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Association among Non-parametric Measures of Phenotypic Stability in Four Annual Crops

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ABSTRACT

This work was investigated to find interrelationships and similarities among 10 non-parametric phenotypic stability and wide adaptability measures derived from grain yield of 15 durum wheat genotypes, 20 bread wheat genotypes, 13 barley and 16 safflower genotypes which were grown in 12, 18, 18 and 18 environments during 2003-2006 cropping seasons, respectively in Iran. Results of nonparametric tests of Genotype-by-environment (GE) interaction and a combined ANOVA across environments indicated the presence of crossover and non-crossover interactions, and grain yield of genotypes varied significantly. According to rank correlation analysis the 10 non-parametric methods, in four set of crop trials, can be categorized in three groups: the methods are not correlated with mean yield and can be define in the sense of homeostasis. This group consisted of the statistics $S_1^{(i)}$, $S_2^{(i)}$, $S_3^{(i)}$ and $NP_1^{(i)}$; those which positively correlated with mean yield and are related to dynamic concept of stability were comprised the TOP and rank-sum (RS) parameters. The third group influenced simultaneously by grain yield and stability included the measures $S_3^{(i)}$, $S_6^{(i)}$, $NP_2^{(i)}$ $NP_3^{(i)}$ and $NP_4^{(i)}$. This study verified that the statistics $Si^{(2)}$, RS and TOP give sufficient information about the stability performance and adaptability of the studied genotypes in each crop to breeders.

Keywords: rank correlation, similarity, static and dynamic stability

INTRODUCTION

Genotype-by-environment (GE) interaction is the differential response of genotypes evaluated under different environmental conditions. It is a complex phenomenon as it involves environmental (agro-ecological, climatic and agronomic) conditions and all physiological and genetic factors that determine the plant growth and development.

There are many statistical methods for assessing, studying and interpreting GE interactions (Flores *et al*. 1998; Hussein *et al*. 2000; Sabaghnia *et al*. 2006). Many of the nonparametric methods have recently been compared by others (Sabaghnia *et al*. 2006; Mohammadi *et al*. 2007a, 2007b). Nonparametric stability statistics, requiring no statistical assumptions, have been proposed by Huehn (1990a) and Kang and Pham (1991). They reduce the bias caused by outliers, and no assumptions are needed about the distribution of observed values. They are easy to use and interpret, and additions or deletions of one or a few genotypes have little effect on the results (Huehn 1990a). Nonparametric procedures proposed by Huehn (1979), Nassar and Huehn (1987), Kang (1988), Fox *et al*. (1990) and Thennarasu (1995) are based on the ranking of genotypes in each environment; genotypes with similar ranking across environments are classified as stable. Huehn (1979) and Nassar and Huehn (1987) proposed four non-parametric measures of phenotypic stability: 1) $S_i^{(1)}$ is the mean of the absolute rank differences of a genotype over n environments; 2) $S_i^{(2)}$ is the variance among the ranks over the n environments; 3) $S_i^{(3)}$ and 4) $S_i^{(6)}$ are the sum of the absolute deviations and sum of squares of ranks for each genotype relative to the mean of ranks, respectively. Kang (1988) assigned ranks for mean yields and Shukla's (1972) stability parameter for simultaneously selection based on yield and stability. Fox *et al*. (1990) suggested a non-parametric superiority measure for assessing general adaptability. They used stratified ranking of cultivars that was done at each environment to determine the proportion of sites in which each cultivar occurred in the top, middle and bottom third of the ranks, forming the non-parametric measures TOP, MID and LOW, respectively. Thennarasu (1995) proposed as stability measures, the non-parametric statistics $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ based on ranks of adjusted means of genotypes as those whose position in relation to the others remained unaltered in the set of environments.

There are an increasing number of stability non-parametric methods for genotypes grown in different environments. It is therefore useful to study the statistical relations between these parameters to find the best appropriate parameters for testing the genotypes in breeding programs. One approach is to calculate the rank correlations between different stability parameters on the basis of empirical data sets (Piepho and Lotito 1992).

In this study 10 non-parametric measures of phenotypic stability were chosen so that they cover a wide range of philosophies of stability analysis. Most breeders have used the term 'stability' to characterize a genotype which shows a relatively constant yield, independent of environmental conditions. This idea of stability is in agreement with the concept of homeostasis widely used in quantitative genetics (Becker and Leon 1988) and may be considered as a 'biological' or 'static' concept of stability (Becker 1981; Becker and Leon 1988). A genotype showing a constant performance in all environments does not necessarily respond to improved growing conditions with increased yield. This type of stability, therefore, is not acceptable to most agronomists, who would prefer an 'agronomic' or 'dynamic' concept of stability (Becker 1981; Becker and Leon 1988), where for each environment the performance of a stable genotype corresponds completely to the estimated level or the prediction. In the dynamic concept of stability, it is not required that the genotypic response to environmental con-

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Table 1 The bread wheat, durum wheat, barley and safflower genotypes used in this study.

Code	Bread wheat	Durum wheat	Barley	Safflower
G1	Unknown-1	Omgenil-3	Lignee131/3/4679/105//YEA168.4	CH-5
G2	Unknown-2	Omrabi-5	Roho//Alger/Ceres362-1-1/3/Alpha/Durra	PI-250537
G3	Unknown-9	Syrian-4	Alpha//Gumhuriyet/Sonja	Syrian
G4	Unknown-11	Mrb3/Mna-1	B-C-74-2	CW-74
G5	135U8.01	Waha	Antares/KY36-1294//SLR	Dincer
G6	5294 Karaj 98-99	Mna-1/Rfm-7	CWB117-77-9-7/3/Roho//Alger/Ceres362-1-1	Zarghan279
G7	1-27-6149/Sabalan//84.40023	9A-Kor8081	4679/105//YEA168.4/3/Lignee131/ArabiAbiad	LRV-55-245
G8	Manning/Sdv1//Dogu88	12A-Mar8081	Antares/KY36-1294//Lignee131	PI-198290
G9	RECITAL/TIA.2//TRK13	14A-Mar8081	Wiselburger/Ahor1303-61//SLS	Hartman
G10	Sardari//Ska/Aurifen	15A-Mar8081	SLS/BDA	Gila
G11	Unknown-3	18A-Mar8081	CWB117-77-9-7//Antares/KY63-1294	Kino-76
G12	Unknown-7	19A-Mar8081	Sadik8	Yenice
G13	Pf 82200/Sardari	20A-Mar8081	National Check (Sahand)	PI-537636
G14	Ghafghaz//F9.10/Maya"s	Zardak (National check)		PI-537636-s
G15	Khazar/3/Jcam/Emu"s"//Dove"	Sardari (National check)		LRV-51-51
G16	Kvz/Tm71/3/Maya"s"//Bb/Inia/4/Sefid			PI-537598
G17	Anza/3/Pi//Nar/Hys/4/Sefid			
G18	Fengkang15/Sefid			
G19	Sardari (National check)			
G20	Azar-2 (National check)			

ditions should be equal for all genotypes (Becker and Leon 1988).

Crossa (1990), Gregorious and Namkoong (1986) stated that GE interaction becomes very important in agricultural production, when there are changes in a genotype's rank over environments. These are called crossovers or qualitative interactions, in contrast to non-crossovers or quantitative interactions (Peto 1982; Gail and Simon 1985). With a qualitative interaction, genotype differences vary in direction among environments, whereas with quantitative interactions, genotypic differences change in magnitude but not in direction. If significant qualitative interactions occur, subsets of genotypes are to be recommended only for certain environments, whereas with quantitative interactions the genotypes with superior means can be used in all environments. Therefore, it is important to test for crossover interactions (Baker 1988).

Therefore, the non-parametric measures mentioned above can help breeders and agronomists to assess the response of genotypes to changing environments. The objectives of the paper are: (i) to apply non-parametric test methods to investigate the crossover and non-crossover interactions in comparison with ANOVA method in different crops, (ii) to study the interrelationships among the non-parametric stability and adaptability measures in different field crops, and (iii) to evaluate the similarity between non-parametric methods to recommend the best one to be used by breeders.

MATERIALS AND METHODS

Data

Data sets of grain yield were obtained from trials conducted by the Dryland Agricultural Research Institute (DARI) for four annual field crops grown in the rainfed drylands of Iran. For bread wheat (*Triticum aestivum* L.), 20 genotypes were grown in six locations across 2003-2005 growing seasons; for durum wheat (*Triticum turgidum* var. *durum*), 15 genotypes in four locations across 2004-2006 cropping seasons; for barley (*Hordeum vulgar*e L.), 13 genotypes in six locations across 2003-2005 growing seasons; and safflower (*Carthamus tinctorious* L.) with 16 genotypes tested in six locations across cropping seasons 2003-2005 (**Table 1**). All genotypes were selected from international nurseries provided by the International Center for Agricultural Research in the Dry Areas (ICARDA) within its collaborative program with Iran. The experiments were arranged in a randomized complete block design, with four replications for bread wheat, barley and safflower, and three replications for durum wheat in each environment. Sowing was done by an experimental drill in 1.2 m × 6 m plots, consisting of six rows with 20 cm between rows for bread wheat, durum wheat and barley and seeding rate was 350 seeds m^{-2} for each location. In the case of safflower a plot size of 1.5 m × 4 m with four rows with 30 cm between rows and a seeding rate of 20 seeds m^{-2}. For all crops, yield (kg ha^{-1}) was obtained by converting plot yields.

Statistical analysis

From original yield data, the effects of genotype (G), environments (E) and GE interactions and their variances were estimated using combined analysis of variance (ANOVA) and the F-tests were used to determine the significance of these factors. Two non-parametric statistical methods were also used to test the significance of G, E and GE and were compared to the ANOVA method; the Bredenkamp method (Bredenkamp 1974; Huehn and Leon 1995) used the usual model for interactions which are defined as deviations from the additivity of main effects and the van der Laan-de Kroon method (de Kroon and van der Laan 1981; Huehn and Leon 1995), which used the crossover GE interactions [G (E) and E (G) interactions; for details see Mohammadi *et al*. 2007a]. The statistical test of significance of the two methods uses a χ^2-distribution with (l-1) (m-1) degrees of freedom, where l = number of genotypes and m = number of environments (for detail, see Huehn and Leon 1995; Mohammadi *et al*. 2007a).

For a two-way data set with l genotypes and m environments, we denote r_{ij} as the rank of genotype i in the environment j, and $\bar{r}_{i.}$ as the mean rank across all environments for genotype i. The genotype with the highest yield was given a rank of 1 and that with the lowest yield was assigned a rank of l (l = number of genotypes). The Huehn's (1979) and Nassar and Huehn's (1987) stability measures based on yield ranks of genotypes in each environment are expressed as follows:

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

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

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

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

Kang's (1988) rank-sum is another non-parametric stability procedure where both yield and Shukla's (1972) stability variance were used as selection criteria. This index assigns a weight of 1 to both yield and stability statistics to identify high-yielding and stable genotypes. The genotype with the highest yield is given a rank of 1 and a genotype with the lowest stability variance is assigned a rank of 1. All genotypes were ranked in this manner, and the ranks by yield and by stability variance were summed for each genotype; the genotypes with the lowest rank-sums are the most desirable.

The stratified ranking technique of Fox *et al*. (1990) consists of scoring the number of environments in which each genotype ranked in the top, middle and bottom thirds of trial entries. A genotype that occurred mostly in the top third (high TOP value) was considered a widely adapted cultivar.

Thennarasu (1995) proposed the four following non-parametric stability measures based on adjusted ranks. The adjusted rank, r_{ij}^* (Thennarasu 1995) is determined on the basis of the adjusted values ($x_{ij}^* = x_{ij} - x_{i.} + x_{..}$), where $x_{i.}$ is the mean performance of genotype *i*, x_{ij} is the performance of genotype *i* in environment *j* and x is the overall mean across environments. The ranks, obtained from these adjusted values (x_{ij}^*), depend only on GE interaction and error effects.

$$NP_i^{(1)} = \frac{1}{m}\sum_{j=1}^{m}\left|r_{ij}^* - M_{di}^*\right|$$

$$NP_i^{(2)} = \frac{1}{m}\left(\sum_{j=1}^{m}\left|r_{ij}^* - M_{di}^*\right| / M_{di}\right)$$

$$NP_i^{(3)} = \frac{\sqrt{\sum(r_{ij}^* - \bar{r}_{i.}^*)^2 / m}}{\bar{r}_{i.}}$$

$$NP_i^{(4)} = \frac{2}{m(m-1)}\left[\sum_{j=1}^{m-1}\sum_{(j'=j+1)}^{m}\left|r_{ij}^* - r_{ij'}^*\right| / \bar{r}_{i.}\right]$$

In the above formulas, r_{ij}^* is the rank of x_{ij}^*, and $\overline{r_{i.}^*}$ and M_{di}^* are the mean and median ranks for adjusted values, where $\bar{r}_{i.}$ and M_{di} are the same parameters computed from the original (unadjusted) data.

The non-parametric statistics measures were derived from the grain yield data of each studied crop and the Spearman's rank correlation between these methods was estimated to assess the interrelationship and similarity among them.

RESULTS

Analysis of GE interactions in all crops

The values of the test statistics for the used statistical procedures in each crop are presented in **Table 2**. F and χ^2-values were respectively used for ANOVA and non-parametric methods (Bredenkamp and van der Laan-de Kroon) to test the effects of G, E and GE interaction. Both crossover and non-crossover interactions for all crops were significant. ANOVA and non-parametric test procedures were in agreement for all crops.

Interrelationship among non-parametric measures

The non-parametric stability measures of $Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$ and $NPi^{(1)}$ were significantly correlated over environments and crops (P<0.01) (**Table 3**). The $Si^{(2)}$ also showed significant correlation with $Si^{(6)}$ (except in barley and safflower), $NPi^{(2)}$ (except in barley), $NPi^{(3)}$ in durum wheat and safflower and $NPi^{(4)}$ (except in bread wheat). $Si^{(2)}$ is the common variance of rank yields over environments, and due to its highly significant correlations with the statistics measures, there is no need to compute these later parameters and $Si^{(2)}$ could be a useful criterion in selecting stable genotypes. Significant correlations were found between $NPi^{(1)}$ and $NPi^{(2)}$ in bread wheat and safflower, $NPi^{(3)}$ and $NPi^{(4)}$ for all crops (except in barley) and $NPi^{(2)}$ with $Si^{(3)}$ in all crops and $Si^{(6)}$ in all crops (except safflower). $NPi^{(2)}$ and $NPi^{(4)}$ as well as $NPi^{(4)}$ and $Si^{(3)}$ in all crops (except in bread wheat), and $Si^{(6)}$ and $NPi^{(4)}$ in durum wheat and barley were highly positively correlated. Significantly negative associations were also found between $NPi^{(2)}$ and TOP in all crops, $NPi^{(3)}$ and TOP in durum wheat and safflower and also found between $NPi^{(4)}$ and TOP in all crops (except bread wheat).

Rank correlation between mean yield and $Si^{(2)}$ was not significant for all crops then repeatable, indicating that $Si^{(2)}$ is not related to yield. Therefore, stable genotypes selected based on $Si^{(2)}$ do not have to posses superior grain yields. This measure was considered as static stability defined previously by Nassar and Huehn (1987). Some non-parametric stability measures had significantly negative correlations with grain yield but were not repeatable for all crops. For example, $Si^{(3)}$, $Si^{(6)}$ and $NPi^{(2)}$ in durum wheat and barley, $NPi^{(3)}$ in bread and durum wheat and $NPi^{(4)}$ for all crops (except in safflower) showed negative significant correlations with grain yield (**Table 3**). TOP in durum wheat and barley had significantly positive correlations with yield but was not correlated with RS.

Rank-sum (RS) showed positive correlations with grain yield across all crops. Like RS, $Si^{(2)}$ measure is repeatable, but with non-significant correlations with mean yield (**Table 3**). Considering significant rank correlation of the non-parametric measures with mean grain yield, the best methods for analyzing the yield stability of a genotype across environments were RS and $Si^{(2)}$ (**Table 3**). According to the above results, it may be better considered RS and $Si^{(2)}$ as the reliable parameters of choice for screening the stable genotypes ($Si^{(2)}$) and the genotypes which having high stability and yield performance (RS parameter) in changing environments for the four annual field crop species.

DISCUSSION

The genotype × environment (GE) interaction is a major challenge to plant breeders. Many stability parameters for genotypes grown in different environments were developed for this purpose and each has its advantages and limitations. Non-parametric methods were developed based on genotype ranking and the correlations among them were used for finding which one is repeatable in different crops and which ones are similar and can be used as an alternative to others. In various methods, GE interactions are used to characterize the response of genotypes to changing environments along with mean grain yields. Accordingly, genotypes with a minimal variance for yield across environments are considered stable. This idea of stability may be considered as a biological or static concept of stability (Becker and Leon 1988). This concept of stability is not acceptable to most breeders and agronomists, who prefer genotypes with high mean yields and the potential to respond to agronomic inputs or better environmental conditions (Becker 1981). Therefore, breeders prefer the use of dynamic concept of stability (Becker and Leon 1988). The two concepts of stability (static or dynamic) are strongly related to fit the requirements of breeders, i.e. determination of whether the best genotype in one environment is also the best in other environments, or is the best just in a few environments.

In this study the results of nonparametric tests for GE interactions for all studied crops were similar to combined ANOVA. Similar results were reported by Huehn and Leon (1995) and Truberg and Huehn (2000), who recommended the Bredenkamp test for non-crossover interactions and the van der Laan-de Kroon test for crossover interactions. For an analysis of crossover interactions, there has to be a distinction between G(E) and E(G) crossover interactions (Truberg and Huehn 2000). In this study both G(E) and E(G) crossover interactions were detected by the van der Laan-de Kroon procedure for the crops.

We found that in the data analyzed, the statistics measure of $Si^{(2)}$ was significantly correlated with the Huehn's (1990a) and Thennarasu's (1995) statistics measures. Due to its significant correlations, $Si^{(2)}$ can be used as an alternative to others and consequently as a useful index for selecting stable genotypes in the crops. A significantly positive rank correlation between $Si^{(1)}$ and $Si^{(2)}$ was reported in maize by

Table 2 Test statistics for genotype (G), environment (E) and GE interaction using parametric (ANOVA) and non-parametric (Bredenkamp and Laan-Kroon) methods on grain yields of different crops across environments.

Source	Crop	df	Parametric method	Non-parametric method		
				Berdenkamp (Non-crossover interaction)	Laan-Kroon (Crossover interaction)[c]	
					G(E)	E(G)
			ANOVA (F)[a]	χ^2-statistic[b]	χ^2-statistic	χ^2-statistic
Environment (E)	Bread wheat	17	20.52**	1016**	1052**	1052**
	Durum wheat	11	53.62**	1467.49**	1365.11**	1365.11**
	Barley	17	202.83**	661**	702**	702**
	Safflower	17	102.44**	814**	853**	853**
Genotype (G)	Bread wheat	19	208.85**	1023**	1049**	1049**
	Durum wheat	14	2.11*	430.02**	1457.64**	1457.64**
	Barley	12	2.09**	644**	701**	701**
	Safflower	15	6.04**	820**	852**	852**
GE	Bread wheat	323	2.35**	2159**	1394**	1275**
	Durum wheat	154	1.78*	1740.93**	2160.23**	4156.19**
	Barley	184	1.46**	1396**	918**	39.79^{ns}
	Safflower	255	2.76**	1616**	1122**	886**

*, ** significant at the P< 0.05 and P< 0.01, respectively.

[a] For ANOVA the test statistic for GE interaction was F = mean square (interaction)/ mean square (error) with (l-1)(m-1) degrees of freedom for the numerator and lm(n-1) degrees of freedom for the denominator, where l = number of genotypes, m = number of environments and n = number of replications. For genotype effect, F = mean square (genotype)/ mean square (interaction) with l-1 degrees of freedom for the numerator and (l-1) (m-1) for the denominator. For environment effect, F = mean square (environment)/ mean square (interaction) with m-1 degrees of freedom for the numerator and (l-1) (m-1) for the denominator.

[b] χ^2-values with l-1 (for genotype), m-1 (for environment) and (l-1) (m-1) (for GE interaction) degrees of freedom for the methods of Bredenkamp and van der Laan-de Kroon at the indicated levels probability were tested. The null hypothesis for Bredenkamp is no non-crossover GE interaction and for van der Laan-de Kroon is no crossover GE interaction.

[C] G(E): Crossover interactions (rank changes of genotypes within environments); E(G): crossover interactions (rank changes of environments within genotypes).

Table 3 Spearman's correlation coefficients between ranks of non-parametric stability and wide adaptability measures for grain yield in different crops.

Parameter	Crop	Yield	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	TOP
$S_i^{(1)}$	Bread wheat	0.01									
	Durum wheat	-0.31									
	Barley	-0.22									
	Safflower	-0.44									
$S_i^{(2)}$	Bread wheat	0.01	0.99**								
	Durum wheat	-0.44	0.95**								
	Barley	-0.24	0.98**								
	Safflower	-0.42	0.99**								
$S_i^{(3)}$	Bread wheat	-0.01	0.99**	0.98**							
	Durum wheat	-0.79**	0.74**	0.86**							
	Barley	-0.63*	0.81**	0.81**							
	Safflower	-0.28	0.98**	0.89**							
$S_i^{(6)}$	Bread wheat	-0.03	0.74**	0.75**	0.73**						
	Durum wheat	-0.87**	0.64*	0.77**	0.95**						
	barley	-0.68*	0.28	0.22	0.59*						
	Safflower	0.09	0.06	0.07	0.13						
$NP_i^{(1)}$	Bread wheat	0.01	0.91**	0.95**	0.90**	0.84**					
	Durum wheat	-0.22	0.96**	0.89**	0.63*	0.56*					
	Barley	-0.09	0.92**	0.90**	0.72*	0.23					
	Safflower	-0.42	0.99**	0.98**	0.89**	0.06					
$NP_i^{(2)}$	Bread wheat	0.02	0.93**	0.96**	0.80**	0.80**	0.98**				
	Durum wheat	-0.88**	0.58*	0.71**	0.92**	0.98**	0.51				
	Barley	-0.83**	0.55	0.54	0.87**	0.74**	0.47				
	Safflower	-0.12	0.62*	0.60*	0.83**	0.11	0.62**				
$NP_i^{(3)}$	Bread wheat	-0.92**	0.25	0.24	0.26	0.23	0.19	0.22			
	Durum wheat	-0.88**	0.54*	0.68**	0.92**	0.97**	0.45	0.98**			
	Barley	-0.37	0.07	0.14	0.26	-0.23	-0.01	0.36			
	Safflower	-0.04	0.72**	0.68**	0.90**	0.24	0.70**	0.91**			
$NP_i^{(4)}$	Bread wheat	-0.91**	0.27	0.26	0.29	0.24	0.21	0.23	0.99**		
	Durum wheat	-0.87**	0.68**	0.78**	0.97**	0.97**	0.60*	0.95**	0.94**		
	Barley	-0.72**	0.73**	0.73**	0.97**	0.67*	0.63*	0.94**	0.31		
	Safflower	-0.04	0.70**	0.67**	0.88**	0.23	0.68**	0.92**	0.99**		
TOP	Bread wheat	-0.23	-0.62**	-0.60**	-0.63**	-0.59**	-0.60**	-0.64**	0.04	0.01	
	Durum wheat	0.92**	-0.32	-0.47	-0.78**	-0.87**	-0.21	-0.87**	-0.88**	-0.86**	
	Barley	0.94**	0.38	-0.39	-0.78**	-0.73**	-0.29	-0.95**	-0.35	-0.85**	
	Safflower	-0.11	-0.31	-0.32	-0.56*	0.05	-0.33	-0.85**	-0.66*	-0.69**	
RS	Bread wheat	0.49**	0.52*	0.52**	0.56**	0.14	0.42	0.46*	-0.30	-0.28	-0.38
	Durum wheat	0.51*	0.59*	0.47	0.04	-0.12	0.63*	-0.19	-0.21	-0.07	0.47
	Barley	0.58*	0.59*	0.58*	0.12	-0.33	0.68*	-0.27	-0.25	-0.04	0.44
	Safflower	0.55*	0.44	0.46	0.52*	0.26	0.43	0.33	0.52*	0.52*	-0.26

*, ** significant at 5% and 1% probability level, respectively

Scapim *et al*. (2000) and in faba bean and pea by Flores *et al*. (1998). Nassar and Huehn (1987), Sabaghnia *et al*. (2006) and Mohammadi *et al*. (2007b) reported that $Si^{(1)}$ and $Si^{(2)}$ are associated with the static (biological) concept of stability, as they define stability in the sense of homeostasis. However, $Si^{(2)}$ was not correlated with mean grain yield and therefore, could be used as a compromise method to select genotypes with high stability.

The statistics measures of RS can be used for assessing dynamic stability of genotypes. With this method the breeders will be able to select the genotypes which have high yield performance and stability, while using $Si^{(2)}$ the breeders can find the genotypes which are stable in the whole of environments (Flores *et al*. 1998; Mohammadi and Amri 2008).

The TOP parameter as dynamic concept of stability (Flores *et al*. 1998; Mohammadi *et al*. 2007a; Mohammadi and Amri 2008) its association with mean yield was not repeatable. However this parameter in durum wheat and barley was able to select genotypes with high adaptability. Significant correlation ($P < 0.01$) was also reported between this parameter (TOP) with mean yield in spring safflower (Mohamamdi *et al*. 2008). No correlation between this parameter with mean yield in bread wheat and winter safflower suggesting in these two crops the genotypes with high adaptability may not be found.

Rank correlation is an important useful tool to study the statistical relations between the non-parametric methods in different crops for finding the best method that can be used as an alternative to the other methods and eliminating similar parameters. The use of the rank correlation allowed a study of the relationship among the parameters and the similarity of non-parametric methods for different crops. Consequently, we found that $Si^{(2)}$, RS and TOP give sufficient information about the stability performance and adaptability of the studied genotypes in each crop to breeders. These parameters can be used to diminish the contradictory results obtained by various methods used by breeders to characterize the genotypes in the case of sense homeostasis ($Si^{(2)}$), combining yield and stability performance (RS) and adaptability (TOP) in breeding programs.

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