction types while nonparametric tests can determine the additive or crossover types of GE interaction. However, both interaction types were observed in lentil multi-environment trials. The presence of GE interaction is expressed either as inconsistent responses of genotypes relative to others due to genotypic rank change or as changes in the absolute differences between genotypes without rank change (Annicchiarico, 2002). In these situations, the risk of selecting inferior genotypes from the use of non-parametric measures is minimal. However, the highly significant GE interaction indicate the necessity for multiple environmental testing if the relative performance of lentil genotypes is to be accurately assessed for a large geographic region (DeLacy et al., 1996; Akcura and Kaya, 2008).

Lentil growing in field can be influenced by genetic, environmental and their interaction effects. The climatic factors were the main causes which could affect the expression of genes for the quantitative traits of lentil such as grain yield under different environments (Sabaghnia et al., 2008). Thus, the GE interaction complicates the interpretation of multi-environment trials in plant breeding programs. Understanding the magnitude of G and GE interaction effects is useful for improving the efficiency of breeding efforts and is helpful for plant breeders to select the better genotypes of lentil which can be steadier in various environments. The results in this study showed that the GE interaction is more important in rain fed condition and it must be paid more attention to the GE interaction during the lentil breeding in arid and semi-arid areas.

An ideal lentil genotype should have a high mean yield combined with a low degree of fluctuation under different environments. There are two important concepts of stability as static and dynamic (Becker and Leon, 1988; Rose et al., 2008). Static stability is analogous to the biological concept or homeostasis and in this concept a stable genotype tends to maintain a constant yield across different environments. In contrast, a stable genotype with dynamic stability concept has a yield response which is parallel to the mean response of the tested genotypes. Most of the nonparametric stability statistics have static or biologic concept of stability and usually introduce low or moderate yielding genotypes as the most stable ones. However, this type of stability is not acceptable to most plant breeders, who would prefer to select the high mean yielding genotypes as the most stable genotypes.

Simultaneous consideration of both mean yield and stability would be useful for selecting the most favorable genotypes (Kang, 1998; Karimizadeh etal., 2012). It seems that plotting mean yield versus each of the nonparametric stability statistics helps in identification of high mean yield and the most stable genotypes. Our results demonstrated the utility of this hypostasis and determined the most favorable genotypes. In each graph, the studied genotypes were classified into four distinct groups which only one group could be regarded as the most favorable genotype (high mean yield and the most stable genotype). According to most of the generated figures, genotypes G2, G3, G5, G11, G14, G16 and G18 were the most favorable genotypes. Among these favorable genotypes, G2, G11 and G14 following to G5, G16 and G18 are good candidates for commercial release. Thus, the stability property alone is of limited use and for a successful genotype testing program, both yield stability and mean yield must be considered simultaneously.

There are different forms to the GE interaction, and the different methods may quantify different components of the GE interaction. Besides being robust to violations of statistical assumptions regarding the dataset distribution, and insensitive to outliers, nonparametric rank-based procedures are of value for elucidating meaningful ways that environments differentially affect the seed yield (Huehn, 1996; Sabaghnia et al., 2012). Using rank-based procedures for GE interaction study and yield stability analysis, there were not consistent rankings of genotypes across environments, and environment affected the rank order of lentil genotypes. Thus, the lentil data analyzed here suggested that differences in yield of genotypes or environmental conditions were relatively great enough to affect the rank order of genotypes in different environments. Mohebodini et al. (2006) find a significant GE interaction for lentil grain yield based on the different parametric procedures (i.e., normal distribution assumption) analysis, their results are not inconsistent with ours. As stated by Sabaghnia et al. (2008), most of the GE interaction in multi-environment trials appears to result from changes in the magnitude of differences among genotypes across test environment as well as changes in rankings. The rank-based procedures serve as convenient tools to specifically detect situations where the ranks do change with environment. The methods discussed here can be used for any study where the different crops are tested in each of several environments (different locations and/or years). Finally, the following findings can be summarized from this investigation: (1) G2 (FLIP 92-12L), G11 (Gachsaran) and G14 (ILL 6206) were found to be the most stable and high mean yielding genotype and thus recommended for commercial release; (2) the graphic investigation of yield stability using mean yield versus different nonparametric stability statistics was found to be useful in detecting the phenotypic stability of the studied genotypes; and (3) the significant GE interactions suggest a breeding strategy of specifically adapted genotypes in homogeneously grouped environments.

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