Middle Eastern and Russian Journal of Plant Science and Biotechnology ©2009 Global Science Books

Comparison of Parametric and Non-Parametric Yield Stability Measures and their Relationship in Spring Rapeseed (*Brassica napus* L.) in Warm Dry-Lands of Iran

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ABSTRACT

The genotype × environment interaction and estimation of phenotypic yield stability have been widely used by plant breeders in different crops during the past four decades. Nine advanced spring rapeseed (*Brassica napus* L.) genotypes were tested at nine environments in warm dry-lands of Iran in 2003 and 2004. The phenotypic yield stability estimated through 20 parametric and non-parametric measures to assess G × E interactions. The objectives of present study were to identify stable rapeseed genotypes and the relationships among parametric and non-parametric stability parameters. The result of Spearman's rank correlation showed strong positive correlation between mean yield and superiority index (P_i) and geometric adaptability index (*GAI*) moreover there were negative significant correlation between mean yield and all non-parametric stability statistics except $NP_i^{(1)}$. The results of biplot of first two principal components revealed five groups. The group I including P_i and *GAI* which were strongly and positively correlated with mean yield and integrated both yield and stability. Selection based on these stability parameters is related to the dynamic or agronomic concept of stability. The environmental variance (S^2_{xi}) and all non-parametric measures except $NP_i^{(1)}$ were included in group IV that negatively correlated with mean yield. Selection of stable genotypes based on this group is related to the static or biological concept of stability. The group II was intermediate between group I and Group IV and influenced by both yield and stability simultaneously. The group III including only coefficient of variation (CV_i) that was intermediate between group II and IV. The group V included *IPCA2* and S^2_{di} that was intermediate between group IV and I. According to harsh conditions and high fluctuations of warm dry-lands of Iran genotypes G_4, G_2 and G_9 can be selected as stable and high yielding cultivars.

Keywords: G×E interaction, spring rapeseed, yield stability statistics

INTRODUCTION

Rapeseed cultivars vary in their low temperature requirement to induce flowering (vernalization). Winter types are sown in the fall in cold and semi-cold areas but spring types can be sown in the spring as well as in the fall. Winter cultivars are usually higher yielding than spring cultivars. In Iran, cultivation of spring rapeseed varieties has recently extended in warm dry-lands in rotation with wheat to boost the edible oil production (Pourdad 2007).

Stability of production under different environments is an important consideration in plant breeding. When cultivars are being selected for a large group of environments, stability and mean yield across all environments are more important than yield for specific environments (Piepho 1996). Several parametric and non-parametric statistical methods have been proposed for measuring stability in multi-environmental trials (MET). Each of them reflects different aspects of stability and no single method can adequately explain cultivar performance across environments. Parametric methods can be divided to univariate and multivariate stability statistics.

Joint regression is the most popular univariate method (Yates and Cochran 1938), which was further developed (Finlay and Wilkinson 1963; Eberhart and Russell 1966). Environment variance (S^2_{xi}) (Lin *et al*. 1986; Becker and Léon 1988), Shukla's stability variance (σ_i^2) (Shukla, 1972), Wricke's ecovalance (W^2_i) (Wricke 1962), coefficient of variability (CV_i) (Francis and Kanenberg 1978) and superiority index (P_i) (Lin and Binns 1988) are the some other univariate stability statistics.

The regression model may be extended by adding an environmental main effect and more than one multiplicative term which has been popularized under the acronym AMMI (Main Effect and Multiplicative Interaction) (Gauch 1988, 1992). AMMI is currently the main alternative multivariate approach to the joint regression analysis in many breeding programs (Annicchiarico 1997). This procedure uses a combination of statistical techniques, namely, ANOVA (univariate) and Principal component analysis (*PCA*) (multivariate). AMMI's stability value (*ASV*) calculated based on AMMI model's *IPCA1* and *IPCA2* scores for each genotype it is in effect the distance from the coordinate point to the origin in a two-dimensional scattergram of *IPCA1* score against *IPCA2* scores (Purchase 1997; Purchase *et al*. 2000).

Parametric measures of yield stability may be sensitive to the underlying assumptions. It is therefore of interest to find alternative measures that are more robust to departures from common assumptions such as normality (Piepho and Lotito 1992). Four non-parametric statistics of phenotypic stability $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$ proposed based on ranks of genotypes in each environment and use the idea of homeostasis as a measure of the stability (Huehn 1979, 1990). Distribution-free tests were developed for two of them (Nassar and Hüehn 1987; Huehn and Nassar 1989, 1991). Another four non-parametric measures $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ proposed as stability measures based on adjusted ranks of genotypes within each test environment (Thennarasu 1995).

There are limited studies of yield stability on rapeseed (Huehn 1987; Brandle and Mc Vatty1988; Shafii *et al*. 1992; Wani 1992; Ali *et al*. 2003; Abou El-Nasr *et al*. 2006). Therefore, the objectives of the present study were

Received: 28 April, 2009. Accepted: 7 July, 2009.

Original Research Paper

to: i) identify stable rapeseed genotypes over different environments for seed yield; ii) Study the relationships among parametric and non-parametric stability parameters and their associations with rapeseed mean yield.

MATERIALS AND METHODS

Trials

The rapeseed genotypes used in this study were nine advanced genotypes were selected from a spring rapeseed breeding program in Dry-land Agricultural Research Institute of Iran (DARI). Genotypes were tested at nine environments including five different locations (Sarpol-e-Zahab, Gachsaran, Pol-e-Dokhtar, Gonbad and Masjed soliman) in 2003 and 2004 (**Table 1**). Genotypes were planted in fall under rainfed conditions and were evaluated in a randomized complete block design with three replications in each environment. Plot size was 5 × 1.8 m including 6 rows with 30 cm row spacing. Fertilizer application was 50 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1}.

ANOVA

Combined analysis of variance was performed for all environments included five locations and two years (data of Masjed Soliman was for one year). The treatment sum of squares was partitioned into its three components: genotype (G), environment (E) and genotype by environment interaction (GEI). Furthermore according to AMMI3 model the GEI partitioned into *IPCA1*, *IPCA2*, *IPCA3* and residuals (Gauch 1992).

Parametric measures

According to the joint regression model (Eberhart and Russell 1966), a stable genotype is one with b=1 and S^2_{di}=0. The ecovalence (W^2_i) measure (Wricke 1962) proposed to further describe stability. The GE interaction effect for genotype i, squared and summed across environments, is the stability measures for genotype i. Low ecovalence (W^2_i) value indicates high relative stability, greatest stability is when W^2_i =0. Environmental variance, S^2_{xi} (Lin *et al*. 1986) is a measure for static concept of stability and a genotype with minimum S^2_{xi} under different environments is considered to be stable. The stability was also measured through combining the mean yield and coefficient of variation (CV_i) (Francis and Kannenberg 1978), genotypes with low CV_i and high mean yield were considered as most desirable. Superiority measure (P_i) is the mean square of distance between genotype i and the genotype with the maximum yield within each environment (Lin and Binns 1988). A low value of P_i indicates high relative stability.

Geometric mean can be use as a measure of adaptability of genotype which called as geometric adaptability index (*GAI*). It is calculated as:

$$GAI = \sqrt[E]{(\bar{X}_{1.})(\bar{X}_{2.})....(\bar{X}_{l.})}$$

where $\bar{X}_{1.}$, $\bar{X}_{2.}$ and $\bar{X}_{l.}$ are the mean yields of the first, second and lth genotypes across environments and E is the number of environments. Genotypes with high GAI will be desirable. AMMI's stability value (*ASV*) (Purchase 2000) calculated based on the AMMI model's *IPCA1* and *IPCA2* scores for each genotype. The genotypes with the highest *ASV* values are considered the most stable. It is calculated as below:

$$ASV = \sqrt{\left[\frac{SS_{IPCA1}}{SS_{IPCA2}}(IPCA1_{Score})\right]^2 + (IPCA2_{Score})^2}$$

where SS_{IPCA} = sum of squares of IPCA.

Non-parametric methods

Eight non-parametric parameters were used to measure yield stability of rapeseed genotypes. Four of these are based on yield rank of genotypes in each environment (Huehn 1979; Nassar and Hühn 1987) as shown next:

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

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

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

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

For a two-way data with *l* genotypes and *m* environments, we denote r_{ij} as the rank of the ith genotype in the jth environment, and $\bar{r}_{i.} = \sum_j \frac{r_{ij}}{m}$.

The other non-parametric measures were $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ (Thennarasu 1995) calculated based on ranks of adjusted means of the genotypes in each environment. The adjusted means calculated from adjusted values ($X^*_{ij} = X_{ij} - \bar{X}_{i.} + \bar{X}_{..}$), where X_{ij} is the performance of the i^{th} genotype in the j^{th} environment, $\bar{X}_{i.}$ is the mean performance of the i^{th} genotype and $\bar{X}_{..}$ is the overall mean across environments. These statistics calculated as follows:

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

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

$$NP_i^{(3)} = \frac{\sqrt{\sum_{j=1}^{m}\left(r^*_{ij} - \bar{r}^*_{i.}\right)^2 \Big/ m}}{\bar{r}_{i.}}$$

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

where r^*_{ij} is the rank of adjusted values (X^*_{ij}), M^*_{di} and $\bar{r}^*_{ij}$ are the median and mean ranks based on adjusted values, respectively, while M_{di} and $\bar{r}_{ij}$ are the median and mean ranks based on original values.

Spearman's rank correlation coefficients were used to determine relationships among stability parameters. Statistical analyses were carried out using SAS version 9 (SAS Institute 2002).

RESULTS AND DISCUSSION

ANOVA

The results of additive main effect and multiplicative interaction (AMMI) analysis and partitioning of variances are shown in **Table 2**. The analysis of variance (additive main effect) showed significant effect for environments (E), genotypes (G) and GE interaction. The results revealed that 79.2% of treatment sum of squares ($SS_G + SS_E + SS_{GE}$) was attributed to environment effect; 9.3 and 11.5% were attributed to genotype and GE interaction, respectively. The high proportion of environment sum of squares out of treatment sum of squares could be attributed to the high differences across environments (locations and seasons) so that they ranged from different amounts of precipitation (**Table 1**). On the other hand, the low proportion of genotype effect was due to the plant materials which were advanced genotypes and selected during a breeding program. These are in agreement with data reported for soybean (Gauch and Zobel 1988), cotton (Kerby *et al*. 1996, 2001; Baxevanos *et al*. 2008) and safflower (Mohammadi *et al*. 2008; Pourdad and Mohammadi 2008). Results from analysis of multiplicative effects showed that the first, second and third interaction

Table 1 Genotypes description and environmental characterization of spring rapeseed multi-environment.

Genotype	Code	Origin	Type *	Location	Altitude (m)	Rainfall (mm)	Soil type	Mean temperature (°C)	
								Min	Max
Quinta	G1	Germany	O.P.	Sarpol-e-Zahab	590	390	Silt-loam	-6.8	47
Hyola 308	G2	Australia	Hybrid	Pol-e-Dokhtar	713	373	Silt-clay	-1	48
Option500	G3	Australia	O.P.	Gachsaran	710	460	Silt-loam	-2	46
Hyola 401	G4	Australia	Hybrid	Gonbad	37	428	Silt-loam	-2	38
Global	G5	Canada	O.P.	Masjed Soliman	321	481	Silt-loam	-4.4	51
Kristina	G6	Canada	O.P.						
Regent	G7	Canada	O.P.						
Goliath	G8	Denmark	O.P.						
Shiralee	G9	Australia	O.P.						

* O.P.= Open pollinated

Table 2 ANOVA for seed yield of 9 spring rapeseed genotypes in 9 environments.

Source	d.f.	Mean of squares	Variance explained (%)
Total	242	889408.2	--
Treatment	80	2599962.2 **	96.6
Environments(E)	8	20606869.0 **	79.2
Genotypes (G)	8	2415657.7 **	9.3
GEI	64	372136.9 **	11.5
IPC1	15	1137692.1 **	71.6
IPC2	13	236598.4 **	12.9
IPC3	11	245967.9 **	11.4
Residual	25	38798.3 ^{ns}	4.1

ns and ** indicate non-significant and significant at the 0.01 probability levels, respectively.
IPCA1, IPCA2 and IPCA3 are first, second and third interaction principal component, respectively.

principal component axis (IPCA1, IPCA2 and IPCA3) explained 71.6, 12.9 and 11.4% of GEI sum of squares, respectively (**Table 2**). Theses three *IPCAs* were significant at p≤0.01 and were accumulatively contributed to 95.9% of the GEI sum of squares. The most accurate model for AMMI can be predicted by using the first three *IPCAs*, although *IPCA1* and *IPCA2* can accumulatively accounted to 84.5% of the total GEI.

The mean yield of genotypes over environments was ranged from 696.4 to 1607.4 Kg ha^{-1} along with grand mean yield of 1181 Kg ha^{-1}. The genotype of G_4, G_2, G_3, G_6, G_9, and G_1 were above grand mean yield (**Table 3**).

Parametric measures

Since the GE interaction was significant, the mean yield of the genotypes was subjected to different stability analyses. According to Eberhart and Russell's (1966) the genotypes G_8, G_9, and G_1 had the low S^2_{di} and b_i near 1.0, indicating average stability over environments. Moreover, the genotypes G_9 and G_1 were above grand mean yield. The genotype G_4 with the highest mean yield performance had larger b_i value indicating sensitivity to environmental change that was suitable for favorable environments E_7 and E_8 with 3750 Kg ha^{-1} seed yield (data not shown). Corresponding to environmental variance (S^2_{xi}) the G_5 and G_7 with minimum variance over different environments were considered to be stable and G_2 and G_4 considered to be unstable genotypes. There was very strong negative and significant correlation between seed yield and S^2_{xi} (**Table 5**). By using Francis and Kannenberg's (1978) stability parameter (CV_i) the genotypes G_3, G_5 and G_8 considered to be stable with different mean seed yields in the other hand, G_2, G_4 and G_9 with high CV_i considered to be unstable genotypes with high seed yields. There was no significant correlation between coefficient of variance and seed yield (**Table 5**). When the superiority index (P_i) (Lin and Binns 1988) was used the genotypes G_2 and G_4 with the highest seed yield considered to be stable while G_5 and G_7 with the highest P_i value were the unstable genotypes along with the lowest seed yield (**Tables 3** and **4**). There was very strong positive and significant correlation between seed yield and P_i (**Table 5**). According to Wricke's (1962) stability parameter (W^2_i) the genotypes G_1, G_8 and G_9 with lower ecovalance were considered to be sta-

Table 3 Mean seed yield and estimates of stability measures for 9 spring rapeseed genotypes tested over 9 environments.

Stability measures	Genotypes								
	G1	G2	G3	G4	G5	G6	G7	G8	G9
Mean Yield	1248.74	1374.92	1353.24	1607.36	696.40	1277.65	733.05	1076.56	1260.70
b_i	1.04	1.32	0.93	1.55	0.51	1.04	0.61	0.83	1.17
S^2_{di}	25481.44	59380.56	52764.69	15637.88	19512.85	54869.05	23908.57	22545.53	22073.19
S^2_{xi}/1000	801.45	1301.82	661.46	1740.57	200.28	821.59	290.88	516.83	1000.36
CV_i	65.04	77.44	58.53	76.98	63.21	67.48	68.14	63.04	75.43
P_i/1000	191.32	83.77	182.39	16.98	837.23	176.96	754.69	361.10	154.68
W^2_i/1000	242.18	1268.42	514.22	2327.08	1930.42	504.21	1286.80	403.64	405.45
IPCA1	1.05	19.05	-4.54	28.84	-23.65	3.30	-21.16	-10.00	7.11
IPCA2	-10.48	-3.48	-18.71	-0.02	6.53	21.10	-3.66	3.60	5.12
IPCA3	5.81	105.68	-25.18	160.04	-131.22	18.31	-117.38	-55.49	39.45
ASV	11.99	105.74	31.37	160.04	131.39	27.94	117.44	55.61	39.78
GAI	977.41	1023.40	1178.72	1171.03	595.29	1039.07	576.62	885.80	936.07
$S_i^{(1)}$	0.33	0.26	0.53	0.53	0.31	0.46	0.09	0.20	0.51
$S_i^{(2)}$	2.02	3.96	5.56	6.47	2.49	3.16	0.46	1.46	4.80
$S_i^{(3)}$	4.27	10.38	17.49	25.43	3.15	8.29	0.54	2.58	9.60
$S_i^{(6)}$	2.50	4.14	6.97	8.14	1.47	4.14	0.76	1.84	3.60
$NP_i^{(1)}$	1.64	2.00	1.91	3.27	3.18	1.27	2.46	1.46	2.00
$NP_i^{(2)}$	0.33	0.67	0.64	3.27	0.40	0.42	0.31	0.24	0.40
$NP_i^{(3)}$	0.41	0.62	0.70	1.41	0.44	0.45	0.33	0.31	0.49
$NP_i^{(4)}$	0.09	0.11	0.18	0.24	0.09	0.11	0.06	0.05	0.11

b_i= regression coefficient; S^2_{di}= variance of deviation from regression; S^2_{xi}= Environment variance; W^2_i=Wricke's ecovalance; CV_i= coefficient of variability; P_i=superiority iindex; IPCA1, IPCA2 and IPCA3=First, second and third interaction principal component axis; ASV= AMMI's stability value; GAI= geometric adaptability index; $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$= non-parametric measures suggested by Nassar and Huehn (1987) and Huehn (1979); $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$= non-parametric measures suggested by Thennarasu (1995).

Table 4 Ranks of seed yield and stability parameters for 9 spring rapeseed genotypes over 9 environments.

Stability measures	Genotypes								
	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**
Mean	6	2	3	1	9	4	8	7	5
b_i	1	4	2	7	6	1	5	3	3
S^2_{di}	6	9	7	1	2	8	5	4	3
S^2_{xi}/1000	5	8	4	9	1	6	2	3	7
CV_i	4	9	1	8	3	5	6	2	7
P_i/1000	6	2	5	1	9	4	8	7	3
W^2_i/1000	1	6	5	9	8	4	7	2	3
IPCA1	1	6	3	9	8	2	7	5	4
IPCA2	7	2	8	1	6	9	4	3	5
IPCA3	1	6	3	9	8	2	7	5	4
ASV	9	4	7	1	2	8	3	5	6
GAI	5	4	1	2	8	3	9	7	6
$S_i^{(1)}$	5	3	8	8	4	6	1	2	7
$S_i^{(2)}$	3	6	8	9	4	5	1	2	7
$S_i^{(3)}$	4	7	8	9	3	5	1	2	6
$S_i^{(6)}$	4	6	8	9	2	6	1	3	5
$NP_i^{(1)}$	3	5	4	9	8	1	7	2	5
$NP_i^{(2)}$	3	8	7	9	4	6	2	1	5
$NP_i^{(3)}$	3	7	8	9	4	5	2	1	6
$NP_i^{(4)}$	3	5	8	9	3	7	2	1	6

ble and G_2, G_4, G_5 and G_7 with high ecovalance were unstable genotypes. There was a non-significant correlation between seed yield and W^2_i. On the basis of AMMI stability value (*ASV*) G_1, G_3 and G_6 ranked as three most stable genotypes and G_5 and G_7 as unstable genotypes. There was no significant correlation between seed yield and *ASV*. Geometric adaptability index (*GAI*) revealed that the genotypes G_3 and G_4 were the most stable and G_5 and G_7 were the most unstable genotypes. The *GAI* showed significant and positive correlation with seed yield (0.88**).

Non-parametric measures

Results of non-parametric stability statistics showed that considering to $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ the genotypes G_7 and G_8 were the most stable genotypes but had the low mean yield. Based on $S_i^{(6)}$ the genotypes G_7 and G_5 were considered to be most stable but had the lowest mean yield (**Tables 3** and **4**). All of these non-parametric statistics were identified G_3 and G_4 as most unstable genotypes. There were negative and significant correlations between Nassar and Hühn's (1987) non-parametric stability statistics and mean yield (**Table 5**). The results showed that based on low values of these statistics it is possible to select stable genotypes but to have low mean yield. Therefore, these parameters are not so useful for identification of high yielding stable genotypes. In agreement with our results, Abdollahi *et al*. (2007) reported that $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ parameters represented static concepts of stability and are not correlated with mean yield. Ebadi Segherloo *et al*. (2008) and Mohammadi and Amri (2008) revealed that $S_i^{(3)}$ and $S_i^{(6)}$ were negatively associated with mean yield but $S_i^{(1)}$ and $S_i^{(2)}$ were not correlated with mean yield. According to Thennarasu's (1995) non-parametric stability statistics, which are calculated from ranks of adjusted yield, genotypes with minimum low values are considered more stable. Based on the first method $NP_i^{(1)}$, G_6 and G_8 were stable and G_5 and G_4 were unstable genotypes. According to the other three methods ($NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$) genotypes G_7 and G_8 were stable and the genotypes G_3 and G_4 were unstable. There were strong negative and significant correlation between $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ with mean yield but no relationship between $NP_i^{(1)}$ and mean yield (**Table 5**). Therefore, in the most of cases these statistics selected genotypes with low mean yield as stable genotypes.

Interrelationship among parametric and non-parametric measures

The result of Spearman's rank correlation (**Table 5**) between stability measures and mean yield revealed high positive correlation between mean yield and two parametric measures (P_i and *GAI*) that is expected as the low values of P_i and high values of *GAI* were related to high yielding genotypes. Lin and Binns (1988) proposed P_i as a measure of stability to integrated both yield and stability. Strong relation between yield and P_i reported by Flores *et al*. (1998) and selection based on this measure would favor selection for yield, as Kang and Pham (1991) and Flores (1993) found. The negative significant correlation between mean yield and all non-parametric stability measures except $NP_i^{(1)}$ suggested that selection of stable genotypes based on these statistics should be consider seriously with genotype mean yield. When there is non-significant correlation among mean yield and stability statistics indicated that, stability statistics provide information that cannot be gleaned from average yield alone (Mekbib 2003; Ebadi Segherloo *et al*. 2008).

The regression coefficient (b_i) was positively and strongly correlated with W^2_i, *IPCA1*, *IPCA3*, *ASV* and $NP_i^{(1)}$ and negatively correlated with *IPCA2* (**Table 5**). Worth to mention is the positive correlation of b_i with *IPCA1* and W^2_i in agreement with Baxevanos *et al*. (2008) and Mohebodini *et al*. (2006), respectively. The environmental variance (S^2_{xi}) was significantly and positively correlated with CV_i, $S_i^{(2)}$,

Table 5 Rank correlation among stability measures and mean of seed yield in 9 spring rapeseed genotypes over 9 environments

	Sy	b_i	S^2_{di}	S^2_{xi}	CV_i	P_i	w^2_i	**IPCA1**	**IPCA2**	**IPCA3**	**ASV**	**GAI**	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i^{(1}$	$NP_i^{(2)}$	$NP_i^{(3)}$
b_i	-0.17																		
S^2_{di}	-0.27	-0.61																	
S^2_{xi}	-0.88**	-0.14	0.12																
CV_i	-0.47	0.32	0.00	0.72*															
P_i	0.93**	-0.12	-0.13	-0.98**	-0.67*														
w^2_i	-0.17	0.82**	-0.35	0.03	0.35	-0.10													
IPCA1	0.03	0.97**	-0.60	-0.03	0.37	0.00	0.85**												
IPCA2	0.23	-0.66*	0.38	-0.35	-0.58	0.33	-0.40	-0.73*											
IPCA3	0.03	0.97**	-0.60	-0.03	0.37	0.00	0.85**	1.00**	-0.73*										
ASV	0.03	0.98**	-0.60	-0.03	0.37	0.00	0.85**	1.00**	-0.73*	1.00**									
GAI	0.88**	0.39	-0.32	-0.70*	-0.05	0.72*	-0.03	0.28	-0.17	0.28	0.28								
$S_i^{(1)}$	-0.64*	-0.23	-0.17	0.53	-0.01	-0.59	0.08	-0.18	0.26	-0.18	-0.18	-0.80**							
$S_i^{(2)}$	-0.82**	0.04	-0.10	0.70*	0.28	-0.78*	0.32	0.10	-0.08	0.10	0.10	-0.80**	0.88**						
$S_i^{(3)}$	-0.92**	-0.06	0.07	0.78*	0.33	-0.85**	0.25	0.02	-0.12	0.02	0.02	-0.88**	0.83**	0.97**					
$S_i^{(6)}$	-0.95**	-0.22	0.18	0.79*	0.25	-0.85**	0.15	-0.10	-0.04	-0.10	-0.10	-0.96**	0.81**	0.90**	0.95**				
$NP_i^{(1)}$	-0.03	0.89**	-0.62	0.06	0.44	-0.08	0.83**	0.85**	-0.56	0.85**	0.85**	0.18	0.08	0.28	0.19	-0.02			
$NP_i^{(2)}$	-0.88**	0.11	0.13	0.75*	0.48	-0.82**	0.48	0.18	-0.15	0.18	0.18	-0.80**	0.69*	0.90**	0.93**	0.89**	0.31		
$NP_i^{(3)}$	-0.85**	0.11	0.02	0.70*	0.38	-0.78*	0.45	0.17	-0.12	0.17	0.17	-0.80**	0.80**	0.97**	0.97**	0.89**	0.36	0.97**	
$NP_i^{(4)}$	-0.81**	-0.10	0.02	0.67*	0.26	-0.75*	0.33	-0.02	0.13	-0.03	-0.03	-0.86**	0.91**	0.93**	0.91**	0.91**	0.17	0.90**	0.93**

* and ** indicate significant at the 0.05 and 0.01 probability levels, respectively

$S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ and negatively correlated with P_i and *GAI*. Similar results reported by Mohammadi and Amri (2008). Nassar and Hühn (1987) reported that S^2_{xi}, $S_i^{(1)}$ and $S_i^{(2)}$ are associated with the static or biological concept of stability. Flores et al. (1998) categorized S^2_{xi}, $S_i^{(1)}$ and $S_i^{(2)}$ in same group and defined them in the sense of homeostasis. The superiority index (P_i) was positively correlated with *GAI* and negatively correlated to CV_i, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$. Wricke's stability parameter (W^2_i) was positively correlated with *IPCA1*, *IPCA3*, *ASV* and $NP_i^{(1)}$. The first interaction principal component axis (*IPCA1*) was strongly and positively correlated with *IPCA3*, *ASV* and $NP_i^{(1)}$ and negatively correlated with *IPCA2*. The second interaction principal component axe (*IPCA2*) negatively correlated with *IPCA3* and *ASV*. The third interaction principal component axe (*IPCA3*) strongly and positively correlated with *ASV* and $NP_i^{(1)}$. The AMMI stability value (*ASV*) correlated positively with $NP_i^{(1)}$. The geometric adaptability index (*GAI*) showed strong negative correlation with all non-parametric measures except $NP_i^{(1)}$. Piepho and Lotito (1992) reported high rank correlation among parametric and non-parametric measures. Truberg and Huehn (2000) suggested an alternative use of non-parametric measures, such as stability variance whenever assumptions, such as normal distribution, independence, homogeneity of error variances, absence of outlies, etc. are violated.

The results of Spearman's rank correlation showed that Nassar and Hühn's (1987) non-parametric stability statistics were positively and significantly correlated with each other and with Thennarasu's (1995) non-parametric stability statistics except $NP_i^{(1)}$ (**Table 5**). The $NP_i^{(2)}$ was correlated positively and strongly with $NP_i^{(3)}$ and $NP_i^{(4)}$ also $NP_i^{(3)}$ was correlated positively and strongly with $NP_i^{(4)}$. Positive and significant correlation between some non-parametric measures were reported by Scapim *et al*. (2000) and Kang and Pham (1991) in maize (*Zea mays* L.); Adugna and Labuschagne (2003) in linseed (*Linum usitatissimum* L.); Abdollahi *et al*. (2007) in safflower (*Carthamus tinctorius* L.) and Mohammadi and Amri (2008) in durum wheat (*Triticum durum* L.). The strong positive correlation among seven non-parametric stability methods indicated that they measured similar aspects of stability. Therefore, it is possible to use only one of them as measure of stability.

The relationships among yield stability measures are graphically displayed in a biplot of first two principal components (*PC1* and *PC2*) (**Fig. 1**) leading to five groups to be distinguished as below:

Group I: *GAI*, P_i, Seed Yield (SY)
Group II: b_i, W_i^2, $NP_i^{(1)}$, *ASV*, *IPCA1*, *IPCA3*
Group III: CV_i
Group IV: S^2_{xi}, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$
Group V: S^2_{di}, *IPCA2*

Seed yield is included in group I, suggesting group I comprise those methods where yield has an important influence on the ranking across environments. According to group I genotypes G4, G2, G3, G6 and G9 introduced as stable genotypes that were the first five high yielding genotypes (**Tables 3** and **4**). There were strong positive rank correlation between these two measures and seed yield (**Table 5**). Lin and Binns (1988) superiority measure (P_i) and *GAI* as measures of genotypic performance attempt to integrate both yield and stability. Selection based on these stability parameters is related to the dynamic or agronomic concept of stability. Becker and Léon (1988) mentioned that it was not required that the genotypic response to environmental conditions should be equal for all genotypes. Thus, stable genotypes selected by these measures recommended for warm dry-lands of Iran with favorable growing condition.

Nassar and Hühn's (1987) non-parametric stability statistics $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$ and all Thennarasu's (1995) non-parametric measures except $NP_i^{(1)}$ ($NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$) and environmental variance (S^2_{xi}) (Lin *et al*. 1986) were included in group IV. These methods selected G7, G8, G5 and G1 as stable genotypes that were the low yielding genotypes. The measures of this group were negatively correlated with mean seed yield (**Table 5**). Nassar and Hühn (1987) pointed out that the environmental variance (S^2_{xi}) and non-parametric measures of $S_i^{(1)}$ and $S_i^{(2)}$ are associated with the static or biological concept of stability. Selection of stable genotypes based on group IV measures is related to the static or biological concept of stability. Therefore, stable genotypes according to these methods recommended for warm rainfed areas where growing conditions are unfavorable.

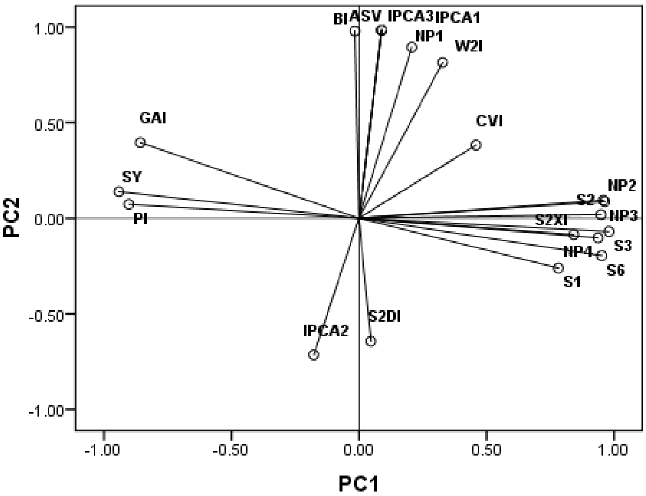

Fig. 1 Biplot of first two principal components of ranks of yield stability, estimated by 19 parametric and non-parametric methods.

Group II including regression coefficient (b_i) (Eberhart and Russell 1966), Wricke's (1962) ecovalence (W^2_i), AMMI's stability value (*ASV*) (Purchase 2000), the first and third interaction principal component axis (*IPCA1*, *IPCA3*) and Thennarasu's (1995) non-parametric measure ($NP_i^{(1)}$). There were non-significant correlation between these stability parameters and seed yield. Group II was intermediate between group I and Group IV and consist of methods that were influenced by both yield and stability simultaneously. It was noted that selected genotypes based on these parameters showed an average stability and these genotypes may not be as good as the responsive ones under favorable conditions.

Coefficient of variation (*CVi*) (Francis and Kannenberg 1978) was the only member of group III. This measure selected G3, G8 and G5 as stable genotypes that were low and medium yielding genotypes. There was not significant relationship between *CVi* and seed yield (**Table 5**). This group was intermediate between group II and IV.

Group V included second interaction principal component axis (*IPCA2*) and the variance of deviations from the regression (S^2_{di}) (Eberhart and Russell 1966). This group selected G4 (the highest yield), G5 (the lowest yield), G2, G8 and G9 (the medium yield) as stable genotypes. There were non-significant correlation between these stability parameters and seed yield (**Table 5**). This group was intermediate between group IV and I.

In conclusion, several parametric and non-parametric stability methods that have been employed in the present study quantified stability of genotypes with or without concerning yield. Both yield and stability of performance should be considered simultaneously to exploit the useful effect of GE interaction and to make selection of the genotypes more precise and refined. Selection of high yielding and stable genotypes is needed in warm dry-lands of Iran where the farmers grow rapeseed under harsh conditions and variable and unpredictable environments therefore, superiority measure (P_i) and GAI are suitable statistics. The superiority measure (P_i) require no assumption of linearity even where the data do not fit the linear model for GE interaction moreover the merit of P_i becomes more apparent as the geographical area covered by the test sites increases in scope (Lin and Binns 1988, 1991). These measures are mathematically simple and more easily interpretable that can be use by plant breeders and agronomists.

The spring rapeseed cultivars have recently extended in warm dry-lands of Iran in rotation with wheat where the farmers use limited inputs and fluctuations in growing conditions are very high. Therefore, it is essential to develop more adapted and higher yielding varieties to increase the cultivation area of this crop.

ACKNOWLEDGEMENTS

The data information of this study was part of a National rapeseed Research Program of Dry-land Agricultural Research Institute (DARI) of Iran. We thank all members of the rapeseed program in Gachsaran, Sarpol-e-Zahab, Pol-e-Dokhtar, Gonbad and Masjed Soliman for any contribution they may have made towards this study. This research is sponsored by the Agricultural Research, Education and Extension Organization (AREEO) of Iran and is gratefully acknowledged.

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