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Comparison of parametric and non-parametric stability statistics for selecting stable chickpea (*Cicer arietinum* L.) genotypes under diverse environments

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Abstract

In order to study phenotypic stability of 17 chickpea genotypes and comparison among parametric and non-parametric stability procedures, a randomized complete block design with four replications was carried out in five different research stations of Iran across two years (2004- 2005). Principal component analysis (PCA) indicated that the first four PCAs explained 88% of the variance of original variables. Biplot analysis of stability measures revealed that stability measures can be classified into four groups. Group 1 included the mean yield with non-parametric measures Ys_i and TOP (proportion of environments in which a genotype ranked in the top third). Group 2 consisted of non-parametric measures ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $NP_i^{(1)}$) and parametric measures (b_i, S^2_{xi}, ASV, S^2d_i and W_i^2), which were correlated with mean yield (except for b_i and $NP_i^{(1)}$). Group 3 included the non-parametric measures $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ which were not correlated with mean yield and group 4 consisted of parameters R, R_i^2, RSM and P_i that were negatively associated with most of the stability methods and mean yield, hence they can be excluded as suitable stability indices. The results of biplot analysis based on rank correlation showed that ASV, S^2_{xi}, W^2_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $NP_i^{(1)}$ can be used for evaluating the responses of chickpea genotypes to changing environments. Most of the stability methods indicated that the genotype G13 (FLIP 97-114) was the most phenotypically stable with high mean yield.

Key words: Chickpea; Parametric and non-parametric stability indices; Principal component analysis; Rank correlation.

Abbreviations: AMMI- additive main effects and multiplicative interaction; ASV- AMMI stability value; b_i- regression coefficient; CV_i- coefficient of variation; GEI- genotype × environment interaction; $IPCA_1$- interaction principal components axes 1; $IPCA_2$- interaction principal components axes 2; $MS_{y/l}$- intra-locational variance; $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$- Thennarasu's non-parametric stability statistics; PCA- principal component analysis; P_i- superiority index; R- mean of rank; R_i^2- coefficient of determination; r_s- rank correlation; SDR- standard deviation of rank; RSM- rank-sum method; S^2d_i- deviation from regression; S^2_{xi}- environmental variance; $S_i^{(1)}$: mean of absolute rank difference; $S_i^{(2)}$- sum of square deviations; $S_i^{(3)}$- variance among the ranks over environments; $S_i^{(6)}$- sum of absolute deviation; TOP, MID and LOW- top, middle and bottom third of ranks; W_i^2- Wricke's ecovalence; Ys_i- yield and stability; σ_i^2- stability variance.

Introduction

Chickpea is the most important legume in Iran and includes nearly 84% of the food legume with 17-24% protein, 41-51% carbohydrates, high percentage of other mineral nutrients and unsaturated linoleic and oleic acid (Farshadfar and Farshadfar, 2008; Cobos et al., 2009). It is apparent that the phenotype of chickpea is a joint contribution of both genes as well as environment. The genotype-environment interaction reduces association between phenotypic and genotypic values and leads to bias in the estimates of gene effects and combining ability for various characters sensitive to environmental variations. Such traits are less amenable to selection (Farshadfar et al., 2000). The importance of GEI in national cultivar evaluation and breeding programs have been demonstrated in almost all major crops, including chickpea genotypes (Yaghotipoor and Farshadfar, 2007; Ebadi et al., 2008; Zali et al., 2011). Lin et al. (1986) identified three concepts of stability (Type 1, 2, 3); later Lin and Binns (1988b) proposed a fourth type (Type 4). Type 1 is also called a static or a biological concept of stability (Becker and Léon, 1988). It is useful for quality traits, disease resistance, or for stress characters like winter hardiness. Parameters used to describe this type of stability are coefficient of determination (R_i^2) (Pinthus, 1973), coefficient of variability (CV_i) (Francis and Kannenburg, 1978) for each genotype as a stability parameter and the genotypic variances across environments (S^2_{xi}) ([Roemer (1917) cited in Becker and Léon (1988)]. Type 2 is also called the dynamic or agronomic concept of stability (Becker and Léon, 1988). A stable genotype has no deviations from the general response to environments and thus permits a predictable response to environments. A regression coefficient (b_i) and $b_i = 0$ is more stable (Finlay and Wilkinson, 1963) and Shukla's (1972) stability variance (σ_i^2) can be used to measure type 2 stability. Type 3 is also part of the dynamic or agronomic stability concept according to Becker and Léon (1988). Methods to describe type 3 stability are the methods of Eberhart and Russel (1966) and Perkins and Jinks (1968). Eberhart and Russel (1966) used the regression coefficient (b_i) and $b_i = 1$ is more stable and the deviation from regression (S^2d_i). Becker and Léon (1988) stated that all stability procedures based on quantifying GEI effects belong to the dynamic concept. This includes the procedures for partitioning the GEI of Wricke's (1962) ecovalence and Shukla's (1972) stability of variance, procedures using the regression approach such as what proposed by Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Perkins and Jinks (1968), as well as non-parametric stability analyses. Lin & Binns (1988a, 1988b) proposed the cultivar performance measure (P_i) and within location variance ($MS_{y/l}$) as type 4 and defined P_i of genotype i as the mean square of distance between genotype i and the genotype with the maximum response. The main problem with stability statistics is that they do not provide an accurate picture of the complete response pattern (Hohls, 1995). The reason is that a genotype's response to varying environments is multivariate (Lin et al., 1986) whereas the stability indices are usually univariate. Through multivariate analysis, genotypes with similar responses can be clustered, and thus the data can be summarized and analyzed more easily (Gauch, 1988; Crossa, 1990). Characterization of the response patterns of genotypes to environmental changes enables extrapolation to a much wider range of environments than those tested (Hohls, 1995). One of the multivariate techniques is the AMMI model. It combines the analysis of variance of genotypes and the environment main effects with principal component analysis of the GEI into a unified approach (Zobel et al., 1988; Gauch and Zobel, 1996). Purchase (1997) developed the AMMI stability value (ASV) based on the AMMI model's $IPCA_1$ and $IPCA_2$ scores for each genotype. Besides the above mentioned parametric methods, various non-parametric methods have also been used based on the ranks of genotypes in each environment and use the idea of homeostasis (environmental resistance) as a measure of stability. Genotypes with similar rankings across environments are classified as stable. Nassar and Huehn (1987) proposed four non-parametric statistics of phenotypic stability ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$) based on the classification of the genotypes in each environment and defined stable genotypes as those whose position in relation to the others remained unaltered in the set of environments assessed. Fox et al. (1990) suggest a non-parametric superiority measure for general adaptability. They used stratified ranking of the cultivars in 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. Rank-sum (Kang and Pham 1991) and simultaneous selection for yield and stability (Ys_i) (Kang, 1993) are other non-parametric stability statistics where both yield and Shukla's (1972) stability variance are used as selection criteria. This statistics assigns a weight of one to both yield and stability and enables the identification of high-yielding and stable genotypes. Thennarasu (1995) proposed non-parametric statistics $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ based on ranks of adjusted means of the genotypes in each environment and defined stable genotypes using Nassar and Huehn (1987)'s definition. The objectives of the present study were (i) to evaluate GEI for seed yield in chickpea genotypes selected from the Iran/ICARDA collaborative project in the environments of Iran, and (ii) identify similar or redundant stability measures to help streamline stability analysis in MET data in breeding programs.

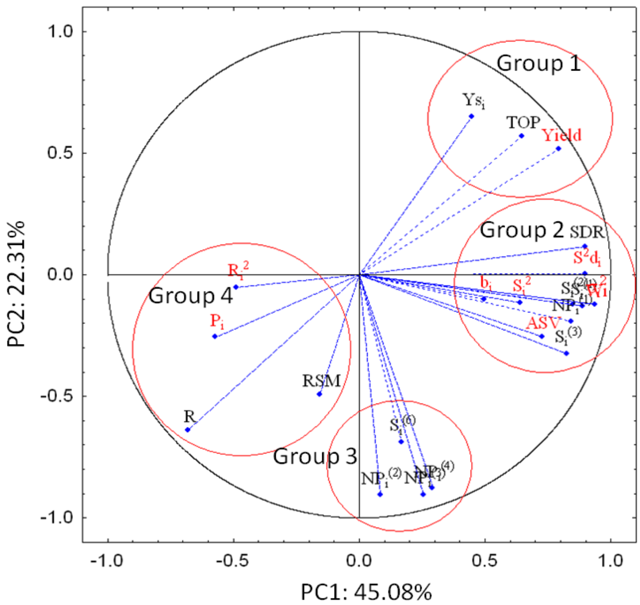

Fig 1. Biplot analysis of parametric and non-parametric indicators of phenotypic stability in chickpea genotypes over 10 environments. The interesting interpretation of biplot is that the cosine of the angle between the vectors of two indices approximates the correlation coefficient between them.

Results

Analysis of G × E interaction

The results of different statistical procedures to determine the effect of GEI on grain yield of chickpea genotypes are presented in Table 2. GEI effect, revealed the same level of significance (P<0.01) in parametric (ANOVA) and non-parametric (*De* Kroon and *Van* der Laan and Kubinger and Hildebrand) methods. The null hypothesis for Hildebrand and Kubinger is no non-crossover GEI and for *De* Kroon and *Van* der Laan is no crossover GEI. Results of these indicated that both significant non-crossover and crossover interactions were found in these multienvironment trials (MET) according to Kubinger and Hildebrand procedures (for non-crossover) and the *De* Kroon and *Van* der Laan test (for crossover). This result is in agreement with the ANOVA, but provides more specific information about the nature of GEI action (Sabaghnia et al., 2006; Mohammadi et al., 2007).

Stability analysis procedures

Evaluations of the genotypes based on 12 different parametric and 15 different non-parametric measurements with mean yield are presented in Table 3 and 4, respectively. For each genotype, $Z_i^{(1)}$ and $Z_i^{(2)}$ values were calculated based on the rank of the corrected data and summed over genotypes to obtain Z values (Table 4); $Z_i^{(1)}$sum = 19.34 and $Z_i^{(2)}$ sum = 26.30. Since both of these statistics were less than the critical value $\chi^2_{0.05,\ df=16}$ = 26.30, therefore no significant differences were found in rank stability among the 17 genotypes grown in 10 environments. The individual Z values, for genotypes, however were significantly unstable relative to others, because they showed large Z values, in comparison with the critical value $\chi^2_{0.05,\ df=1}$ = 3.84.

Table 1. Genotype code, name and origin of 17 chickpea genotypes.

Genotype code	Name	Origin	Genotype code	Name	Origin
G1	FLIP 97-211	ICARDA	G10	X95TH154	ICARDA
G2	FLIP 97-113	ICARDA	G11	FLIP 97-43	ICARDA
G3	FLIP 97-85	ICARDA	G12	FLIP 97-95	ICARDA
G4	FLIP 97-78	ICARDA	G13	FLIP 97-114	ICARDA
G5	FLIP 97-41	ICARDA	G14	X94TH45K10	ICARDA
G6	FLIP 97-30	ICARDA	G15	X95TH5K10	ICARDA
G7	FLIP 97-102	ICARDA	G16	X45TH150K10	ICARDA
G8	FLIP 97-79	ICARDA	G17	Arman	ICARDA
G9	X95TH1	ICARDA			

Table 2. The parameric (ANOVA) and non-parametric tests statistics for the effect of G×E interaction over 10 environments.

Statistics	df	χ^2-statistic
ANOVA (F)	144	396837**
Kubinger (1986)	144	7020**
Hildebrand (1980)	144	6627**
De Kroon and *Van* der Laan (1981)	144	4241**

**: Significant at the 0.01 probability level.

Association among mean yield, parametric and non-parametric stability statistics

Spearman's rank correlation (Steel & Torrie, 1980) was determined for each pair of mean yield and stability statistics (Table 6). Mean yield showed highly significant (P<0.01) positive rank correlation with Ys_i, σ_i^2, W_i^2, $S_i^{(2)}$, S^2d_i, TOP and SDR (P<0.01) and significant (P<0.05) rank correlation with parameters $S_i^{(1)}$, $S_i^{(3)}$ and S^2_{xi} (P<0.05), but highly negatively (P<0.01) correlated with R and P_i. P_i parameter and rank mean (R) revealed negative correlation compared to the other measurements. P_i was significantly positively correlated with RSM but significantly negatively (P<0.01) correlated with Ys_i, S^2_{xi} and mean yield. Lin and Binns (1988a) defined stability as the deviation of a specific genotype's performance from the performance of the best cultivar in a trial. This implies that a stable cultivar is one that performs in tandem with the environment. Non-parametric indices ($S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$, Ys_i and RSM) indicated the greatest deviation from parametric procedures, but the parameters $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $NP_i^{(1)}$, R, SDR and TOP showed the greatest correlation with parametric measures. $S_i^{(1)}$, $S_i^{(2)}$, $NP_i^{(1)}$ and TOP were highly significantly positively correlated with the parametric measures S^2d_i and W_i^2, but significantly negatively (P<0.01) correlated with R_i^2. The procedures of Shukla (σ_i^2) and Wricke (W_i^2) had a total correspondence (r =1.00). This indicates that these two procedures are equivalent for ranking purposes. Shukla's stability variance (σ_i^2) is a linear combination of deviation mean squares, in other words the W_i^2. Therefore, in this study the only procedure used was Wricke's ecovalence (W_i^2).

Parametric procedures S^2d_i and W_i^2 exhibited high significant positive correlation with most of the stability measures but R_i^2 displayed high significant negative correlation with most of the stability measures. The statistics CV_i and $MS_{y/l}$ showed the greatest deviation from all the other procedures. ASV was correlated with the non-parametric measures $S_i^{(3)}$, SDR and the parametric measures S^2_{xi}, S^2d_i and W_i^2. The Wricke's ecovalence (W_i^2) showed the highest significant positive correlation with non-parametric methods ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $NP_i^{(1)}$, SDR and TOP) and significant negative correlation with R. To better understand the relationships among the parametric and non-parametric statistics, principal component analysis (PCA), based on the rank correlation matrix (Tables 3 and 4) was used. The first four PCAs explained 87.71% (45.08, 22.31, 13.22 and 4.10% by PCA_1, PCA_2, PCA_3 and PCA_4, respectively) of the variances in the original variables (Table 7). The relationships among different stability parameters are graphically displayed in a biplot of PCA_1 and PCA_2 (Fig. 1). The PCA_1 and PCA_2 axes mainly distinguish the parametric and non-parametric measures in different groups. Mean yield groups with non-parametric measures of Ys_i and TOP and we refer to group 1 stability measures. The PCs axes separated non-parametric measures ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $NP_i^{(1)}$) and parametric measures (b_i, S^2_{xi}, ASV, S^2d_i and W_i^2) (We refer to as group 2) from the statistics $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ (We refer to as group 3). R, RSM, Ri^2 and P_i were separated from the other classes (We refer to as group 4) (Fig. 1). Group1 included the Fox et al. (1990) adaptability measure (TOP), adaptability parameter of simultaneous selection for yield and stability statistic (Ys_i) and mean yield. The existence of mean yield in group 1 suggested that the genotypes G4, G8, G15, G17 and G1 comprised those methods where the mean yield showed the main influence on the ranking of genotypes across environments (Table 3). Ys_i and TOP as measures of genotypic performance, are attempting to integrate both yield and adaptability. Figure 1 indicates that these two measures are strongly related to grain yield. Based on these parameters, selection based on grain yield is favored, and is related to the dynamic (agronomic) concept of stability. According to Becker and Léon (1988), it was not a requirement that the genotypic response to

Table 3. Yield and parametric stability statistics for grain yield on 17 genotypes grown in 10 environments.

Code	P_i	$MS_{y/l}$	S^2_{xi}	CV_i	W_i^2	σ_i^2	S^2d_i	b_i	R_i^2	$IPCA_1$	$IPCA_2$	ASV	yield
G1	17889	334693	582396	40.51	1030323	123131	90368	1.27	0.90	-16.78	4.60	29.04	1774
G2	181869	152608	691385	45.24	868358	102735	89656	0.81	0.79	16.11	3.07	27.70	1610
G3	50276	166635	898018	1.64	492270	55376	58636	1.08	0.91	-9.65	4.78	17.17	1647
G4	4609	114452	771184	48.90	1194538	143809	149293	0.99	0.77	-15.94	-13.15	30.26	1884
G5	109879	92836	816601	50.94	1165090	140101	74794	0.63	0.73	10.93	-6.74	19.86	1734
G6	137150	209694	246490	28.63	583446	668857	66112	0.89	0.86	11.07	-9.00	20.94	1631
G7	12377	211155	419977	37.72	996324	118849	114952	1.14	0.85	-8.86	-14.55	21.00	1838
G8	126796	134527	894363	56.03	248790	24715	31049	1.01	0.94	6.38	6.36	12.62	1579
G9	116656	113618	265648	30.62	317027	33308	21660	0.81	0.94	4.40	-10.33	12.78	1579
G10	41947	131160	504929	42.50	1384354	167712	123067	1.31	0.88	-21.39	5.14	36.92	1688
G11	149965	263417	462991	41.14	692931	80644	83588	0.92	0.84	13.77	1.79	23.60	1654
G12	148618	232757	579149	46.66	1012020	120826	124006	0.93	0.78	14.71	10.82	27.36	1672
G13	75228	194750	415721	39.53	301936	31408	34766	0.92	0.93	4.36	-7.86	10.83	1718
G14	131855	97353	599626	48.04	800113	94141	51903	0.69	0.83	12.37	-11.65	24.14	1683
G15	33870	212684	377582	38.17	1602561	195190	157326	0.29	0.84	-0.64	26.79	26.81	1835
G16	74970	295668	492966	44.47	6633583	76948	79943	1.08	0.88	-3.21	14.60	15.59	1612
G17	16070	155775	320475	35.85	931459	110807	88986	1.23	0.90	-17.62	-4.66	30.46	1796
mean	84119	183164	549277	42.74	840360	99209	84771	1.00	0.86			22.77	1702

P_i- superiority index; $MS_{y/l}$- intra-locational variance; S^2_{xi}- environmental variance; CV_i- coefficient of variation; W_i^2-Wricke´s ecovalence; σ_i^2- stability variance of Shukla; S^2d_i- deviation from regression; b_i- regression coefficient; R_i^2- coefficient of determination; $IPCA_1$ and $IPCA_2$- interaction principal components axes 1 and 2, respectively; ASV-AMMI stability value.

Table 4. Non-parametric stability statistics for grain yield and tests of non-parametric stability measures ($Z_i^{(1)}$ and $Z_i^{(2)}$) for 17 chickpea enotypes across environments.

Code	$S_i^{(1)}$	$Z_i^{(1)}$	$S_i^{(2)}$	$Z_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	Ys_i	RSM	R	SDR	TOP	MID	LOW
G1	5.76	0.01	23.79	0.00	28.53	4.69	3.70	0.32	0.47	0.59	6	5.10	7.90	5.10	50	20	30
G2	5.27	0.16	23.21	0.01	20.77	4.05	3.50	0.44	0.57	0.65	-10	4.15	9.55	4.15	20	50	30
G3	5.80	0.03	25.21	0.03	22.21	4.33	3.90	0.65	0.65	0.79	1	4.10	10.4	4.10	10	30	60
G4	5.89	0.06	24.32	0.00	26.20	3.67	3.90	0.27	0.38	0.48	11	5.54	5.60	5.54	80	0	20
G5	6.71	1.24	34	1.71	24.70	4.08	4.20	0.41	0.57	0.69	5	4.69	7.80	4.69	30	50	20
G6	3.71	4.11*	10.72	3.02	17.40	3.73	2.30	0.29	0.41	0.49	-4	3.62	10.0	3.62	10	60	30
G7	6.62	1.04	35.51	2.27	19.85	3.38	4.20	0.38	0.54	0.64	9	4.39	7.20	4.39	20	70	10
G8	4.18	2.36	12.71	2.19	12.15	3.17	2.80	0.33	0.41	0.51	1	2.96	9.90	2.96	0	70	30
G9	3.84	3.58	12.06	2.44	19.58	5.91	2.70	0.54	0.56	0.66	-1	3.34	11.9	3.34	10	10	80
G10	6.00	0.14	26.40	0.10	33.17	5.91	4.20	0.76	0.71	0.87	1	4.70	10.6	4.70	10	30	60
G11	5.96	0.11	25.96	0.07	23.62	4.73	4.60	0.54	0.53	0.65	-2	4.50	7.35	4.50	30	30	40
G12	6.67	1.15	32.04	1.11	24.47	4.60	4.60	0.48	0.57	0.71	-1	4.87	8.10	4.87	40	30	30
G13	4.40	1.71	14.18	1.65	18.31	4.02	3.00	0.27	0.37	0.45	12	4.20	8.10	4.20	50	20	30
G14	5.09	0.34	31.43	0.95	29.42	4.88	4.50	0.41	0.55	0.53	0	5.45	8.20	5.45	30	30	40
G15	7.38	3.29	40.84	4.86*	34.00	4.79	5.40	0.39	0.52	0.64	8	6.52	6.50	6.52	470	0	30
G16	5.76	0.01	23.21	0.01	27.00	5.00	3.90	0.46	0.57	0.72	-5	4.70	9.70	4.70	20	50	30
G17	5.73	0.01	25.96	0.07	25.77	4.80	3.80	0.40	0.55	0.65	7	4.64	8.65	4.62	20	40	40
		19.34		20.46													
mean	5.57		24.78		23.94	4.46	3.84	0.43	0.53	0.63	2.2	18	8.67	4.56	29.40	34.71	35.88

Test statistics

$E(S_i^{(1)}) = 6.65$ $E(S_i^{(2)}) = 24$

$V(S_i^{(1)}) = 0.912$ $V(S_i^{(2)}) = 58.4$

χ^2 Sum = 26.30 $\chi^2 Z_1Z_2 = 3.84$

Yield mean: 1702 kg ha^{-1}

$S_i^{(1)}$- mean of absolute rank difference of a genotype over environments; $S_i^{(2)}$- sum of square deviations of the rank; Z-statistics- measures of stability; Z_1, Z_2- chi-square for $Z_i^{(1)}$ and $Z_i^{(2)}$; χ^2- sum chi-square for sum of $Z_i^{(1)}$, $Z_i^{(2)}$; $S_i^{(3)}$- variance among the ranks over environments; $S_i^{(6)}$- sum of absolute deviation; $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$- Thennarasu's non-parametric stability statistics; Ys_i- simultaneous selection for yield and stability; RSM- rank-sum method; R- mean of rank; SDR- standard deviation of rank; TOP, MID and LOW- top, middle and bottom third of ranks.

environmental conditions should be equal for all genotypes. Therefore, these parameters can be used to recommend genotypes adapted to favorable conditions in Iran. So, according to statistics Ys_i and TOP, genotypes G4, G13 and G15 were introduced as stable genotypes (Tables 4 and 5). Group 2 included the non-parametric measures ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $NP_i^{(1)}$) and parametric measures (b_i, S^2_{xi}, ASV, S^2d_i and W_i^2). These stability methods were positively and linearly correlated with each other (except for S^2_{xi} and b_i). All these parameters (except $NP_i^{(1)}$ and b_i) were significantly correlated with mean yield. Therefore, these parameters allow the identification of genotypes adapted to environments with favorable growing conditions. Non-parametric stability parameters of group 2 namely $Si^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $NP_i^{(1)}$, revealed that genotypes G6, G9, G8 and G13 with the lowest values for this stability parameters were stable genotypes and genotype G15 with highest values was unstable (Tables 4 and 5). According to parametric statistics of group 2 (S^2_{xi}, ASV, S^2d_i and W_i^2), genotypes G9, G8 and G13 were introduced as stable genotypes (Tables 3 and 5), but only genotype G13 had the highest mean yield. Stability statistics employed in this study quantified stability of genotypes based on yield or stability or yield and yield stability. But both yield and stability of performance should be considered simultaneously to exploit the useful effect of GEI and to make selection of the genotypes more precise and refined. Group 3 included the non-parametric measures of $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$. These provide a measure of stability in the static sense. These non-parametric methods were positively linearly correlated with each other (Table 5) indicating that they were similar for

Table 5. Ranks of 17 genotypes in different environments using non-parametric and parametric methods.

Stability measures	Genotypes																
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
$S_i^{(1)}$	8	6	10	11	16	1	14	3	2	13	12	15	4	5	17	8	7
$S_i^{(2)}$	7	5	9	8	15	1	17	3	2	12	10	14	4	13	16	5	10
$S_i^{(3)}$	14	6	7	12	10	2	5	1	4	16	8	9	3	15	17	13	11
$S_i^{(6)}$	10	6	8	4	7	2	3	1	17	16	11	9	5	14	12	15	13
$NP_i^{(1)}$	6	5	8	8	11	1	11	3	2	11	14	14	4	13	17	8	7
$NP_i^{(2)}$	4	11	15	1	10	3	6	5	13	16	14	13	2	9	7	12	8
$NP_i^{(3)}$	5	12	16	2	14	4	8	3	11	17	7	13	1	10	6	15	9
$NP_i^{(4)}$	6	10	16	2	13	3	8	4	12	17	11	14	1	5	7	15	9
Ys_i	6	17	8	2	7	15	3	8	12	8	14	12	1	11	4	16	5
RSM	7	15	5	4	10	17	2	7	10	15	7	14	1	5	10	10	3
R	6	10	13	1	5	17	3	14	16	15	4	7	7	9	1	12	11
SDR	6	17	8	2	7	15	3	8	12	8	14	12	1	11	4	16	5
TOP	3	6	7	1	5	7	6	8	7	7	5	4	3	5	2	6	6
P_i	16	8	9	2	1	13	11	7	4	5	15	14	12	3	10	17	6
$MS_{y/l}$	17	7	9	4	1	11	12	6	3	5	15	14	10	2	13	16	8
S^2_{xi}	10	13	17	14	15	1	6	16	2	9	7	11	5	12	4	8	3
CV_i	7	11	16	14	15	1	4	17	2	9	8	12	6	13	5	10	3
W_i^2	12	8	4	14	13	17	10	1	2	15	6	11	3	7	16	5	9
S^2d_i	12	11	5	16	7	6	13	2	1	14	9	15	3	4	17	8	10
b_i	15	3	11	9	1	5	13	10	4	17	6	8	7	2	16	12	14
R_i^2	6	14	4	16	17	9	10	2	2	8	12	15	3	13	12	8	6
ASV	14	13	5	15	6	7	8	2	3	17	9	12	1	10	11	4	16
yield	5	15	12	1	6	13	2	16	16	8	11	10	7	9	3	14	4

classifying genotypes according to their stability under different environmental conditions (Tables 4 and 5). Hence, only one of these statistics is sufficient for selecting stable genotypes. Not all of these parameters were significantly correlated with mean yield. Therefore, these parameters allow the identification of genotypes adapted to environments with unfavorable growing conditions. The non-significant correlation and negative significant correlation between yield and stability parameters suggest that, stability parameters provide information that cannot be gleaned from average yield alone. Therefore, according to procedures of group 3 ($NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$), genotypes G4 and G13 were introduced as stable and genotype G10 with highest values was unstable (Tables 4 and 5). Group 4 consists of parameters that were negatively associated with most of the stability methods and mean yield. This group included the measures of R, R_i^2, RSM and P_i. These measures exhibited negative rank correlation coefficients with most of the stability statistics and mean yield, compared to the other procedures (Table 6). However, these measures may not be as suitable as the other methods.

Discussion

Breeders can use stability analysis methods to identify cultivars that have predictable performance and that respond positively to improvements in environmental conditions. Currently, plant breeders have a full hand of methods for the analyses of genotype yield adaptability and stability to help in the difficult task of identifying superior cultivars in the presence of significant GEI (Eskridge, 1990). However, they frequently have difficulty in choosing the most suitable method for use in different situations. However, the choose of the best methodology depends on some factors, such as the number of genotypes and environment available, environmental variation, mathematical model fit to the data set, stability concept adopted and the facility to apply and interpret the results. Bsides, some methodologies are alternative while others are complementary, being able to be used jointly (Marcus et al., 2009). Genotype × environment interactions are important sources of variation in any crop and the term stability is sometimes used to characterize a genotype, which shows a relatively constant yield, independent of changing environmental conditions. On the basis of this idea, genotypes with a minimum variance for yield across different environments are considered stable. This idea of stability may be considered as a biological or static concept of stability (Becker and Léon, 1988). This concept of stability is not acceptable to most breeders and agronomists, who would prefer an agronomic or dynamic concept of stability; therefore they prefer genotypes with high mean yields and the potential to respond to agronomic inputs or better environmental conditions (Becker, 1981; Becker and Léon, 1988; Robert, 2002). In the dynamic concept of stability, it is not required that the genotype response to environmental conditions should be equal for all genotypes (Becker and Léon 1988). The measure of dynamic stability depends on the specific set of tested genotypes, unlike the measure of static stability (Lin et al., 1986). Static stability may be more useful than dynamic stability in a wide range of situations especially in developing countries (Simmonds, 1991). The parameter TOP and Ys_i were related to the dynamic concept of stability. Additionally, Sabaghnia et al. (2006) and Mohammadi and Amri (2008) pointed out that the TOP procedure was associated with mean yield and the dynamic concept of stability, therefore these parameters could be used to recommend cultivars adapted to favorable conditions. According to Huehn (1990a), non-parametric stability analysis procedures have the following advantages: they reduce the bias caused by outliers, 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 do not cause much variation of results. As a result, many researchers applied different non-parametric statistics to evaluate stability (Scapim et al., 2000; Yaksel et al., 2003; Solomon et al., 2007; Mevlut and Yuksel, 2008;

Table 6. Spearman rank correlation between mean yields and stability parametric and non-parametric measures for 17 genotypes across 10 environments.

	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	Ys_i	RSM	R	SDR	TOP	P_i	$MS_{y/l}$	S^2_{xi}	CV_i	W_i^2	S^2d_i	b_i	R_i^2	ASV
$S_i^{(1)}$	1.00																					
$S_i^{(2)}$	0.87**	1.00																				
$S_i^{(3)}$	0.55*	0.59*	1.00																			
$S_i^{(6)}$	0.06	0.14	0.59*	1.00																		
$NP_i^{(1)}$	0.84**	0.90**	0.64*	0.27	1.00																	
$NP_i^{(2)}$	0.27	0.23	0.19	0.62*	0.36	1.00																
$NP_i^{(3)}$	0.34	0.32	0.32	0.54*	0.33	0.86**	1.00															
$NP_i^{(4)}$	0.43	0.30	0.26	0.55*	0.36	0.92**	0.93**	1.00														
Ys_i	0.30	0.34	0.15	-0.29	0.11	-0.53*	-0.45	-0.43	1.00													
RSM	0.03	-0.13	0.07	0.25	-0.03	0.39	0.41	0.41	-0.70*	1.00												
R	0.59*	-0.56*	-0.30	0.33	-0.54*	0.45	0.44	0.38	-0.53*	0.40	1.00											
SDR	0.60*	0.62*	0.89**	0.31	0.68*	-0.10	0.03	-0.01	0.30	-0.06	-0.60*	1.00										
TOP	0.45	0.41	0.47	-0.04	0.46	-0.40	-0.37	-0.35	0.47	-0.29	-0.84**	0.76**	1.00									
P_i	-0.31	-0.28	-0.39	0.01	-0.08	0.33	0.13	0.11	-0.77*	0.52*	0.31	-0.38	-0.24	1.00								
$MS_{y/l}$	0.20	0.01	0.07	0.00	0.16	-0.05	-0.14	0.04	-0.10	0.02	-0.24	0.15	0.24	-0.04	1.00							
S^2_{xi}	0.44	0.31	0.50*	0.42	0.28	-0.04	-0.01	0.13	0.40	-0.13	-0.20	0.43	0.06	-0.71**	0.51*	1.00						
CV_i	0.21	0.14	0.10	-0.25	0.23	0.17	0.25	0.18	-0.05	0.05	-0.04	0.12	0.53*	0.15	-0.32	-0.20	1.00					
W_i^2	0.77**	0.72**	0.75**	0.15	0.62*	0.00	0.17	.017	0.32	0.18	-0.54*	0.79**	0.53*	-0.44	0.01	0.49*	0.01	1.00				
S^2d_i	0.73**	0.59*	0.58*	0.00	0.57*	-0.04	0.05	0.12	0.25	0.14	-0.57*	0.69**	0.02	-0.40	0.34	0.66*	-0.06	0.87**	1.00			
b_i	0.35	0.24	0.42	0.16	0.18	-0.02	0.01	0.14	0.41	-0.14	-0.06	0.31	0.02	-0.69**	0.47	0.98**	-0.20	0.37	0.52*	1.00		
R_i^2	-0.57*	-0.56*	-0.37	0.14	-0.60*	0.01	-0.14	-0.50*	0.08	-0.24	0.59*	-0.57*	-0.53*	-0.15	0.11	0.18	-0.27	-0.64*	-0.57*	0.34	1.00	
ASV	0.39	0.42	0.64*	0.22	0.36	0.06	0.13	0.10	0.10	0.14	-0.26	0.60*	0.30	-0.29	0.02	0.48*	-0.07	0.78**	0.77**	0.38	-0.45	1.00
yield	0.58*	0.63*	0.49*	-0.13	0.45	-0.42	-0.27	-0.27	0.81**	-0.48*	-0.75**	0.66*	0.67*	-0.74	0.06	0.50*	-0.15	0.71**	0.64*	0.41	-0.37	0.50*

Ns, * and **: non-significant, significant at the 0.05 and 0.01 level of probability, respectively.

Kan et al., 2010; Zali et al., 2011). Huehn (1990 a,b) suggested for a cultivar with maximum stability, $Si^{(1)} = S_i^{(2)} = S_i^{(3)}$. $Si^{(1)}$ and $S_i^{(2)}$ are based on ranks of the genotypes across environments and they give equal weight to each environment. $Si^{(1)}$ estimates are based on all possible pair-wise rank differences across environments for each genotype, whereas $S_i^{(2)}$ is based on the variance ranks for each genotype across environments (Nassar and Huehn, 1987). In this experiment, classification of genotypes based on these parameters was similar. This agrees with the earlier findings of Scapim et al. (2000), Sabaghnia et al. (2006) and Yaksel et al. (2003). According to Huehn (1990b) $Si^{(1)}$ and $S_i^{(2)}$ are functions only of the stability measurements whereas numerical values of $Si^{(3)}$ and $S_i^{(6)}$ combine yield and stability based on yield ranks of genotypes in each environment. The results of this experiment showed that these parameters were significantly (P<0.05) and positively correlated with each other. Flores et al. (1998) also reported significant and positive association between $Si^{(1)}$ and $S_i^{(2)}$. Scapim et al. (2000) also found high significant correlation among $Si^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$. This suggests that one of the three statistics could be used to assess stability. All of these statistics were positively correlated with grain yield. Nassar and Huehn (1987) indicated that $Si^{(1)}$ and $S_i^{(2)}$ are associated with the static biological concept of stability, as they define stability in the sense of homeostasis. Sabaghnia et al. (2006) also reported that $Si^{(1)}$ and $S_i^{(2)}$ represent static concept of stability. Thus, $Si^{(1)}$ and $S_i^{(2)}$ could be used as a compromise method that select genotypes with moderate yield and yield stability. Distinct clustering of $Si^{(1)}$ and $S_i^{(2)}$ also confirms that these two non-parametric statistics can define stability in terms of static or biological concept and hence would have little relevance in selecting genotypes that can respond to changing environmental conditions. $S_i^{(3)}$ and $S_i^{(6)}$ were strongly correlated to Thennarasu's non-parametric statistics. Sabaghnia et al. (2006) and Solomon et al. (2007) also found similar association between $S_i^{(3)}$ with $NP_i^{(1)}$ and $S_i^{(6)}$ with ($NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$) and pattern of grouping based on principal component analysis. Thennarasu's non-parametric stability statistics (1995) uses ranks from adjusted yield. According to these procedures, stable genotypes are those whose adjusted ranks remain unaltered in relation to the other in the set of environments assessed. $NP_i^{(3)}$ and $NP_i^{(4)}$ express stability in units of mean ranks; therefore they are very much similar to $S_i^{(3)}$ and $S_i^{(6)}$. $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ were grouped in the same group 3 (Fig. 1) and showed high correlations. These suggest that Thennarasu's non-parametric stability estimates did not add important information to those statistics obtained by Nassar and Huehn (1987). Thus, the use of Huehn (1990b) stability parameters could be a method of choice as there is a statistical procedure available to test the significance of $Si^{(1)}$ and $S_i^{(2)}$. However, Thennarasu's non-parametric stability estimates (1995) would be important alternatives to parametric models. The non-parametric approaches used in our study did not however seem to provide an overall picture of the individual genotype responses to environment. Some genotypes displayed stability using some parameters and instability for others. For example, genotype G6 was assessed as stable using $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ but unstable with RSM, R and SDR parameters, thus making it difficult to reconcile these assessments into a unified conclusion. This is a problem that has been identified in GEI studies (Lin et al., 1986). This difficulty is brought about by the use of parametric approaches for the analysis, which transform a genotypes response to environments from its multivariate state to a univariate one. One method of getting over this problem is to assign genotypes into qualitatively homogeneous stability subsets through principal component analysis. With regards to most of the stability estimates, the genotype G13 was found to be the most stable with high yield.

Materials and methods

Plant materials

In order to evaluate phenotypic stability and comparison between parametric and non-parametric stability indices 17 chickpea genotypes were studied in five different research stations (Ghachsaran, Gorgan, Ilam, Kermanshah and Lorestan) in Iran across the years 2004 and 2005. The genotypes were developed at different research Institutes/ Stations of Iran and that of the International Center for Agricultural Research in the Dray Areas (ICARDA), Syria. The names, origin and genotypic codes of these genotypes are given in Table 1.

Experimental design

Experimental layout was a randomized complete block design with four replications in each environment. Each plot consisted of 4m rows and at 10×30 cm inter-plant and inter-row distances, respectively. After separation of border effects, data on seed yield were taken from the middle two rows of each plot for each genotype at each test environments.

Statistical analysis

Test of significance GEI

A parametric combined analysis of variance (ANOVA) (F-test) and three non-parametric statistical procedures were used as follows to test the significance of GEI.

$$\frac{12}{lm(N+1)}\sum_{i=1}^{l}\sum_{j=1}^{m}(\overline{R}^{**}_{ij.}-\overline{R}^{**}_{i..}-\overline{R}^{**}_{.j.}+\overline{R}^{**}_{...})^2$$

(Kubinger, 1986)

$$\frac{12}{lm(N+1)}\sum_{i=1}^{l}\sum_{j=1}^{m}(\overline{R}_{ij.}-\overline{R}_{i..}-\overline{R}_{.j.}+\overline{R}_{...})^2$$

(Hildebrand, 1980)

$$\frac{12}{n^2l(nl+1)}(\sum_{i=1}^{l}\sum_{j=1}^{m}R^2_{ij.}-\frac{l}{m}\sum_{i=1}^{l}R^2_{i..})$$

(*De* Kroon and *Van* der Laan, 1981)

Where, i = 1, 2, …, l genotypes; j = 1, 2, …, m environments; k = 1, 2, …, n replications; R_{ij} = rank of original data X_{ijk}; R_{ij}^{**}= rank of transformed data X^*_{ijk} (= X_{ijk} - $\overline{X}_{i..}-\overline{X}_{.j.}+2\overline{X}_{...}$) and $\overline{R}$ = mean of ranks.

The test statistics of nonparameric methods are pproximately χ^2- distributed with (n-1) (m-1) degrees of freedom, where n = number of genotypes and m = number of environments.

Table 7. Loadings of rank derived from different parametric and non-parametric measures for PC1, 2, 3 and 4.

Stability measures	Principal components (PC)1, 2, 3 and 4			
	PC_1	PC_2	PC_3	PC_4
$S_i^{(1)}$	0.887	-0.128	0.127	-0.270
$S_i^{(2)}$	0.849	0.122	0.243	-0.347
$S_i^{(3)}$	0.825	-0.323	-0.024	0.027
$S_i^{(6)}$	0.167	-0.687	-0.215	-0.056
NP_1	0.841	-0.192	0.202	-0.355
NP_2	0.083	-0.906	-0.115	-0.221
NP_3	0.255	-0.903	-0.020	-0.277
NP_4	0.292	-0.877	-0.128	-0.192
Ys_i	0.446	0.650	-0.419	-0.243
RSM	-0.155	-0.492	0.404	0.691
R	-0.680	-0.638	-0.250	0.117
SDR	0.898	0.117	0.144	-0.040
TOP	0.646	0.568	0.137	0.033
P_i	-0.573	-0.257	0.695	0..027
S^2_{xi}	0.639	-0.115	-0.660	0.287
W_i^2	0.934	-0.121	0.151	0.211
σ_i^2	0.934	-0.121	0.151	0.211
S^2d_i	0.897	0.002	0.089	0.292
b_i	0.495	-0.100	-0.767	0.269
R_i^2	-0.488	-0.052	-0.822	-0.02
ASV	0.726	-0.254	0.067	0.439
yield	0.793	0.515	-0.162	-0.016
Eigen value	9.92	4.91	2.91	1.07
Explained variance	45.08	22.31	13.22	4.10
Cumulative variance	45.08	67.39	80.62	87.71

Parametric stability statistics

Environmental variance **(S^2_{xi})**

The environmental variance (Roemer, 1917) is one of the major stability measures for the static stability concept (Lin et al., 1986) and is calculated for each genotype across test environments. This measure was calculated as follows:

$$S^2_{xi} = \frac{\sum \left(x_{ij} - \bar{x}_{i.}\right)^2}{\left(E-1\right)}$$

where x_{ij} is the grain yield of genotype i in environment j, $\bar{x}_{i.}$ is the mean yield of genotype i and E is the number of environments.

Coefficient of variation (CV_i)

Stability was also measured by the combining use of coefficient of variation (CV_i) and mean yield (Francis and Kannenberg, 1978):

$$CV_i = \left(\sqrt{S_i^2} / \bar{x}_{i.}\right) \times 100$$

Wricke's ecovalence **(W_i^2)**

Wricke's ecovalence was calculated for the genotype i as:

$$W_i^2 = \sum_{i=1}^{n} \left(x_{ij} - \bar{x}_{i.} - \bar{x}_{.j} + \bar{x}_{..}\right)^2$$

where X_{ij} is the observed yield response (averaged across experiment replicates), $\bar{X}_{i.}$ = mean yield of genotype i, $\bar{X}_{.j}$ = mean yield of environment j and X.. is the grand mean.

Shukla' (1972) stability variance (σ_i^2)

$$\sigma_i^2 = \left[p/(p-2)(q-1)\right]W_i^2 - \left[SS(GE)/(p-1)(p-2)(q-1)\right]$$

Where

$$SS(GE) = \sum_i W_i^2 = \sum_i \sum_j \left(x_{ij} - \bar{x}_{i.} - \bar{x}_{.j} + \bar{x}_{..}\right)^2$$

, p = number of genotypes and q = number of environments. With this statistics the genotype that is most stable is the one that minimizes the σ_i^2.

Superiority index **(P_i)**

P_i-value was calculated as (Lin and Binns, 1988a):

$$P_i = \frac{\sum_{j=1}^{n} \left(x_{ij} - M_j\right)^2}{2E}$$

Where X_{ij} is the grain yield of genotype i in environment j, M_j is the yield of the genotype with maximum yield at environment j and E is the number of environments.

Regression approach

Eberhart and Russell (1966) proposed an assessment of cultivar responses to environmental changes using a linear regression coefficient (b_i) and the variance of the regression deviations (S^2_{di}):

$$b_i = 1 + \frac{\sum_i \left(x_{ij} - \bar{x}_{i.} - \bar{x}_{.j} + \bar{x}_{..}\right)\left(\bar{x}_{.j} + \bar{x}_{..}\right)}{\sum_j \left(\bar{x}_{.j} + \bar{x}_{..}\right)^2}$$

$$S_{di}^2 = \frac{1}{E-2}\left[\sum_i \left(x_{ij} - \bar{x}_{i.} - \bar{x}_{.j} + \bar{x}_{..}\right) - \left(b_i - 1\right)^2 \sum_i \left(\bar{x}_{.j} + \bar{x}_{..}\right)^2\right]$$

where X_{ij} is the grain yield of genotype i in environment j, $\bar{X}_{i.}$ is the mean yield of genotype i and $\bar{X}_{.j}$ is the mean yield of the environment j, X.. is the grand mean and E is the number of environments.

***Coefficient of determination* (R_i^2)**

Pinthus (1973) proposed this parameter as a measure of stability instead of S^2_{di}. With this parameter the most stable genotype have minimum R_i^2.

$$R_i^2 = \frac{b_i^2 \sum_j \left(\bar{x}_{ij} - \bar{x}_{..}\right)^2}{\sum_j \left(\bar{x}_{ij} - \bar{x}_{i.}\right)^2}$$

Intra-locational variance (*$MS_{y/l}$*)

($MS_{y/l}$) = (sum of within location variances)/ (number of locations) (Lin and Binns, 1988b).

AMMI stability value (*ASV*)

Purchase et al. (2000) suggested ASV for each genotype and each environment according to the relative contribution of $IPCA_1$ to $IPCA_2$ to the interaction SS as follows:

$$ASV = \sqrt{\left[\frac{IPCA1_{sumofsquare}}{IPCA2_{sumofsquare}}\left(IPCA1_{score}\right)\right]^2 + \left(IPCA2_{score}\right)^2}$$

Non-parametric stability approaches

Huehn (1979) and Nassar and Huehn (1987) proposed four non-parametric stability statistics that combine mean yield and stability. Four parameters based on yield ranks of genotypes in each environment are derived as follows:

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

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

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

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

Kang's (1993) rank-sum is another non-parametric stability procedure where both yield and Shukla's (1972) stability variance are used as selection criteria. 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 third of trial entries. Thennarasu (1995) proposed the four following non-parametric stability measures:

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

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

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

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

In the above formulas, r_{ij}^* is the rank of x_{ij}^*, $\bar{r}_{i.}^*$ 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. Standard deviation of rank (SDR) and rank mean (R) (Ketata, 1988) were measured as:

$$S_i^2 = \frac{\sum_{j=1}^{m} (R_{ij} - \bar{R}_{i.})^2}{l-1}$$

Where R_{ij} is the rank of X_{ij} within the jth environment, $\bar{R}_{i.}$ is the mean rank across all environments for the ith genotype and SDR= $(S^2_i)^{0.5}$. Genotypes with minimum R and SDR are the most stable. Spearman's coefficient of rank correlation (r_s) was employed (Steel and Torrie, 1980) as:

$$r_s = 1 - \frac{6\sum d_i^2}{(n-1)n(n+1)}$$

To understand better relationships among stability methods, principal component analysis (PCA), was performed. For statistical analysis the sofwares IRRISTAT, MSTAT-C, SPSS and STATISTICA were used.

Conclusions

Despite the fact that different stability measures are indicative of high, intermediate or low stability performance, the stability values do not provide information for reaching definitive conclusions. Therefore, the results of biplot analysis based on rank correlation showed that statistics ASV, S^2_{xi}, W^2_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $NP_i^{(1)}$ are indispensable because farmers would prefer to use high-yielding genotypes that perform consistently from one environment to another. Among type 1 stability measures, S^2_{xi} has the advantages of moderately repeatable in most instances, theoretical advantage of independent estimate from the set of tested genotypes and allow, therefore, for a broader generalization (Lin *et al*., 1986). But does not react to changing environmental conditions. Type 2 stability statistics (e.g., ASV, W^2_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $NP_i^{(1)}$) has the advantage of reaction to changing environmental conditions similarly to the mean reaction within the pool of genotypes. The main problem with stability statistics is that they do not provide an accurate picture of the complete response pattern (Hohls, 1995). The reason is that a genotype's response to varying environments is multivariate (Lin et al., 1986) whereas the stability indices are usually univariate. Therefore, among the results of this investigation ASV has the advantages of a slight increase of repeatability compared with other type 2 measures (Annicchiarico, 2002), multivariate response and dynamic or agronomic concept of stability (Becker and Léon, 1988), accordingly it is recommended as the most appropriate measure of stability among the stability indices investigated. Most of the stability methods also indicated that the genotype G13 (FLIP 97-114) was the most phenotypically stable with high mean yield. However, several stability measures that have been used in this study quantified stability of genotypes with respect to yield, stability or both. Therefore, both yield and stability should be considered simultaneously to exploit the useful effects of GEI and to refine selection of genotypes. It is to be mentioned that methods producing ranks highly correlated with yield do not necessarily produce the same ranks neither for stability nor simultaneously for both stability and yield. Thus, mean yield was also included as a comparison or reference (Flores et al., 1998). The results of the correlation matrix and the PCA analysis from parametric and non-parametric measures showed that these parameters can be used for evaluating the responses of chickpea genotypes to changing environments. In other words, any one of them can be used for genotypic evaluation. The repeatability, similarity and power of parametric and non-parametric methods for selecting the best genotypes in different crops need to be further investigated.

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