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Using Huehn's Nonparametric Stability Statistics to Investigate Genotype × Environment Interaction

Rahmatollah KARIMIZADEH[1*], Mohtasham MOHAMMADI[1], Naser SABAGHNIA[2], Mohammad Kazem SHEFAZADEH[3]

[1]*Dryland Agriculture Research Institute, Gachsaran Agriculture Research Station P.O. Box. 178, Kohgiloyeh va Boyerahmad Province, Gachsaran, Iran; Karimizadeh_ra@yahoo.com (*corresponding author)*

[2]*University of Maragheh, Faculty of Agriculture, Department of Agronomy and Plant Breeding, Maragheh, Iran*

[3]*Islamic Azad University, Yasooj branch, Department of Agronomy, Yasooj, Iran*

Abstract

Genotype × environment interaction (GEI) is of special interest in breeding programs to identify adaptation targets and test locations as well as to determine the most favorable genotypes. There are several nonparametric procedures used to interpret the GEI in multi-environmental trials. The purposes of this investigation were (i) to compare the effect of correction on Huehn's nonparametric stability statistics and (ii) to use nonparametric statistics for a GEI study on lentil. Nine improved lentil genotypes and one local cultivar were grown in 5 sites during two consecutive years. Results of the nonparametric analysis demonstrated both additive and crossover GEIs. According to uncorrected nonparametric statistics, genotypes G8 and G9 were the most stable and based on corrected nonparametric statistics of Huehn, genotypes G1, G2 and G10 were the most stable. In this investigation, mean of ranks (MR) and coefficient of variation of ranks (CV) with $S_i^{(6)}$ were associated with high mean yield (within the dynamic concept of stability), but the other nonparametric statistics were not positively correlated with mean yield and were identified within a static concept of stability. Results also indicated that corrected nonparametric statistics were not suitable for simultaneous selection of mean yield and stability. Such an outcome could be used to delineate predictive, more rigorous recommendation strategies as well as to help define stability concepts to identify recommendations for lentil and other crops.

Keywords**:** biologic stability, dynamic stability, lentil, nonparametric statistics, yield stability

Introduction

Most statistical procedures assume that data follow a certain distribution, especially normal distribution. These procedures are known as parametric statistics and estimate population parameters (such as mean and standard deviation) that delineate the underlying distribution of a dataset (Steel and Torrie, 1980). In some cases a specific form of distribution is not known so then suitable transformation is applied to make data normal; however transformed data does not always fulfill an assumption of normality (Cochran and Cox, 1957).

There are some other statistical procedures, which do not make tight assumptions about distribution of data and are known as distribution free or nonparametric methods (Huehn, 1979). Nonparametric statistical procedures make use of nominal and ordinal scales so data are arranged in an ascending order and then assigned ranks according to those observations (Bredenkamp, 1974; Spearman, 1904). Ranking classifies observations according to their values but not to their absolute differences. However, nonparametric procedures are used less often then parametric procedures despite certain advantages (Kubinger, 1986).

Genotype by environment interactions (GEI), have assumed importance in plant breeding programs because the yield performance of a genotype is the result of both genotype and environment and their interaction. GEI results from changes in the magnitude of differences between genotypes in different environments (Falconer and Mackay, 1996). Environmental factors such as precipitation, temperature and soil play important roles in genotype yield performance. GEI makes it difficult to select the most favorable genotypes but is an important consideration in plant breeding programs because it reduces the constraint that results from selection according to any one particular environment (Yau, 1995).

Several nonparametric procedures have been developed to interpret the GEI in multi-environmental trials (MET). Huehn (1979), Ketata *et al.* (1989), Fox *et al.* (1990), Huehn (1990b) and Thennarasu (1995) proposed several nonparametric indices of stability and GEI studies. Also, Bredenkamp (1974), Hildbrand (1980), de Kroon and van der Laan (1981) and Kubinger (1986) have proposed some procedures to test the GEI instead of the conventional analysis of variance. Among these nonparametric procedures, Huehn's (1979, 1990b) statistics have been used widely to determine whether or not genotypes evaluated in MET are stable (Flores *et al.,* 1998; Hussein *et al.,* 2000; Lin *et al.,* 1986; Liu *et al.*, 2010; Sabaghnia *et al.*, 2006).

Firstly, Huehn (1979) developed six nonparametric stability methods using yield to rank genotypes in different environments. This method was later developed to incorporate the statistical properties and significance for the two first nonparametric methods (Z_1, Z_2) given by Nassar and Huehn (1987). Huehn (1990b) proposed the use of corrected means instead of original means for rank determination. Therefore, ranks of genotypes in each environment were corrected according to adjusted values, which will be described in the next section. Huehn (1990b) used this correction only on the three nonparametric measures of phenotypic stability that were previously introduced and discussed in Huehn (1979). The mentioned measures were $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ statistics while the $S_i^{(3)}$ statistic was reintroduced instead of the sixth measure of stability in Huehn (1979). It is necessary to mention that this $S_i^{(2)}$ statistic was different from the equivalent statistics of Huehn (1979) and so it was assigned it as $S_i^{(7)}$ statistic. Although, a few authors (Dehghani, 2008; Kang and Pham, 1991) have used nonparametric measures of phenotypic stability introduced by Huehn (1979) only relatively few (Ebadi-Segerloo *et al.,* 2008; Flores *et al.,* 1998; Kaya and Taner, 2002; Sabaghnia *et al.,* 2006) have used nonparametric measures of stability as proposed and discussed in Huehn (1990a, b). However, it seems that it is necessary to follow these procedures, evaluating the effect of correction on each of them and to conduct a comprehensive discussion about their natures.

Many papers have used nonparametric stability statistics to analyze GEI in agricultural trials. Plant breeders worldwide have been interested in using nonparametric stability statistics due to their potential returns relative to stability parameters. What has not yet been produced, however, is an evaluation and comparison of various nonparametric statistics for stability analysis. The objective of this investigation was to study the effect of correction on Huehn's nonparametric measures of phenotypic stability and their comparison.

Materials and methods

Plant materials

This research data set involved 10 lentil genotypes tested in 10 environments (five locations during two years), extracted from the Iran lentil performance trial programs. Nine lentil genotypes were selected from the ICARDA lentil improvement program, one of which (G10) was the check cultivar ('Gachsaran'). Genotype names, pedigrees and origin of their parental lines are given in Tab. 1. Trial sites were selected to sample climatic and edaphic conditions likely to be encountered in lentil growing areas and to vary in agro-climatic factors. The experimental characteristics of the test sites are given in Tab. 2. Shirvan and Gonbad, in northeast Iran, were characterized by semi-arid conditions and had complex soil series of silty, clay and loam soil. Kermanshah and Ilam, in western Iran, had moderate rainfall and silt loam soil. Gachsaran, in south western Iran, was relatively arid and had silt loam soil.

In all trials seeds were sown in the winter (February), which is the optimal sowing time for lentil in test sites.

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

Code	Location	Altitude (meter)	Longitude/Latitude	Soil texture	Rainfall (mm)	Yield (kg ha^{-1})
1	Gonbad	45	55°12' E/37°16' N	Silty Clay Loam	367	767
2	Kermanshah	1351	47°19' E/34°20' N	Clay Loam	455	1923
3	Ilam	975	46°36' E/33°47' N	Clay Loam	350	805
4	Gachsaran	710	50°50' E/30°20' N	Silty Clay Loam	460	1747
5	Shirvan	1131	58°07' E/37°19' N	Loam	267	384

Tab. 2. Mean yield and origin of the 10 lentil genotypes, studied in 10 environments

Code	Name	Yield (kg ha^{-1})	Pedigree	Origin of parents
G1	'FLIP 97-1L'	1187.73	ILL 5989 × ILL6199	ICARDA × ICARDA
G2	'FLIP 82-1L'	1145.10	Landrace	ICARDA
G3	'FLIP 92-15L'	989.10	ILL 5588 × ILL5714	ICARDA × ICARDA
G4	'FLIP 96-9L'	997.15	ILL 6199 × ILL 6198	ICARDA × ICARDA
G5	'FLIP 92-12L'	1168.70	ILL 5582 × ILL 707	Jordan × Cyprus
G6	'FLIP 96-4L'	1152.93	ILL 467 × ILL 45	Chile × Syria
G7	'ILL 7946'	1107.65	ILL 6209 × ILL5671	ICARDA × ICARDA
G8	'ILL 6037'	1200.23	ILL 4349 × ILL 4605	Canada × Argentina
G9	'ILL6199'	1267.83	ILL LL 9755746	ICARDA × Chile
G10	'Gachsaran'	1002.30	Cultivar	Iran

The experimental design, at each environment (site × year combination), was a randomized complete block with four replicates. Planting was done according to local practice with a planting rate of about 50 seeds m^{-2}. Plot size was 4 m^2; each plot contained four 4 m long rows with 25 cm between each row. Appropriate pesticides were used to control insects, weeds and diseases, and appropriate fertilizers were applied (at recommended rates usual for the site × year). The harvested plot size was 1.75 m^2 (two 3.5^{-m} rows at the center of each plot). Mean grain yield was estimated for each genotype at each site × year.

Huehn's nonparametric stability statistics

Huehn (1979) proposed six *nonparametric* methods for assessing GEI and stability analysis. For a two-way dataset with *k* genotypes and *n* environments, it was denoted the phenotypic value of *i*th genotype in *j*th environment as 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 $\bar{r}_{ij}$ as the mean rank across all environments for the *i*th genotype. The nonparametric stability statistic $S_i^{(4)}$ is similar to that of Yau and Hamblin (1994), which used relative yield not only to give equal weight to each environment, but also to provide a measure of yield stability. The method of Yau and Hamblin (1994) expresses the yield of each genotype, in each environment, in a way relative to the average of the environment in which it was determined, assigning the value 100 to the latter. Statistics based on yield ranks of genotypes in each environment were expressed as follows:

$$S_i^{(1)} = 2\sum_{j}^{n-1} \sum_{j=j+1}^{n} \left| r_{ij} - r_{ij'} \right| / [\mathrm{n}(\mathrm{n}-1)]$$

$$S_i^{(2)} = \sum_{j=1}^{n} (r_{ij} - \bar{r}_i)^2 / \sum_{j=1}^{n} \left| r_{ij} - \bar{r}_{i.} \right|$$

$$S_i^{(3)} = \frac{\sum_{j=1}^{n} (r_{ij} - \bar{r}_{i.})^2}{\bar{r}_{i.}}$$

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

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

$$S_i^{(6)} = \frac{\sum_{j=1}^{n} \left| r_{ij} - \bar{r}_{i.} \right|}{\bar{r}_{i.}}$$

Huehn (1990b) proposed the correction $[x_{ij}^{*} = x_{ij} - (\bar{x}_{ij} - x_i)]$ where in a two-way dataset with k genotypes and n environments, it was denoted the phenotypic value of ith genotype in jth environment as x_{ij} , x_{ij}^{*} is the corrected phenotypic value; $\bar{x}_{ij}$ is the grand mean and $x_{i..}$ is the mean of genotype i in all environments. Huehn (1990b) used this correction on the two nonparametric measures consists on $S_i^{(1)}$ and $S_i^{(6)}$ and a new nonparametric statistics as $S_i^{(2)}$ while it was used term $S_i^{(7)}$ with this formula:

$$S_i^{(7)} = \sum_{j=1}^{n} (r_{ij} - \bar{r}_i)^2 / (\mathrm{n}-1)$$

These seven mentioned nonparametric measures of phenotypic stability were calculated according to original (uncorrected) and corrected datasets.

Lu (1995) developed a SAS-based computer program that computed the first two nonparametric measures of Huehn (1990b). A comprehensive SAS program called SASGESTAB (Hussein *et al.,* 2000) is available that calculates two nonparametric stability statistics of Huehn (1990b) and $S_i^{(6)}$ of Huehn (1979). Both of these, SAS programs and Microsoft Excel, were used to calculate different uncorrected and corrected nonparametric stability statistics.

Results and discussion

Analysis of variance

A combined analysis of variance showed high significance of GE (genotype × site × year) interaction (Tab. 3). The main effect of year was not significant but the main effect of year and site × year interaction effects were highly significant. The genotype × site genotype interaction effect was highly significant but the × site × year interaction effect was not significant (Tab. 3). The environment effect (year, site and site × year interaction) explained 89.5 percent of the total variation due to G+E+GE. Genotype main effect expressed only 1.87 percent of the total variation while GEI (genotype × site, genotype × year and genotype × site × year) expressed 8.64 percent of the total variation due to G+E+GE. Although the measured yield was a combined result of the effects of genotype, environ-

Tab. 3. Analysis of variance for seed yield of 10 lentil genotypes

Source	df	Mean squares	PC†
Year (Y)	1	1431612.3^{ns}	0.81
Site (S)	4	36527808.4^{**}	82.17
Y × S	4	2899551.5^{**}	6.52
Replication within (S × Y)	30	120655.0	
G	9	369593.3^{**}	1.87
G × S	36	301718.9^{**}	6.11
G × Y	9	47017.9^{ns}	0.24
G × S × Y	36	113022.2^{**}	2.29
Pooled Error	270	51214.0	

† Percentage contribution of Environment (Year, Site and Y × S), Genotype and Genotype by environment interaction (G × S, G × Y and G × S × Y) to sum of squares of them (Environment+ Genotype+GE). **, * and ns, respectively significant at the 0.01and 0.5 probability level and non-significant

ment and their interaction, only G and GE were relevant to the genotype evaluation (Dehgahni *et al.,* 2009; Sabaghnia *et al.,* 2008). Typically, environment explains most (80% or higher) of the total yield variation, while genotype and GEI are usually small (Yan and Kang, 2003). The results in this investigation were in agreement with other reports of multi-environmental trials. However, effective interpretation and utilization of a multi-environmental trial dataset in making selection decisions remains a major challenge to researchers.

Results of the alternative analysis of variance (nonparametric statistical procedures) are presented in Tab. 4. The null hypothesis of Bredenkamp, Hildbrand and Kubinger tests has no additive GEI while the null hypothesis of van der Laan-de Kroon test has no crossover GEI. Results of these indicated that both significant additive and crossover interactions were found in grain yield of 10 lentil genotypes tested across five locations according to Bredenkamp, Hildbrand and Kubinger procedures (for additive) and the van der Laan-de Kroon test (for crossover). These findings are in agreement with the conventional ANOVA, but provided more specific information such as the additive or crossover nature of the GEI (Sabaghnia *et al.,* 2006).

Nonparametric stability statistics

According to mean yield, genotype G9 (1267 kg ha^{-1}) was the highest yielding genotype, although remarkable differences were not evident among the studied lentil genotypes (Tab. 5). It has been suggested that, in unfavorable environments such as rain-fed conditions, plant breeders should look at GEI in a different way (Stroup *et al.,* 1993). Yield stability is more important than mean yield in an unfavorable environment. According to Ceccarelli (1996), in an unfavorable environment, the lowest mean yield of landraces was always higher than the lowest mean yield of non-landraces. This particular property of landraces is identifiable as stability by farmers but it would have been missed in a selection process within a breeding program to select landraces for unfavorable environments (Ceccarelli, 2000).

Tab. 4. Analysis of GEI using different nonparametric tests on 10 lentil genotypes grown in 10 environments

Nonparametric tests	df	Statistic χ^2	P-value
Bredenkamp	81	156.77^{**}	<0.001
Hidebrand	81	164.82^{**}	<0.001
Kubinger	81	168.25^{**}	<0.001
de Kroon-van der Laan	81	153.96^{**}	<0.001

** Significant at the 0.01 level

The following three descriptive statistics; mean of ranks (MR), standard deviation of ranks (SD) and coefficient of variation of ranks (CV) were calculated for original ranks (Tab. 5). According to these statistics, genotypes G8 and G9 were the most stable, while genotypes G3, G4 and G10 based on MR, genotypes G5 and G6 based on MR and genotypes G3 and G4 based on MR, were identified as the most unstable (Tab. 5). It seems that these simple descriptive statistics based on rank can be used for genotype evaluation. Ketata *et al.* (1989) proposed two ranking methods according to mean and standard deviation of ranks and Cravero *et al.* (2010) reported advantages of these nonparametric procedures in phenotypic stability studies.

All seven nonparametric measures of phenotypic stability ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(4)}$, $S_i^{(5)}$, $S_i^{(6)}$, and $S_i^{(7)}$) proposed by Huehn (1979, 1990b) were calculated based on original datasets and indicated that genotypes G8 and G9 were the most stable, however in most stability statistics, genotype G5 was identified as the most unstable genotype (Tab. 6). It seems that more stable genotypes according to Huehn's (1979, 1990b) nonparametric measures of stability from calculations based on uncorrected values demonstrated high mean yield. In other words, with maintenance of genotype effect in each cell of two-way data, mean yield confounds GEI and affects stability analysis.

Simultaneous selection for both mean yield and stability is an important consideration in breeding programs

Tab. 5. Three descriptive statistics of ranks and seven nonparametric stability statistics based on original values for seed yield of 10 lentil genotypes evaluated in 10 environments

Genotypes	MR	SD	CV	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(4)}$	$S_i^{(5)}$	$S_i^{(6)}$	$S_i^{(7)}$
G9	7.90	1.73	0.22	1.89	3.16	3.41	1.64	1.14	1.44	2.99
G8	6.50	2.07	0.32	2.47	3.47	5.92	1.96	1.70	2.62	4.28
G1	6.40	2.63	0.41	3.02	4.59	9.75	2.50	2.12	3.31	6.93
G5	6.60	3.60	0.54	4.18	6.19	17.64	3.41	3.08	4.67	12.93
G6	5.95	3.10	0.52	3.66	5.24	14.49	2.94	2.65	4.45	9.58
G2	5.55	2.91	0.52	3.29	4.82	13.73	2.76	2.45	4.41	8.47
G7	5.40	2.55	0.47	3.02	4.29	10.81	2.42	2.12	3.93	6.49
G10	3.70	2.16	0.58	2.51	3.73	11.38	2.05	1.90	5.14	4.68
G4	3.70	2.54	0.69	2.96	4.37	15.70	2.41	2.10	5.68	6.46
G3	3.30	2.50	0.76	2.73	4.56	17.00	2.37	1.82	5.52	6.23

MR is the mean of ranks, SD is the standard deviation of ranks and CV is the coefficient of variation of ranks

Tab. 6. Three descriptive statistics of ranks and seven nonparametric stability statistics based on corrected values for seed yield of 10 lentil genotypes evaluated in 10 environments

Genotypes	CMR	CSD	CCV	$CS_i^{(1)}$	$CS_i^{(2)}$	$CS_i^{(3)}$	$CS_i^{(4)}$	$CS_i^{(5)}$	$CS_i^{(6)}$	$CS_i^{(7)}$
G9	5.00	3.20	0.64	3.82	5.35	18.40	3.03	2.60	5.20	10.22
G8	4.50	3.03	0.67	3.53	5.19	18.33	2.87	2.50	5.56	9.17
G1	5.60	2.63	0.47	3.07	4.52	11.14	2.50	2.00	3.57	6.93
G5	5.70	3.56	0.62	4.20	6.04	20.02	3.38	3.10	5.44	12.68
G6	5.30	3.30	0.62	3.89	5.61	18.51	3.13	2.90	5.47	10.90
G2	5.40	2.59	0.48	3.07	4.38	11.19	2.46	2.20	4.07	6.71
G7	5.50	2.72	0.49	3.22	4.59	12.09	2.58	2.20	4.00	7.39
G10	6.30	2.50	0.40	2.96	4.22	8.90	2.37	1.90	3.02	6.23
G4	5.70	3.20	0.56	3.84	5.32	16.16	3.03	2.70	4.74	10.23
G3	6.00	2.94	0.49	3.47	5.00	13.00	2.79	2.40	4.00	8.67

MR is the mean of ranks, SD is the standard deviation of ranks and CV is the coefficient of variation of ranks

(Yan and Kang, 2003). Kang and Pham (1991) studied several stability methods for simultaneous selection for yield and stability. Furthermore, Kang (1988) proposed a nonparametric stability statistic named as rank-sum using stability variance of Shukla (1972) and genotype mean rank. A greater emphasis on stability during a selection process would be beneficial to agronomists (Kang, 1993). Finally it can be expressed that, there is good potential in nonparametric stability methods for identification of favorable genotypes in plant breeding programs. These methods thus provide a lot of flexibility for plant breeders for the simultaneous selection for both mean yield and stability.

According to Tab. 6, genotype G10 following genotypes G1 and G2 were the most stable based on a corrected dataset that produced a mean of corrected ranks (CMR), standard deviation of corrected ranks (CSD), coefficient of variation of corrected ranks (CCV) and all seven of Huehn's (1979, 1990b) nonparametric measures of stability ($CS_i^{(1)}$, $CS_i^{(2)}$, $CS_i^{(3)}$, $CS_i^{(4)}$, $CS_i^{(5)}$, $CS_i^{(6)}$ $CS_i^{(7)}$). Also genotypes G5 and G6 were identified as the most unstable based on the above mentioned nonparametric measures of phenotypic stability (Tab. 6). In the mentioned strategy, the following concept of stability was applied; it determines the stability of genotype over environment if its rank is similar over other environments (biological concept). Many authors that have used the corrected Huehn's (1979, 1990b) nonparametric measures of phenotypic stability and demonstrated that these statistics were associated with the biological concept of stability (Ebadi-Segerloo *et al.,* 2008; Flores *et al.,* 1998; Kaya and Taner, 2002; Sabaghnia *et al.,* 2006).

To group genotypes according to mean yield and different nonparametric measures of phenotypic stability, a hierarchical cluster analysis with squared Euclidean

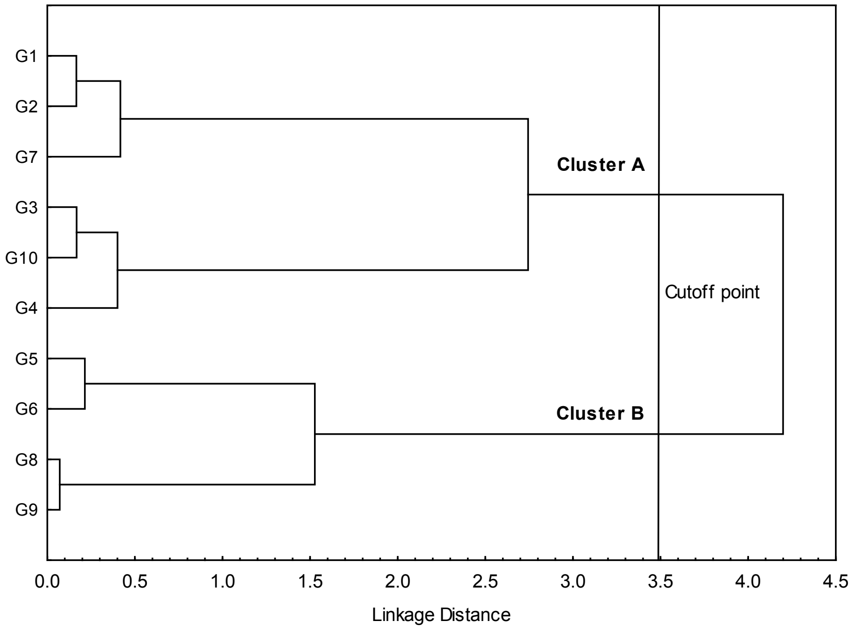

Fig. 1. Hierarchical cluster analysis of the 10 lentil genotypes based on Ward's method

Tab. 7. Spearman's rank correlation coefficients among 20 nonparametric stability statistics for seed yield of 10 lentil genotypes

	Y	MR	SD	CV	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(4)}$	$S_i^{(5)}$	$S_i^{(6)}$	$S_i^{(7)}$	CMR	CSD	CCV	$CS_i^{(1)}$	$CS_i^{(2)}$	$CS_i^{(3)}$	$CS_i^{(4)}$	$CS_i^{(5)}$	$CS_i^{(6)}$
MR	0.96*																			
SD	0.09	-0.05																		
CV	0.89	0.77	0.24																	
$S_i^{(1)}$	0.12	-0.04	0.99	0.25																
$S_i^{(2)}$	0.16	0.02	0.95	0.39	0.94															
$S_i^{(3)}$	0.64	0.44	0.60	0.86	0.61	0.72														
$S_i^{(4)}$	0.09	-0.05	0.99	0.24	1.00	0.95	0.60													
$S_i^{(5)}$	0.09	-0.05	0.98	0.23	0.99	0.90	0.56	0.98												
$S_i^{(6)}$	0.87	0.75	0.26	0.98	0.27	0.38	0.85	0.26	0.26											
$S_i^{(7)}$	0.09	-0.05	0.99	0.24	1.00	0.95	0.60	1.00	0.98	0.26										
CMR	-0.74	-0.66	-0.13	-0.83	-0.13	-0.23	-0.61	-0.13	-0.14	-0.80	-0.13									
CSD	-0.29	-0.46	0.24	-0.02	0.24	0.26	0.33	0.24	0.20	0.05	0.24	0.27								
CCV	-0.53	-0.60	-0.18	-0.39	-0.17	-0.18	-0.13	-0.18	-0.21	-0.35	-0.18	0.66	0.81							
$CS_i^{(1)}$	-0.22	-0.40	0.27	0.04	0.28	0.29	0.39	0.27	0.23	0.12	0.27	0.25	0.99	0.80						
$CS_i^{(2)}$	-0.33	-0.50	0.21	-0.07	0.22	0.24	0.28	0.21	0.17	-0.01	0.21	0.30	1.00	0.82	0.98					
$CS_i^{(3)}$	-0.38	-0.55	0.19	-0.13	0.20	0.21	0.25	0.19	0.15	-0.08	0.19	0.41	0.97	0.88	0.96	0.98				
$CS_i^{(4)}$	-0.29	-0.46	0.24	-0.02	0.24	0.26	0.33	0.24	0.20	0.05	0.24	0.27	1.00	0.81	0.99	1.00	0.97			
$CS_i^{(5)}$	-0.21	-0.40	0.29	0.06	0.30	0.32	0.42	0.29	0.25	0.13	0.29	0.27	0.98	0.79	0.99	0.97	0.96	0.98		
$CS_i^{(6)}$	-0.50	-0.58	0.09	-0.31	0.10	0.09	0.02	0.09	0.07	-0.26	0.09	0.68	0.79	0.92	0.80	0.79	0.88	0.79	0.83	
$CS_i^{(7)}$	-0.24	-0.41	0.26	0.02	0.27	0.28	0.37	0.26	0.22	0.10	0.26	0.24	1.00	0.79	1.00	0.99	0.95	1.00	0.98	0.78

* Critical values of correlation at 5% and 1% level of significance (D.F. 8) are 0.63 and 0.76, respectively

distance as dissimilarity measure and Ward's method was performed (Fig. 1). The square root of the SS difference between values for lentil genotypes was used as Euclidean distance. In Ward's procedure, the dissimilarity between two clusters is shown by the "loss of information" from joining the two clusters with this loss of information measured by the increase in error sum of squares. The cluster analysis revealed two distinct clusters among ten genotypes: cluster A consisted of genotypes G1, G2, G3, G4, G7 and G10 as the most favorable, and cluster B consisted of genotypes G5, G6, G8 and G9 as the most unfavorable. Finally it seems that according to corrected statistics, genotypes G1, G2 and G10 were the most stable, but when based on uncorrected statistics, genotypes G8 and G9 were the most stable. Regarding mean yield regardless of stability, the most favorable genotypes were G2, G8 and G9.

Therefore they can be presented as good candidates for commercial release in dry areas of Iran and other similar areas of the Middle East.

Relationship among nonparametric statistics

Each one of these nonparametric statistics produced a unique genotype ranking and the Spearman's rank correlations between each pair were then calculated (Tab. 7). According to results of rank correlations there was a highly significant (p<0.01) positive rank correlation between mean yield with MR, CV and $S_i^{(6)}$ significant (p<0.05) positive rank correlation with $S_i^{(3)}$. Also mean yield had a highly significant negative rank correlation with CMR while there was no significant positive or negative rank correlation with other nonparametric stability statistics (Tab. 7). These findings indicate the good potential of $S_i^{(3)}$ and $S_i^{(6)}$ (in form of uncorrected statistics) for selecting the most stable high yielding genotypes. Kang and Pham (1991) reported similar results for both $S_i^{(3)}$ and $S_i^{(6)}$ statistics and found that $S_i^{(6)}$ was the more strongly correlated with mean yield and less with stability statistics than $S_i^{(3)}$. Furthermore, nonparametric statistics were reviewed by Becker and Leon (1988) and their statistical properties were determined as agronomical concepts for stability. The effect of correction and removing the genotype effect is clear on the negative association between mean yield and CMR.

Mean rank (MR) had a highly significant positive rank correlation with CV and $S_i^{(6)}$ while it had a significant negative rank correlation with CMR and had no significant positive or negative rank correlation with the other nonparametric stability statistics (Tab. 7). The standard deviation of ranks (SD) showed highly significant (p< 0.01) positive rank correlation with $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(4)}$, $S_i^{(5)}$ and $S_i^{(7)}$ statistics. It seems that CV was the best parameter among the three descriptive statistics (MR, SD and CV) because it had significantly high (p<0.01) positive rank correlation with $S_i^{(3)}$ and $S_i^{(6)}$ statistics. Also CV indicated highly significant (p< 0.01) negative rank correlation with CMR (Tab. 7). Statistic $S_i^{(1)}$ had highly significant (p< 0.01) positive rank correlation with $S_i^{(2)}$, $S_i^{(4)}$, $S_i^{(5)}$ and $S_i^{(7)}$ statistics. Also, statistic $S_i^{(2)}$ had highly significant (p < 0.01) positive rank correlation with $S_i^{(3)}$, $S_i^{(4)}$, $S_i^{(5)}$ and $S_i^{(7)}$ statistics (Tab. 7). Nassar and Huehn (1987) pointed out that the $S_i^{(1)}$ and $S_i^{(2)}$ nonparametric measures of stability, were similar in concept to GEI and defined stability in terms of homeostasis. Statistic $S_i^{(3)}$ had highly significant (p<0.01) positive rank correlation only with $S_i^{(6)}$ statistics (Tab. 7). Also, statistic $S_i^{(4)}$ had highly significant (p<0.01) positive rank correlation with $S_i^{(5)}$ and $S_i^{(7)}$ statistics. Statistic $S_i^{(5)}$ with $S_i^{(7)}$ and $S_i^{(6)}$ with CMR had highly significant (p<0.01) positive rank correlation (Tab. 7).

Although CMR had significantly high significant positive rank correlation only with CSD and $CS_i^{(6)}$, other two descriptive statistics of a corrected dataset (CSD and CCV) indicated highly significant (p< 0.01) positive rank correlation with all of the corrected Huehn's nonparametric measures of stability (1979, 1990b) (Tab. 7). Also all seven nonparametric measures of stability ($CS_i^{(1)}$, $CS_i^{(2)}$, $CS_i^{(3)}$, $CS_i^{(4)}$, $CS_i^{(5)}$, $CS_i^{(6)}$ and $CS_i^{(7)}$) were correlated with each other. The most prominent relation in Tab. 7, was no positive or negative association between corrected and uncorrected conditions of ten nonparametric statistics. This finding revealed the importance of genotype effect in stability determination and GEI studies. The mean yield of each genotype in each environment was a mixture of environment effect, genotype main, and GEI. Usually, environment explains most of the yield variation, but genotype effect and GEI are small (Yan, 2002). The genotype effect and GEI are related to genotype evaluation in multi-environmental trials and should be regarded simultaneously for recommendation targets (Yan and Kang, 2003). Therefore, instead of trying to separate genotype effect and GEI (Huehn, 1990a) it is preferable to put the two together and refer to the mixture as original data as used in Huehn (1979).

To better understand relationships among nonparametric measures of phenotypic stability, a principal component (PC) analysis according to the rank correlation matrix was performed. When applying the PC analysis, the two first PCs (PC1 and PC2) explained 79% (45 and 34 % by PC1 and PC2, respectively) of the total variance. Relationships among the different measures of phenotypic stability and mean yield (Y) are graphically displayed in a plot of PC1 and PC2 (Fig. 2). In this plot, the PC1 axis mainly distinguished mean yield besides the measures of CV, MR and $S_i^{(6)}$ from the other measures. Thus, the first principal component separated the measures into two groups according to the two stability concepts (biological and agronomic concept of stability). The second PC separated the nonparametric measures of phenotypic stability into two groups according to the yield and stability (Fig. 2). The original data-based nonparametric measures of phenotypic stability (SD, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(4)}$, $S_i^{(5)}$, $S_i^{(6)}$, and $S_i^{(7)}$) were related to yield and the corrected data-

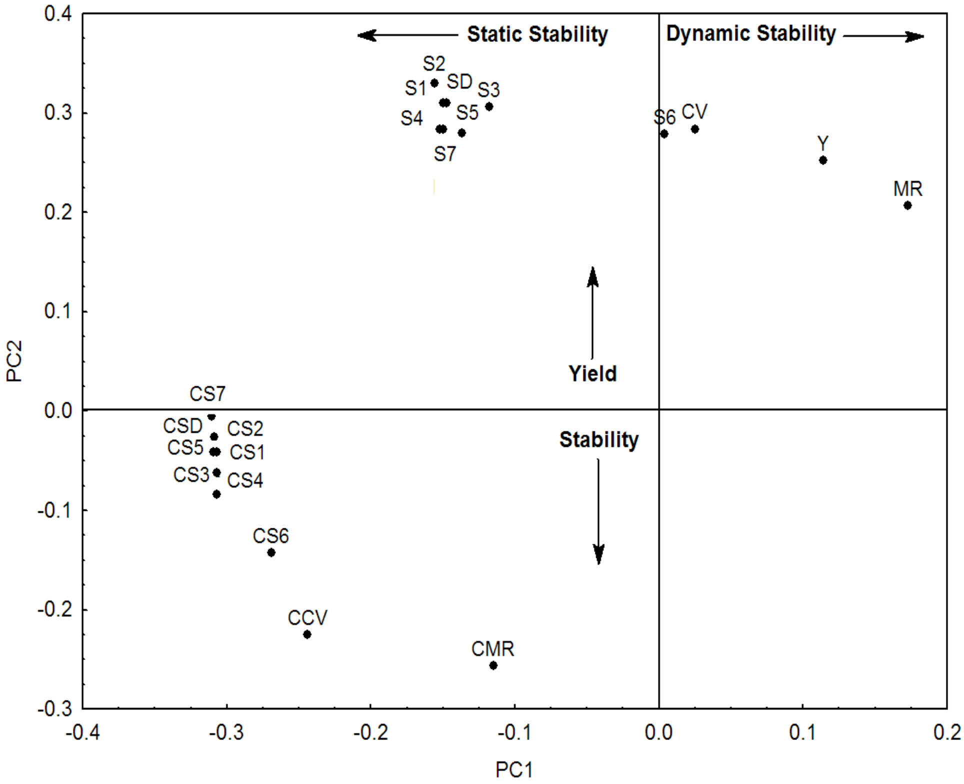

Fig. 2. Principal component analysis (PC1 and PC2) plot of ranks of stability of yield, estimated by 20 methods for 10 lentil genotypes grown in 10 environments and showing interrelationships among these statistics

based nonparametric measures of phenotypic stability (CMR, CSD, CCV, $CS_i^{(1)}$, $CS_i^{(2)}$, $CS_i^{(3)}$, $CS_i^{(4)}$, $CS_i^{(5)}$, $CS_i^{(6)}$ and $CS_i^{(7)}$)were related to stability aspect (Fig. 2).

Conclusions

Most plant breeders prefer simultaneous selection for mean yield and stability because the selected genotypes must have high mean values coupled with stable performance. It seems that using correction on Huehn's nonparametric measures of phenotypic stability changes their nature to a static concept of stability. There is good potential in nonparametric stability methods to identify favorable genotypes in plant breeding programs. Therefore, using the agronomic or dynamic concept of stability is the better use of an original dataset because two of the descriptive statistics of original ranks consist on mean of ranks (MR), coefficient of variation of ranks (CV) and $S_i^{(6)}$ were highly correlated with mean yield and indicated the dynamic concept of stability. The nonparametric method provided a lot of flexibility for plant breeders for simultaneous selection for yield and stability. For making practical recommendations for selecting high yielding genotypes in a yield stability analysis, it is essential to use the Huehn's nonparametric measures based on original datasets.

References

Alagarswamy G, Chandra S (1998). Pattern analysis of international sorghum multi-environment trials for grain-yield adaptation. Theor Appl Genet 96:397-405.

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

Berteroa HD, de la Vegab AJ, Correaa G, Jacobsenc SE, Mujica A (2004). Genotype and genotype-by-environment interaction effects for grain yield and grain size of quinoa (*Chenopodium quinoa* Willd.) as revealed by pattern analysis of international multi-environment trials. Field Crops Res 89:299-318.

Bredenkamp J (1974). Non-parametriche prufung von wechsewirkungen. Psychol Beitr 16:398-416.

Ceccarelli S (1996). Positive interpretation of genotype by environment interaction in relation to sustainability and biodiversity, 467-486 p. In: Cooper M, Hammer GL (Eds.). Plant adaptation and crop improvement. Wallingford, UK, CABI.

Ceccarelli S (2000). Decentralized-participatory plant breeding: adapting crops to environments and clients. Proc of the 8th Int Barley Genetics Symposium, Adelaide 22-27 Oct., 1:159-166.

Cochran WG, Cox GM (1957). Experimental Designs. Second Edition. Wiley Publication. N.Y.

Cooper M, Rajatasereekul S, Immark S, Fukai S, Basnayake J (1999). Rainfed lowland rice breeding strategies for Northeast Thailand. I. Genotypic variation and genotype × environment interactions for grain yield. Field Crops Res 64:131-151.

Cravero V, Martin E, Anido FL, Cointry E (2010). Stability through years in a non-balanced trial of globe artichoke varietal types. Sci Hort 126:73-77.

de Kroon J, van der Laan P (1981). Distribution-free test procedures in two-way layouts. A Concept of rank-interaction. Stat Neerl 35:189-213.

Dehghani H (2008) Estimating yield stability by nonparametric stability analysis in maize (*Zea mays* L.). Plant Breed Seed Sci 58:61-77.

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 For 33:139-148.

Ebadi-Segherloo A, Sabaghpour SH, Dehghani H, Kamrani M (2008). Non-parametric measures of phenotypic stability in chickpea genotypes (*Cicer arietinum* L.). Euphytica 2:221-229.

Falconer DS, Mackay TFC (1996). Introduction to Quantitative Genetics. 4th Edition. Pearson Education Ltd., Essex, England.

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

Fox PN, Skovmand B, Thompson BK, Braun HJ, Cormier R (1990). Yield and adaptation of hexaploid spring triticale. Euphytica 47:57-64.

Hildebrand H (1980). Asymptotosch verteilungsfreie rangtests in linearen modellen. Med Inform Stak 17:344-349.

Hill J, Becker HC, Tigerstedt PMA (1998). Quantitative and ecological aspects of plant breeding. Chapman and Hall, London.

Huehn M (1990a). Non-parametric measures of phenotypic stability. Part 1: Theory. Euphytica 47:189-194.

Huehn M (1990b). Non-parametric measures of phenotypic stability: Part 2. Application. Euphytica 47:195-201.

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

Hussein MA, Bjornstad A, Aastveit AH (2000). SASG × ESTAB: A SAS program for computing genotype 3 environment stability statistics. Agron J 92:454-459.

Kang M, Pham N (1991). Simultaneous selection for high yielding and stable crop genotypes. Agron J 83:161-163.

Kang MS (1988). A rank–sum method for selecting high-yielding, stable corn genotypes. Cereal Res Comm 16:113-115.

Kang MS (1993). Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. Agron J 85:754-757.

Kaya Y, Taner S (2002). Estimating genotypes ranks by nonparametric stability analysis in bread wheat (*Triticum aestivum* L.). J Cent Europ Agric 4:47-53.

Ketata H, Yan SK, Nachit M (1989). Relative consistency performance across environments. Int Symp on Physiology and Breeding of Winter Cereals for Stressed Mediterranean Environments. Montpellier, July 3-6.

Kubinger KD (1986). A note on non-parametric tests for the interaction on two-way layouts. Biomet J 28:67-72.

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

Liu YJ, Duan C, Tian ML, Hu EL, Huang YB (2010). Yield stability of maize hybrids evaluated in maize regional trials in southwestern china using nonparametric methods. Agric Sci China 9:1413-1422.

Lu HY (1995). PC-SAS program for Estimation Huehn's nonparametric stability statistics. Agron J 87:888-891.

Nassar R, Huehn M (1987). Studies on estimation of phenotypic stability: Test of significance for nonparametric measures of phenotypic stability. Biometrics 43:45-53.

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

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

Shukla GK (1972). Some aspects of partitioning genotype-environmental components of variability. Heredity 28:237-245.

Spearman C (1904). The proof and measurement of association between two things. Amer J Psychol 15:72-101.

Steel RGD, Torrie JH (1980). Principles and Procedures of Statistics. McGraw Hill Book Company, NY.

Stroup WW, Hildebrand PE, Francis CA (1993). Farmer participation for more effective research in sustainable agriculture, 153-186 p. In: Ragland J, Lal R (Eds.). Technologies for sustainable agriculture in the tropics, ASA Spec. Publ. 56 ASA, CSSA, and SSSA, Madison.

Thennarasu K (1995). On certain non-parametric procedures for studying genotype × environment interactions and yield stability. PhD. Thesis. P.J. School, IARI, New Delhi, India.

Yan W, Kang MS (2003). GGE-biplot analysis: A graphical tool for breeders, geneticists, and agronomists. CRC Press, Boca Raton, FL.

Yan W (2002). Singular-value partitioning in biplot analysis of multienvironment trial data. Agron J 94:990-996.

Yau SK, Hamblin J (1994). Relative yield as a measure of entry performance in variable environments. Crop Sci 34:813-817.

Yau SK (1995). Regression and AMMI analyses of genotype × environment interactions: An empirical comparison. Agron J 87:121-126.