International Journal of Plant Breeding ©2008 Global Science Books

Stability Analysis of Grain Yield in Barley (*Hordeum vulgare* L.)

Reza Mohammadi* • Kouresh Nader Mahmoodi

Dryland Agricultural Research Institute, P O Box 67145-1164, Kermanshah, Iran

Corresponding author: * **rmohammadi1973@yahoo.com**

ABSTRACT

Identifying high-yielding and stable genotypes is a primary objective of most applied breeding programs. Several parametric and non-parametric statistics of phenotypic stability were used for assessing yield performance and stability simultaneously of thirteen advanced barley genotypes across eighteen environments during 2003-2005 in Iran. Spearman's rank correlation analysis indicated that the non-parametric methods can be used as a good alternative for most parametric methods. The parameters of ecovalence (W^2i), variance in regression deviation (S^2di), coefficient of determination (R^2) and AMMI stability value (ASV) had a significant positive correlation with variance of ranks ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$). Genotypic mean yield had a significant positive correlation with coefficient of variation (CV), geometric adaptability index (GAI), superiority index (Pi), yield reliability index (Ii), coefficient of regression (bi), rank-sum, while was negatively correlated with variance of ranks ($Si^{(3)}$ and $Si^{(6)}$). Corresponding to most phenotypic stability measures, genotypes G5 (Antares/KY36-1294//SLR) and G8 (Antares/KY36-1294//Lignee131) were identified as the most stable genotypes with high yielding performance and a high degree of reliability, whereas genotypes G13 (Sahand), G3 (Alpha//Gumhuriyet/Sonja) and G4 (Antares/KY36-1294//SLR) with highest yielding performance considered to be unstable. In conclusion, both yield and stability should be considered simultaneously to exploit the useful effect of GE interaction and to make selection of genotypes more precise and refined.

Keywords: phenotypic stability, rank correlation, yield performance

INTRODUCTION

Iran is currently one of the world's largest net importers of agricultural products, importing about 30% of its requirements. Rapid population growth is expected to increase the demand for food. The extension acreage and the improvement of barley could contribute to food security in Iran. The main objectives are attempting to improve barley production through identification and introduction of stable and adaptive cultivars. Plant breeders continuously strive to increase yield as well as broaden the genetic base of a crop to prevent its vulnerability to changing environments.

The interaction of cultivar with environmental factors is an important consideration for plant breeders. Genotype x environment (GE) interaction has been defined as failure of genotypes to achieve the same relative performance in different environments (Baker 1988).

Analysis of GE interaction on grain yield and estimation of phenotypic stability has been widely studied (Becker and Leon 1988; Huehn 1990; Flores *et al.* 1998; Grausgruber *et al.* 2000; Hussein *et al.* 2000; Purchase *et al.* 2000; Mekbib 2002, 2003; Rharrabti *et al.* 2003; Mohebodini *et al.* 2006; Mohammadi and Amri 2008; Mohammadi *et al*. 2008). There are two major approaches to studying GE interaction and determining the adaptation of genotypes (Huehn 1996). The first and most common approach is parametric, which relies on distributional assumptions about genotypic, environmental and GE interaction effects. The second major approach is the non-parametric or analytical clustering approach, which does not need any assumption.

For practical applications, however, most breeding programs incorporate some elements of both approaches (Becker and Leon 1988; Romagosa and Fox 1993). Although several methods for the statistical measurement of stability have been proposed, no single method can adequately explain genotype performance across environments. From the parametric measures, the most widely used is the univariate stability parameters are the Wricke's ecovalence (W^2i) (Wricke 1962), the joint regression including coefficient regression (bi) and variance in regression deviations (S^2di) (Eberhart and Russell 1966), Shukla's stability variance (Shukla 1972), coefficient of determination (R^2) (Pinthus 1973) and Francis and Kanenberg's (1978) coefficient of variability (CVi), environmental variance (S^2e) (Lin *et al.* 1986; Becker and Leon 1988). More recently, Purchase *et al*. (2000) developed the AMMI stability value (ASV) based on the AMMI model's IPCA1 and IPCA2 (Interaction Principle Components Axes 1 and 2, respectively) scores for each genotype. The practical interest of combining high levels of mean yield and yield stability has led to the development of a yield reliability concept (Eskridge 1990; Kang and Pham 1991), where a reliable genotype is characterized by consistently high yield across environments (Annicchiarico 2002). The use of a yield reliability index (Ii) facilitates genotype selection or recommendation, as the mean yield and the yield stability are combined into a unique measure of genotype merit (Annicchiarico 2002).

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 ranks over *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 yield, with the genotype with the highest yield receiving the rank of 1, and ranks for the stability variance of Shukla (1972), with the lowest estimated value receiving the rank of 1. The sum of these two ranks provides a final index, in which the genotype with the lowest rank-sum (RS) is regarded as the most desirable. Different stability parameters allowed researchers to identify the stable and widely adapted genotypes to recommend to farmers faced with varying and unpredictable growing conditions. In Iran, information pertaining to GE interaction analysis for barley is limited. Therefore, the objectives of this study were to (i) evaluate the stability and

Received: 17 July, 2008. Accepted: 23 August, 2008.

Original Research Paper

Table 1 Description of the environments, genotypes and status of rainfall for each environment.

Environments			Rainfall	Genotypes		
Code	**Cropping season**	**Location**	**(mm)**	**Code**	**Name/Pedigree**	**Origin**
E1	2002-03	Sararood	424	G1	Lignee131/3/4679/105//YEA168.4	ICARDA*
E2	2002-03	Maragheh	367	G2	Roho//Alger/Ceres362-1-1/3/Alpha/Durra	ICARDA
E3	2002-03	Shirvan	301	G3	Alpha//Gumhuriyet/Sonja	ICARDA
E4	2002-03	Khodabandeh	381	G4	B-C-74-2	ICARDA
E5	2002-03	Ghamlo	354	G5	Antares/KY36-1294//SLR	ICARDA
E6	2002-03	Ardebil	274	G6	CWB117-77-9-7/3/Roho//Alger/Ceres362-1-1	ICARDA
E7	2003-04	Sararood	588	G7	4679/105//YEA168.4/3/Lignee131/ArabiAbiad	ICARDA
E8	2003-04	Maragheh	416	G8	Antares/KY36-1294//Lignee131	ICARDA
E9	2003-04	Shirvan	251	G9	Wiselburger/Ahor1303-61//SLS	ICARDA
E10	2003-04	Khodabandeh	533	G10	SLS/BDA	ICARDA
E11	2003-04	Ghamlo	425	G11	CWB117-77-9-7//Antares/KY63-1294	ICARDA
E12	2003-04	Ardebil	282	G12	Sadik8	ICARDA
E13	2004-05	Sararood	432	G13	National Check (Sahand)	Iran
E14	2004-05	Maragheh	368	*International Center for Agricultural Research in the Dry Areas		
E15	2004-05	Shirvan	242			
E16	2004-05	Khodabandeh	347			
E17	2004-05	Ghamlo	334			
E18	2004-05	Ardebil	286			

adaptation of advanced lines of barley genotypes in various environments in Iran and (ii) study the relationship among different stability parameters.

MATERIALS AND METHODS

This study was carried out with thirteen barley genotypes in 18 environments, including six locations during 2003-2005, in Iran (**Table 1**). All sites, representative of major barley rain-fed growing areas, are located in cold regions of Iran and including Sararood (in Kermanshah province) and Ghamlo (in Kordestan province) in west of Iran; Maragheh (in East Ajarbaiejan province) and Ardabil (in Ardabil province) in the northwest; Shirvan (in North Khorasan province) in the northeast and Khodabandeh (in Zanjan province) in the north-central part of Iran. These locations have an elevation of more than 1100 m above sea level and mean annual minimum temperature of less than –14°C. The used genotypes were selected from the barley improvement program of Iran /ICARDA joint project. The experimental layout was a randomized complete block design with four replications in each location. Sowing was done by an experimental drill in 1.5 m × 6 m plots, consisting of six rows with 25 cm between the rows. Seeding rate was 400 seeds m^{-2} for each location. Fertilizer application was 41 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} at planting. Yield (kg ha^{-1}) was obtained by converting the grain yields obtained from plot to hectare.

The parametric measures were performed in accordance with the use of joint regression analysis of Eberhart and Russell (1966) which included a regression coefficient (bi) and variance from regression deviations (S^2di), Francis and Kannenberg's (1978) coefficient of variability, environmental variance (S^2e) (Lin *et al*. 1986), Wricke's (1962) ecovalence, coefficient of determination (R^2) (Pinthus 1973) and superiority measure (Pi) (Lin and Binns 1988).

AMMI stability value (ASV) (Purchase *et al*. 2000) and Kataoka's (1963) yield reliability index (Ii) were also considered. The measure of geometric adaptability index (GAI) (Mohamamdi and Amri 2008) was also used to further describe the adaptability of genotypes. Genotypes with a higher GAI are desirable. Non-parametric measures as suggested by Huehn (1979) and Nassar and Huehn (1987) ($Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$ and $Si^{(6)}$) and Kang's (1988) rank-sum were considered to further describe stability analysis. To compute these measures, however, the mean yield data have to be transformed into ranks for each genotype and environment, and the genotypes are considered stable if their ranks are similar across environments. Stability ranks were started from the smallest values or variances to the largest ones, unlike the ranks of grain yield that were given in descending order (**Table 3**). Ranks were assigned to genotypes for each stability parameter and a simple correlation coefficient using Spearman's rank correlation was calculated from the ranks to measure the relationship between the studied parameters. Analysis of variance was conducted using IRRISTAT (version 5.0) statistical software to determine the effect of E (consisting of year [Y] and location [L]), genotype [G] and their interactions (GE) on grain yield. Analysis of GE interaction effects was also subjected to partitioning multiplicative effects in the AMMI model.

Table 2 AMMI analysis for grain yield of 13 barley genotypes across 18 environments.

Source	D.F.	M.S.	% Variance explained
Genotype (G)	12	607691.7**	1.68
Environment (E)	17	23319059**	91.4
GE	204	147252.5**	6.93
IPCA1	28	538416**	50.2
IPCA2	26	164161**	14.2

** Significant at 0.01 probability level.

RESULTS AND DISCUSSION

Analysis of variance (**Table 2**) indicated significant GE interaction ($P < 0.01$) and showed the influence of changes in environment on the yield performance of the genotypes evaluated. The environment (E) and genotype (G) main effects were also to be significant ($P < 0.01$). Environment was the most important source of yield variation, accounting for more than 91% of the (G + E + GE). This reveals that these environments represented a range of agro-climatic conditions of barley highland regions of Iran (Mohammadi *et al*. 2007) to assess the performance and stability of the genotypes. The significant difference of GE interactions for grain yield also is indicating differential response of genotypes to environments. Results of AMMI analysis showed that the first two interaction principal components (IPCA1 and IPCA2) were to be significant ($P < 0.01$) and captured 50.2 and 14.2% of the interaction sum of squares (SS), respectively (**Table 2**).

Taking the mean yield as the first parameter for evaluating the genotypes, G4 followed by G3, G8, G5 and G13 gave the best mean yield and G9 and G10 had the lowest mean yield across environments (**Table 3**). The genotypes G2, G6, G11 and G12 with a regression coefficient (*bi*) higher than one, with low- to average-yielding performance, were adapted to favorable environments, whereas G13, G4, G3, G7 and G1 with the lowest *bi*, with the highest yielding performance, were stable and highly adapted to unfavorable environments (Eberhart and Russell 1966). The G5 with a high mean yield had the minimum variance in regression deviation (S^2di), while the G13 with the highest S^2di ranked for high yielding performance as fifth genotype (**Table 3**).

Table 3 Mean yield and different estimates of stability measures for barley yields across 18 environments and ranks of genotypes for the stability parameters (in brackets).

Genotype	Mean Yield	bi	S^2di	S^2e	CV	W^2i	Pi	R^2	GAI	Ii	AMMI Model			$S_i^{(1)}$	$Z_1^{(1)}$	$S_i^{(2)}$	$Z_2^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	RS
											IPCA1	IPCA2	ASV							
G1	2492	1.00	20095	1874626	55.0	1295549	355979	0.99	2145	739	3.8	-0.4	12.7	3.79	0.25	10.58	1.19	26.10	6.94	14
	(9)	(5)	(2)	(5)	(7)	(3)	(8)	(1)	(7)	(7)			(2)	(6)		(6)		(6)	(4)	(4)
G2	2517	1.15	90971	2371579	61.2	2119904	382326	0.96	1969	546	10.8	16.5	39.8	4.46	3.40	15.09	0.12	34.20	16.80	18
	(7)	(12)	(11)	(13)	(10)	(9)	(9)	(3)	(10)	(10)			(9)	(12)		(11)		(9)	(9)	(7)
G3	2849	0.85	99640	1687678	45.6	3282686	116383	0.94	2530	1186	-12.3	-10.0	42.5	3.67	0.07	10.58	1.19	35.17	28.38	8
	(2)	(3)	(12)	(3)	(3)	(11)	(1)	(5)	(2)	(2)			(11)	(5)		(5)		(11)	(12)	(2)
G4	2915	0.70	58024	1222820	37.9	4808001	117467	0.95	2693	1499	-19.4	-10.0	65.9	4.31	2.39	16.93	0.87	70.00	15.81	13
	(1)	(2)	(8)	(1)	(1)	(12)	(2)	(4)	(1)	(1)			(12)	(11)		(12)		(13)	(8)	(3)
G5	2642	1.07	10757	2094175	54.8	784962	226454	0.99	2234	789	5.7	1.4	19.3	3.09	0.79	7.51	4.29	20.33	22.94	6
	(4)	(8)	(1)	(9)	(6)	(2)	(3)	(1)	(5)	(6)			(4)	(2)		(2)		(3)	(10)	(1)
G6	2505	1.13	31747	2224059	59.5	1404456	348897	0.99	2078	596	8.2	-8.7	29.0	4.19	1.68	12.64	0.19	30.47	25.09	15
	(8)	(10)	(6)	(11)	(9)	(4)	(7)	(1)	(8)	(9)			(7)	(8)		(7)		(8)	(11)	(5)
G7	2611	0.99	67841	1973456	53.8	1624188	259639	0.97	2191	813	-0.8	15.7	15.9	4.28	2.19	13.32	0.05	34.85	13.62	15
	(6)	(4)	(10)	(7)	(5)	(7)	(5)	(2)	(6)	(5)			(3)	(9)		(9)		(10)	(7)	(5)
G8	2644	1.06	25052	1980734	53.2	684223	241225	0.99	2288	843	6.4	2.2	21.5	3.21	0.43	8.03	3.62	22.14	10.89	6
	(3)	(7)	(4)	(8)	(4)	(1)	(4)	(1)	(4)	(4)			(6)	(3)		(3)		(4)	(6)	(1)
G9	2261	1.04	25620	1971897	62.1	1586129	577197	0.99	1808	463	1.5	6.1	7.9	2.84	1.92	6.76	5.33	11.43	10.64	14
	(13)	(6)	(5)	(6)	(12)	(6)	(13)	(1)	(13)	(13)			(1)	(1)		(1)		(1)	(5)	(4)
G10	2375	1.07	51609	1860875	57.4	1643896	473332	0.97	1985	628	5.7	-8.8	21.1	3.62	0.03	9.53	2.03	18.69	6.58	16
	(12)	(9)	(7)	(4)	(8)	(8)	(11)	(2)	(9)	(8)			(5)	(4)		(4)		(2)	(2)	(6)
G11	2375	1.16	66128	2198469	62.4	2164629	487266	0.97	1890	477	12.2	-5.3	41.4	4.06	1.08	12.88	0.13	24.18	5.85	19
	(11)	(13)	(9)	(10)	(13)	(10)	(12)	(2)	(12)	(12)			(10)	(7)		(8)		(5)	(1)	(8)
G12	2465	1.14	20933	2301256	61.5	1578077	396068	0.99	1962	523	8.5	-7.4	29.5	4.31	2.35	14.38	0.02	29.94	6.74	20
	(10)	(11)	(3)	(12)	(11)	(5)	(10)	(1)	(11)	(11)			(8)	(10)		(10)		(7)	(3)	(9)
G13	2612	0.63	229205	1323924	44.0	7064603	340744	0.83	2376	1139	-30.2	8.7	102.2	4.88	7.10	18.73	2.28	58.49	30.14	18
	(5)	(1)	(13)	(2)	(2)	(13)	(6)	(6)	(3)	(3)			(13)	(13)		(13)		(12)	(13)	(7)
	Grand Mean= 2558kg/ha													Sum	23.67		21.29			
														X^2 Sum =21.0			X^2 Z_1 , Z_2 = 3.84			

Note: The Z-statistics are measures of stability; X^2 Z_1, Z_2 are Chi-squares for $Z_1^{(1)}$, $Z_2^{(2)}$; X^2 Sum is chi-square for sum of $Z_1^{(1)}$, $Z_2^{(2)}$; tabulated X^2 0.05, 12=21.0 and X^2 0.05,1=3.84

Table 4 Spearman's rank correlation between mean yields and parametric and non-parametric measures of phenotypic stability for 13 barley genotypes across 18 environments.

Parameter	Yield	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	RS	bi	S^2di	CV	GAI	Pi	S^2e	R^2	Ii	W^2i
$S_i^{(1)}$	-0.22														
$S_i^{(2)}$	-0.24	0.99**													
$S_i^{(3)}$	-0.63*	0.81**	0.81**												
$S_i^{(6)}$	-0.68*	0.28	0.22	0.59*											
RS	0.58*	0.60*	0.59*	0.12	-0.33										
Bi	0.55*	-0.09	-0.13	-0.49	-0.49	0.47									
S^2di	-0.24	0.56*	0.56*	0.65*	0.41	0.33	-0.28								
CV	0.86**	-0.20	-0.23	-0.60*	-0.60*	0.54*	0.83**	-0.28							
GAI	0.92**	-0.18	-0.20	-0.61*	-0.64*	0.59*	0.75**	-0.24	0.98**						
Pi	0.96**	-0.09	-0.10	-0.57*	-0.68*	0.67*	0.60*	-0.14	0.87**	0.93**					
S^2e	0.34	0.03	-0.04	-0.30	-0.21	0.37	0.86**	-0.29	0.70**	0.63*	0.38				
R^2	-0.41	0.57*	0.60*	0.71**	0.41	0.19	-0.43	0.90**	-0.49	-0.46	-0.31	-0.51			
Ii	0.88**	-0.19	-0.23	-0.62*	-0.57*	0.54*	0.78**	-0.30	0.99**	0.99**	0.90*	0.68*	-0.51		
W^2i	-0.16	0.58*	0.63*	0.63*	0.24	0.38	-0.33	0.86**	-0.26	-0.22	-0.05	-0.48	0.93**	-0.27	
ASV	-0.47	0.65*	0.69**	0.70**	0.40	0.28	-0.13	0.64*	-0.36	-0.42	-0.32	-0.19	0.74**	-0.40	0.73**

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

Corresponding to environmental variance (S^2e), G4 followed by G13, G3, G10 and G1 had the lowest variation across environments. Wricke's ecovalence (W^2i) was lowest for genotypes G8 followed by G5, G1, G6 and G12 and highest for genotypes G13 followed by G4, G3, G11 and G2 (**Table 3**). A robust correlation between W^2i and S^2di (r=0.86**) showed that these two measures lead to similar results (**Table 4**). According to Francis and Kannenberg's (1978) stability parameter (CVi), the genotypes G4, G13, G3, G8 and G7 were considered to be stable with high yield performance.

In an alternative procedure for assessing the behavior of genotypes with a significant GE interaction, Lin and Binns (1988) proposed the superiority index (Pi), defined as the deviation of the genotype *i* relative to the genotype with maximum performance in each environment. The superior genotype would be that one with the lowest Pi value (Lin and Binns 1988). Genotypes G4, G3, G8, G5 and G7 with the greatest mean yield had the lowest Pi values (**Table 3**).

For ranking purposes, high R^2-values and low values of S^2e, W^2i, bi and S^2di are regarded as being desired (Becker and Leon 1988). Accordingly, genotypes with high R^2-values, however, were G1, G5, G6, G8, G9 and G12. According to the GAI parameter, genotypes G4 followed by G3, G13, G8 and G5 were the best in yielding adaptability, whereas genotypes G9, G11, G12, G2 and G10 were lowest (**Table 3**).

With the assumption that the technological level of agriculture in Iran falls between subsistence and modern farming, we took P=0.90% which correspond to Z(p)=1.28 to calculate the yield reliability index (Ii) as has already been suggested by Mohammadi and Amri (2008) in durum wheat breeding program for Iran. The Ii ranks genotypes according to the lowest average yield one can expect for each genotype across environments. The genotypes G4 followed by G3, G13, G8 and G7 had the highest Ii. The IPCA scores of a genotype in the AMMI analysis are an indicator of the stability of a genotype over environments (Purchase *et al.* 2000). The lowest IPCA1 was observed for the genotypes

G7 followed by G9 and G1, whereas IPCA2 was the lowest for genotypes G1, G5 and G8 (**Table 3**). According to both IPCA1 and 2 as stability statistics (Annicchiarico 1997; Grausgruber *et al*. 2000; Mohammadi *et al*. 2008), G1, G5 and G8 were the most stable genotypes. The ASV-derived AMMI model confirms the results of IPCA1 and 2 scores. However, ASV ranked genotype G9 with the lowest ASV, as the most stable genotype, although it had the lowest yield performance (2261 kg/ha). Corresponding to ASV, G13 followed by G4 and G3 were the most unstable although they had the highest yield performance.

To further describe stability, several nonparametric measures were also considered (**Table 3**). The significant tests (Z_1 and Z_2) for $Si^{(1)}$ and $Si^{(2)}$ were developed by Nassar and Huehn (1987). For each genotype, Z_1 and Z_2 values were calculated based on the ranks of adjusted data and summed over genotypes to obtain Z values (**Table 3**). It is seen that Z_1-sum = 23.67 and Z_2-sum = 21.29. Since both of these statistics were higher than the critical value $X^2_{(0.05,\ df=12)} = 21.0$, significant differences in rank stability were found among the 13 genotypes grown in 18 environments. On inspecting the individual Z values, it was found that the genotypes were significantly unstable relative to others, because they showed large Z values, in comparison with the critical value $X^2_{(0.05,df=1)} = 3.84$. The $Si^{(1)}$ and $Si^{(2)}$ statistics are based on ranks of genotypes across environments and they give an equal weight to each environment. Genotypes with fewer changes in rank are considered to be more stable (Becker and Leon 1988). In the studied barley genotypes, regarding both $Si^{(1)}$ and $Si^{(2)}$, G9 followed by G5, G8, G10 and G3 had the smallest changes in ranks and were thus regarded as the most stable genotype unlike G13, G2, G4 and G12. Two other non-parametric statistics of Huehn (1979), $Si^{(3)}$ and $Si^{(6)}$, combine yield and stability based on yield ranks of genotypes in each environment. As for $Si^{(1)}$ and $Si^{(2)}$, G9 was the most stable according to $Si^{(3)}$ and G11 according to $Si^{(6)}$. The mean yield of G9 was the lowest among the genotypes tested. The highest mean yield was for G4 followed by G3 and G8 (**Table 3**). Corresponding to Kang's (1988) rank-sum statistic, G5 followed by G8, G3 and G4 had the minimum value for rank-sum and therefore were stable genotypes with high yield while undesirable genotypes were G12 and G11 (**Table 3**).

In the case of study many parameters, for an efficient estimation and practical application of phenotypic stability, however, knowledge of relationship, consistency and repeatability between parametric and nonparametric stability are very important, as suggested by Huehn (1990). In our study, most phenotypic stability measures identified G9, G5 and G8 as the most stable genotypes, and G13, G4 and G3 as unstable ones, while the remaining genotypes were intermediate between these two groups.

A result of these analyses is that G5 and G8 are recommended for national release in Iran, as they adequately demonstrated stable and good yield performance and with a reasonable degree of reliability. This can help barley farmers in Iran who have been intentionally growing mixed varieties to maintain stable productivity under diversified agro-ecologies.

Interrelationship among stability parameters

Four parameters (W^2i, S^2di, R^2 and ASV-derived AMMI model) are significantly positively correlated with ranks' parameters of $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ (**Table 4**). The strong correlation of W^2i, S^2di and ASV to R^2 is due to the relatively large variability of S^2di compared to the variability of environmental effects (Becker and Leon 1988). However, when the range of environments is very limited and therefore variation of bi is high, correlations of W^2i and S^2di to R^2 are only medium and correlation coefficients between R^2i and bi may be moderate to high (Becker and Leon 1988). Obviously, W^2i, S^2di and ASV are correlated with $S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$ and these relations are much stronger than the respective relationships with other parameters. The parameters of Pi and Ii were negatively associated with $S_i^{(3)}$ and $S_i^{(6)}$ and positively correlated with bi, RS ($P<0.05$), CV and GAI ($P<0.01$). The parameters of GAI was negatively and significantly correlated with $S_i^{(3)}$, $S_i^{(6)}$ ($P<0.05$), and positively correlated with RS, ($P<0.05$), bi and CV ($P<0.01$). Mean yield had also a significant positive correlation with CV, GAI, Pi and Ii ($P<0.01$), bi and RS ($P<0.05$) and was negatively correlated with $Si^{(3)}$ and $Si^{(6)}$ ($P<0.05$).

Most of the stability parameters were closely related in sorting out the relative stability of the evaluated barley genotypes (**Table 3**). Some deviations were, however, observed specifically for the genotypes' superiority measure. Purchase *et al*. (2000) also reported similar results, indicating that it was more of a performance measurement than a yardstick for stability of genotypes across environments. Nassar and Huehn (1978), Becker and Leon (1988), Pham and Kang (1988) and Piepho and Lotito (1992) were also reported high rank correlations among parametric and non-parametric measures of stability. Nassar and Huehn's (1978) variance of ranks and most parametric measures were useful in determining the relative stability of genotypes under the tested environments, reflecting the robustness of these two methods.

The results of this work verify that the ASV-derived AMMI model (Paurchase *et al*. 2000), Wricke's ecovalence (Wricke 1962) and variance in regression deviations (S^2di) (Eberhart and Russell 1966) were also relatively better than other parametric measures in identifying the stable genotypes across environments. However, in general, most of the parametric measures of stability gave similar rankings to the genotypes and also showed correspondence in ranks given by the non-parametric measures. Thus, due to the presence of outliers (Huhn 1990), which affects the performance of stability parameters because of the sensitivity of these stability measures to violation of certain biostatistical assumptions like normal distribution of errors and interaction effects (Huhn 1990), the use of non-parametric measures has been suggested as an alternative whenever such violations occur (Truberg and Huhn 2000). In conclusion, several stability statistics that have been used in this study quantified stability of genotypes with respected to yield, stability, or both. Therefore, both yield and stability should be considered simultaneously to exploit the useful effect of GE interaction and to make selection of genotypes more precise and refined (Mekbib 2002, 2003; Mohammadi and Amri 2008; Mohammadi *et al*. 2008).

ACKNOWLEDGEMENTS

The data used for this work were taken from database of barley project of Dryland Agricultural Research Institute (DARI) of Iran and sponsored by the Agricultural Research and Education Organization (AREO). We thank all members of the project for any contribution they may have made towards this work.

REFERENCES

Annicchiarico P (2002) Defining adaptation strategies and yield stability targets in breeding programmes. In: Kang MS (Ed) *Quantitative Genetics, Genomics, and Plant Breeding*, Wallingford, UK, CABI, pp 365-383

Annicchiarico P (1997) Joint regression vs AMMI analysis of genotype-environment interactions for cereals in Italy. *Euphytica* **94**, 53-62

Baker RJ (1988) Tests for crossover genotype-environmental interactions. *Canadian Journal of Plant Science* **68**, 405-410

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

Eberhart SA, Russell WA (1966) Stability parameters for comparing varieties. *Crop Science* **6**, 36-40

Eskridge KM (1990) Selection of stable cultivars using a safety-first rule. *Crop Science* **30**, 369-374

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

Francis TR, Kannenberg LW (1978) Yield stability studies in short-season maize. I. A descriptive method for grouping genotypes. *Canadian Journal of Plant Science* **58**, 1029-1034

Grausgruber H, Oberforster M, Werteker M, Ruckenbauer P, Vollmann J

(2000) Stability of quality traits in Austrian-grown winter wheats. *Field Crops Research* **66**, 257-267
Huehn VM (1979) Beitrage zur erfassung der phanotypischen stabilitat. *EDV Medical Biology* **10**, 112-117
Huehn M (1990) Non-parametric measures of phenotypic stability: part 1. Theory. *Euphytica* **47**, 189-194
Huehn M (1996) Non-parametric analysis of genotype x environment interactions by ranks. In: Kang MS, Gauch HG (Eds) *Genotype by Environment Interaction*, CRC Press, Boca Raton, FL, pp 213-228
Hussein MA, Bjornstad A, Aastveit AH (2000) A SAS program for computing genotype x environment stability statistics. *Agronomy Journal* **92**, 454-459
Kang MS (1988) A rank-sum method for selecting high yielding stable corn genotypes. *Cereal Research Communications* **16**, 113-115
Kang MS, Pham HN (1991) Simultaneous selection for high yielding and stable crop genotypes. *Agronomy Journal* **83**, 161-165
Kataoka S (1963) A stochastic programming model. *Econometrika* **31**, 181-196
Lin CS, Binns MR (1988) A method for analyzing cultivar × location × year experiments: a new stability parameter. *Theoretical and Applied Genetics* **76**, 425-430
Lin CS, Binns MR, Lefkovitch LP (1986) Stability analysis: Where do we stand? *Crop Science* **26**, 894-900
Mekbib F (2002) Simultaneous selection for yield and stability. *Journal of Agricultural Science (Cambridge University)* **138**, 249-253
Mekbib F (2003) Yield stability in common bean (*Phaseolus vulgaris* L.) genotypes. *Euphytica* **130**, 147-153
Mohammadi R, Amri A (2008) Comparison of parametric and non-parametric methods for selecting stable and adapted durum wheat genotypes in variable environments. *Euphytica* **159**, 419-432
Mohammadi R, Pourdad SS, Amri A (2008) Grain yield stability of spring safflower (*Carthamus tinctorius* L.). *Australian Journal of Agricultural Research* **59 (6)**, 546-553
Mohammadi R, Haghparast R, Aghaee M, Rostaee M, Pourdad SS (2007) Biplot analysis of multi-environmental trials for identification winter wheat mega-environments in Iran. *World Journal of Agricultural Science* **3 (4)**, 475-480
Mohebodini M, Dehghani H, Sabaghpour SH (2006) Stability of performance in lentil (*Lens culinaris* Medik) genotypes in Iran, *Euphytica* **149**, 343-352
Nassar R, Huehn M (1987) Studies on estimation of phenotypic stability: Tests of significance for non-parametric measures of phenotypic stability. *Biometrics* **43**, 45-53
Pinthus JM (1973) Estimate of genotype value: A proposed method. *Euphitica* **22**, 121-123
Piepho HP, Lotito S (1992) Rank correlation among parametric and nonparametric measures of phenotypic stability. *Euphytica* **64**, 221-225
Purchase JL, Hatting H, van Deventer CS (2000) Genotype × environment interaction of winter wheat in South Africa: II. Stability analysis of yield performance. *South Africa Journal of Plant and Soil* **17**, 101-107
Rharrabti Y, Garcia del Morel LF, Villegas D, Royo C (2003) Durum wheat quality in Mediterranean environments III. Stability and comparative methods in analyzing G x E interaction. *Field Crops Research* **80**, 141-146
Romagosa I, Fox PN (1993) Genotype × environment interaction and adaptation. In: Hayward MD, Bosemark NO, Romagosa I (Eds) *Plant Breeding: Principles and Prospects*, Chapman and Hall, London, pp 373-390
Shukla GK (1972) Some aspects of partitioning genotype-environmental components of variability. *Heredity* **28**, 237-245
Truberg B, Huhn M (2000) Contributions to the analysis of genotype × environment interactions: comparison of different parametric and non-parametric tests for interactions with emphasis on crossover interactions. *Journal of Agronomy and Crop Science* **185**, 267-274
Wricke G (1962) Über eine Methode zur Erfassung der ökologischen Streubreite in Feldversuchen. *Zeitschrift für Pflanzenzüchtg* **47**, 92-96