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Evaluation of Promising Rainfed Wheat Breeding Lines on Farmers' Fields in the West of Iran

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ABSTRACT

The final stage of any crop breeding program is to evaluate the promising genotypes, which have been already selected in research stations, in farmers' fields. This study was conducted to examine the superiority of 11 promising durum and bread wheat experimental lines against three farmers' cultivars across five testing sites in 2006-07 cropping season in western Iran. In framers' fields stability and genotypic superiority for grain yield were determined using genotype and genotype × environment (GGE) biplot analysis. The main objectives were to (i) examine whether the selected materials by breeders in research stations can also be successful on farmers' field and (ii) recommend the best genotypes for farmers' fields in western parts of Iran and possibly beyond. Analysis of genotype-by-farmers' field trials data showed that the farmers' fields main effect was the predominant source of variation. The genotype-by-farmers' fields interaction was significant ($P < 0.01$), showing the changes in genotypes ranking in different farmers' fields. The results showed that the promising durum wheat genotype Mrb3/Mna-1 with the highest yield performance and stability was widely adapted genotype to farmers' fields. The bread wheat genotype PATO/CAL/3/7C//BB/CNO/5/CAL//CNO was adapted to some of farmers' fields in western Iran, while the promising genotypes Ghafghaz//F9.10/Maya"s" and Momchil/Katya1 were more adapted to other farmers' fields. The findings support that the farmers' checks were outyielded by promising genotypes in farmers' fields and verified yield improvements and stability are achieved by growing the promising lines on farmers' fields under rainfed conditions.

Keywords: biplot analysis, promising breeding lines, univariate statistics

INTRODUCTION

Wheat in Central and West Asia is cultivated across diverse environments, ranging from warm lowlands to temperate highlands (Trethowan *et al.* 2001, 2003; Lage *et al.* 2008). These environments represent more than one mega-environment for wheat cultivation as defined by International Maize and Wheat Improvement Center (CIMMYT) (van Ginkel and Rajaram 1993). Around 16.4 million ha of facultative and winter type wheats are grown in this region (CIMMYT 2005). The winter wheat yield levels are low in many countries in Central and West Asia (FAO 2008). Wheat productivity must be increased to improve the livelihood of millions of people in the developing world, which can be achieved either by breeding new improved wheat cultivars or by improving crop management practices or both. The national and international wheat research programs often claim to have released high yielding cultivars for their targeted environments. A few reports even assert developing high yielding wheat varieties for target environments worldwide, i.e., differential adaptation of CIMMYT bread wheat to global high temperature environments (Lillemo *et al.* 2005); adapting wheat cultivars to resource conserving farming practices and human nutritional needs (Trethowan *et al.* 2005); new CIMMYT-derived bread wheat germplasm with high yield potential and wide adaptation (Sharma *et al.* 2006); high yielding spring bread wheat germplasm for global irrigated and rainfed production systems (Singh *et al.* 2007); identification of site similarities in western and central Asia using CIMMYT international wheat yield data (Lage *et al.* 2008); and analysis of genotype × environment interactions for grain yield in durum wheat in Iran (Mohammadi and Amri 2009).

To improve productivity of wheat, Iran has started collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) and the CIMMYT since 1992. Wheat is the most important cereal crop in the Iran, with a total area of 6.5 million ha. Wheat is grown under irrigated and rainfed conditions. Rainfed wheat covers two-thirds of the total rainfed wheat area in Iran, but accounts for about one-third of the total wheat production (ICARDA 2004).

Improving grain yield is the major objective of wheat improvement programs in the highland areas of western Iran where the livelihood of poor farmers depends on successful wheat production. Through regional and international collaborations improved durum and bread wheat germplasms are regularly exchanged and tested by the national wheat research programs to identify adapted and high yielding genotypes. The Dryland Agricultural Research Institute (DARI) in Iran receives durum and bread wheat germplasms from ICARDA and CIMMYT and compares them along with the locally improved checks and also farmers' genotypes across diverse environments in Iran.

The climate in west of Iran (particularly Kermanshah province) are diverse because of a great deal of variation in altitude (548 to 1700 masl), where in this province the climate is classified to very cold, cold, moderate cold, and warm. The province is broadly divided into lowlands, foothills including valleys, mid-hills, high hills and mountains. Wheat is grown in flatland, hills and mountainous regions. The farmers in western Iran grow an old bread wheat cultivar, i.e., 'Sardari' and a new one, i.e., 'Azar-2'. Moreover, one old durum wheat cultivar, i.e., 'Zardak' is growing in this region, since improved varieties are not available to farmers.

Wheat grain yield is highly influenced by production environments and breeders often determine stability of high yielding genotypes across environments before recommending a stable cultivar for release. Previous studies showed

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that higher yielding lines might not always be stable across environments (Banziger and Cooper 2001; Koemel *et al.* 2004; Abidin *et al.* 2005; Mohammadi and Nader Mahmoodi 2008; Mohammadi *et al.* 2009; Thapa *et al.* 2009; Fufa *et al.* 2010; Sharma *et al.* 2010), and hence would not be suitable for release as new, improved varieties. The final evaluation of varietal adaptability in any crop breeding program involves on-farm multi-locational yield trials. Although many varieties are included in preliminary yield tests conducted in research fields, only a few better performing varieties with resistance to major pests and diseases are selected for on-farm multi-locational yield trials for further screening for wide adaptability to identify the one or two most superior varieties for recommendation.

There are not much information on advance statistical analysis of on-farm muti-location trials under rainfed conditions in Iran. Such analysis and its out-put make selection of superior genotypes more effective particularly under rainfed condition. Highly stable wheat genotypes could be further tested for their suitability in Iran and other countries with similar environments.

Therefore, this study was carried out (i) to evaluate promising wheat genotypes in multi location trials on farmers' fields under rainfed conditions in western Iran and (ii) to recommend the best genotypes for targeting farmers' fields in western parts of Iran (particularly Kermanshah province) and possibly beyond. However, one specific objective was to use genotype and genotype × environment (GGE) biplot statistical software (Yan and Kang 2002) to identify superior genotypes with high and stable grain yield (Thapa *et al.* 2009; Sharma *et al.* 2010).

MATERIALS AND METHODS

Two durum and bread wheat on-farm yield trials were carried out across five farmers' fields (sites) under rain-fed conditions in western Iran (Kermanshah province). These sites were Islamabad, Ravansar, Sarfirozabad, Harisn and Bistoon. More details on testing sites are given in **Table 1**. The farmers in these districts are mostly small landholders. In this region, one traditional variety 'Sardari', and one improved variety 'Azar-2' (one of the offspring of 'Sardari', introduced by DARI in 2000) are annually grown in 300,000 ha and one old durum variety 'Zardak' are still being grown small area in Kermanshah province.

In this study, two on-farms trails including durum wheat with six promising lines along with a local check ('Zardak'), and bread wheat with five promising lines along with two checks ('Sardari' and 'Azar-2') were conducted. The promising lines in both crops were selected from a few durum and bread wheat genotypes from ICARDA and national breeding program. More details on genotypes are given in **Table 2**. Usually, received material to research our station would be evaluated in observation nursery under rainfed conditions and in the next steps, the best genotypes would be evaluated in preliminary yield trials (PYT) advanced yield trials (AYT) and then elite regional yield trials (ERYT). In ERYT the selected genotypes from the three last steps would be tested for adaptability and yield stability in the other 4-8 national research station in other provinces (representative of rainfed area of Iran) for three subsequent cropping seasons. At the last step of evaluation, the most superior genotypes would be participated in on-farm yield trials on farmers' fields to be tested in target environments.

In DARI On-farm multi-locational yield trials are usually conducted with few selected varieties from ERYT, not more than seven and three replicates within each three to five locations. Large plot size (8 rows × 6 m long with 20 cm apart) is used in order to overcome the problem of high level of environmental heterogeneity found within most of the farmers' fields.

To identify superior varieties across environments, GGE biplot analyses was conducted using GGE biplot software (Yan and Kang 2003). A specific option in GGE biplot analysis allows comparison among a set of locations with discriminating ability and representativeness. Identification of an ideal test location on the basis of discriminating ability and representativeness implies that selections made at that site would have the highest probability of representing truly superior genotypes that perform well in all locations in the growing region. Major benefits to breeders would include the increased efficiency of selecting in discriminating locations and the discontinued use of poorly discriminating locations

Table 1 Description and climatic data of on-farm sites in Kermanshah where the experiments were conducted.

Site	Latitude	Longitude	Altitude (m)	Temperature*		Rainfall$^{\$}$ (mm)
				Max	Min	
Islamabad	34° 60′ N	46° 31′ E	1334	37.0	-12.4	594.7
Ravansar	34° 43′ N	46° 39′ E	1329	37.0	-11.4	610.8
Sarfirozabad	34° 16′ N	46° 46′ E	1365	39.1	-8.2	375.2
Bistoon	34° 25′ N	47° 27′ E	1284	38.6	-8.0	515.0
Harsin	34° 16′ N	47° 34′ E	1549	36.0	-11.2	413.6

*Temperature includes months form October to June 2005-06

$^{\$}$ Received during October to June 2005-06 cropping season

Table 2 Durum wheat and bread wheat promising genotypes in on-farm trials, their attributes, origins and their performance across 2002-2004 at Sararood research station of Kermanshah province.

Crop	Genotype	Attribute	Origin	Performance before going to on-farm				
				PH	DH	DM	TKW	Yield
Durum wheat								
	Syrian-4 (Saji)	Breeding line	ICARDA	118 b*	169 a	201 a	36 a	2469 a
	Mrb3/Mna-1	Breeding line	ICARDA	116 b	171 a	200 a	38 a	2478 a
	Mna-1/Rfm-7	Breeding line	ICARDA	117 b	170 a	200 a	34 a	2152 a
	71-7-3-5	Breeding line	Iran	136 a	184 a	201 a	33 a	2343 a
	Gcn//Stj/Mrb3	Breeding line	ICARDA	112 b	170 a	199 a	37 a	2229 a
	Lgt3/4/Bcr/3/Ch1//Gta/Stk	Breeding line	ICARDA	115 b	174 a	200 a	38 a	2252 a
	Zardak	Local check	Iran	136 a	180 a	202 a	38 a	2168 a
Bread wheat								
	PATO/CAL/3/7C//BB/CNO/5/CAL//CNO	Breeding line	ICARDA	100 b	180 c	219 b	33 a	4228 a
	Ghafghaz//F9.10/Maya"s"	Breeding line	ICARDA	97 b	193 a	231 a	33 a	2626 c
	MOMCHIL/KATYA1	Breeding line	ICARDA	81 c	187 b	225 ab	33 a	2909 bc
	345GBM	Breeding line	Iran (Gene bank)	115 a	189 ab	224 ab	30 a	3465 b
	WW33G/vee"s'//Mrn/4/HD2172/Bloudan//Azd/3/San/Ald's'	Breeding line	Iran (SPII)#	89 bc	182 ab	225 ab	34 a	3120 bc
	Sardari	Old check	Iran	93 bc	191 ab	228 a	35 a	2807 bc
	Azar-2	Improved check	Iran (DARI)†	96 b	189 ab	227 a	37 a	3029 bc

PH, plant height; DH, days to heading; DM, days to maturity; TKW, thousand kernel weight

*Means followed by similar letters are not significant at $P < 0.05$ according to Duncan's multiple range test

SPII: Seed and Plant Improvement Institute; † DARI: Dryland Agricultural Research Institute

Table 3 Analysis of variance for grain yield data derived from durum wheat and bread wheat genotypes in on-farm trials. **, significant at $P < 0.01$.

Crop	Source	df	SS	MS	% TSS	% GL
Durum wheat	Location	4	19397060	4849265**	53.9	
	Genotype	6	7868252	1311375**	21.9	
	GL	24	8707128	362797**	24.2	
	Regression	6	4597460	766243**		52.8
	Deviation	18	4109669	228315**		47.2
	Total	34	35972440			
Bread wheat	Location	4	8483976	2120994**	63.3	
	Genotype	6	1671414	278569**	12.5	
	GL	24	3247129	135297**	24.2	
	Regression	6	1521274	253546**		46.8
	Deviation	18	1725855	95881**		53.2
	Total	34	13402519			

(Blanche and Myers 2006). Discriminating ability refers to a location's ability to maximize the variance among genotypes in a study (Blanche and Myers 2006). Representativeness suggests that a location is representative of the conditions of other locations included in the study. An ideal testing location combines both of these traits for the development of generally adapted plant materials (Yan and Tinker 2006). These values are best viewed with the "discriminating power vs. representativeness of testers' biplot display of GGE biplot (Yan and Kang 2003; Yan and Tinker 2006).

To help in the assessment stability performance of genotypes, regression coefficient, *b*, (Eberhart and Russell 1966) and coefficient of variation, CV, (Francis and Kannenberg 1978) were used. However, when the main concern is directed towards the role of the testing locations (j) rather than the genotypes (i), the mean value of each genotypic group at a given test location can be plotted against the genotypic index (Falconer 1981). The slopes of the regression line (*b*j) in such a plot measure the unit increase of location value per unit improvement in genotypic quality. We calculated *b*j values for each test location and used the term 'genotypic selectivity' to describe the reaction of a test location to an increase in genotypic quality. Thus, the locations with high regression slopes (i.e. *b*j > 1.0) are highly selective, with a relatively high discriminating (or selective) power against poor genotypes, and consequently favor good genotypes (Isik and Kleinschmit 2005). As well as the *b*j method, coefficient of variation (CVj) can be employed to estimate the discrimination ability of test sites and to rank the test sites on the basis of their CV (Fan *et al.* 2001). The comparison of GGE biplot analysis with two univariate statistics (*b* and CV) was undertaken using data from the durum and bread wheat on-farm trials in Kermanshah Province in western Iran.

RESULTS AND DISCUSSION

ANOVA and mean yield performance

The results of analysis of variance (ANOVA) are given in **Table 3**. The proportions of the total sum of squares (SS) due to location (L), genotype (G), and GL interaction were 53.9, 21.9, and 24.2%, respectively in durum wheat, and also were corresponding to 63.3, 12.5 and 24.2% respectively in bread wheat; indicating that location (farmers' field) main effect was the predominant source of variation, followed by GL interaction and G effect. The GL interaction was significant (P < 0.01), showing the changing the genotypes ranking in different locations (farmers' fields). The GL interaction was larger than the genotypic main effect terms in both trials. It means that the GL was important. However, it should be noted that the sum of the GL components is greater than the G component, so GL is clearly dominate. Thus, there seems to be room for breeding for specific adaptation, which may be important for durum and wheat breeders in west of Iran. If GL effect is significant, a linear regression analysis (Perkins and Jinks 1960) may be used to examine the stability of genotypes across locations. Linear regression accounted for 52.8% (in durum wheat) and 46.8% (in bread wheat) of the GL interaction, indicating that a linear approach can be expected to account for the integrated effect of different limiting factors (drought, temperature, etc.) on genotype performance.

ANOVA for agronomic data revealed significant effect of location and genotype. The genotype × location interaction was significant for both grain yield and thousand kernel weight (TKW) examined in farmers' fields in this study. The durum and bread wheat genotypes showed array of variations in grain yield (**Table 3**) and TKW (ANOVA not shown). All promising durum wheat lines showed significantly higher grain yield than the local check, 'Zardak'. None of the promising durum lines had significantly higher TKW than the check. All promising bread wheat genotypes produced higher grain yield than two local bread wheat checks ('Sardari' and 'Azar-2' cultivars) but two genotypes PATO/CAL/3/7C//BB/CNO/5/CAL//CNO and MOMCHIL/KATYA1 produced significantly higher grain yield than 'Sardari' check, but all the promising bread wheat genotypes had lower TKW than the checks.

Genotype evaluation based on GGL biplots

Fig. 1 shows the mean yield and stability performance of the tested durum genotypes based on the "average tester coordinate" (ATC). The mean yield performance of genotypes is approximated by the projections of their markers on the ATC axis. The length of average environment vector was sufficient to select genotypes based on yield mean performance. Genotypes with above average mean yield performance were the Mrb3/Mna-1 followed by Mna-1/Rfm-7, and Syrian-4, while the remaining genotypes had mean yield performance below average mean yield. Genotype Mrb3/Mna-1 with highest-yielding performance was the most stable genotype. Syrian-4 with high-yielding performance was the least stable genotype. In addition to Syrian-4, the genotypes 71-7-3-5 and 'Zardak' with lowest yielding performance were unstable genotypes. 'Zardak' is a durum wheat national check that had low-yielding performance. The results indicate that the Mrb3/Mna-1 with the highest stability was ranked as a first genotype in yield performance and is the best releasing candidate for rainfed areas of western Iran. The next candidate for this purpose is Mna-1/Rfm-7 with good combination of yield and stability.

The GGE biplot analysis of the seven bread wheat genotypes for grain yield revealed that Momchil/Katya1 was close to the point of an ideal genotype (**Fig. 2**). Its performance and stability for grain yield was very close to those for an ideal genotype making it the highest yielding and most stable genotype across farmers' fields condition. The three bread wheat genotypes, i.e., PATO/CAL/3/7C//BB/CNO/5/…, Ghafghaz//F9.10/Maya"s", and WW33G/vee"s'//Mrn/4/HD2172/… also had higher grain yield and were more unstable than Momchil/Katya1. The genotype 345GBM along with two bread wheat checks ('Sardari' and 'Azar-2') had low yield and were relatively unstable by being farthest on the left side of the origin of the biplot as well as away from the performance line.

For further describing of stability analysis, regression analysis was performed. The regression coefficients for the durum genotypes ranged from 0.4 to 1.87 (**Table 4**). Ac-

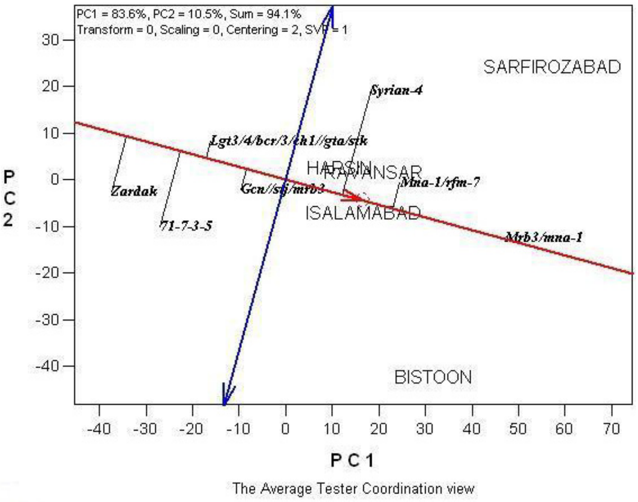

Fig. 1 Genotype plus genotype × location (GGL) interaction biplot showing mean yield and stability of durum wheat promising genotypes in farmers' fields. Sites are in capital letters and genotypes are in italic.

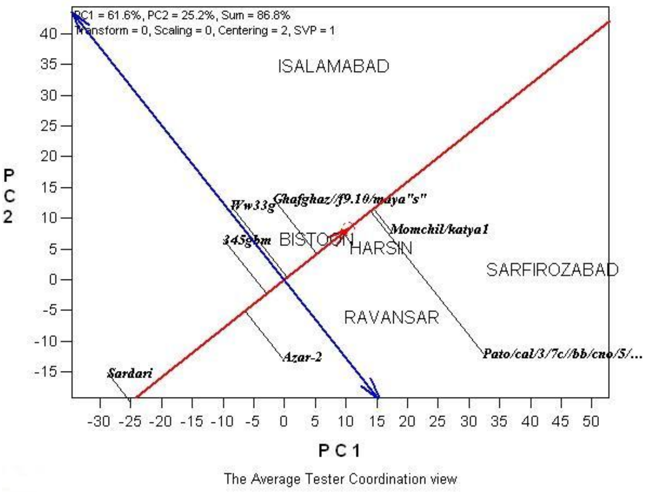

Fig. 2 Genotype plus genotype × location (GGL) interaction biplot showing mean yield and stability of bread wheat promising genotypes in farmers' fields. Sites are in capital letters and genotypes are in italic.

Table 4 Mean values of agronomic traits, regression coefficient (*b*) and coefficient of variation (CV) derived from grain yield of promising durum and bread wheat genotypes across on-farm testing sites.

Crop	Genotype	Mean yield	TKW	*b*	CV
Durum wheat	Syrian-4	2016 abc*	33.6 a	1.12	43.1
	Mrb3/Mna-1	2654 a	30.8 ab	1.87	11.3
	Mna-1/Rfm-7	2184 ab	34.6 a	1.44	16.5
	71-7-3-5	1432 bc	31.6 ab	0.53	32.4
	Gcn//Stj/Mrb3	1610 bc	29.6 b	0.96	13.2
	Lgt3/4/Bcr/3/Ch1//Gta/Stk	1533 bc	32.2 ab	0.69	26.0
	Zardak	1162 c	31.8 ab	0.4	28.0
Bread wheat	PATO/CAL/3/7C//BB/CNO/5/CAL//CNO	1776 a	33.4 ab	1.69	42.3
	Ghafghaz//F9.10/Maya"s"	1512 ab	34.6 ab	1.07	31.1
	Momchil/Katya1	1780 a	34.0 ab	1.29	15.1
	345GBM	1499 ab	35.8 ab	0.72	23.3
	WW33G/vee"s'//Mrn/4/HD2172/Bloudan//Azd/3/San/Ald's'	1568 ab	31.2 b	0.61	27
	Sardari	1116 b	36.4 ab	0.37	17.9
	Azar-2	1332 ab	37.4 a	1.25	13

*Means followed by similar letters are not significant at $P < 0.05$ according to Duncan's multiple range test

cording to Lin and Binns (1985), the genotypes 'Zardak' and 71-7-3-5 were unresponsive ($b < 0.7$), while the Mrb3/Mna-1 was very responsive ($b > 1.3$) and remaining genotypes had average responsive ($0.7 < b < 1.3$). However, utilizing Finlay and Wilkinson's (1963) method, the genotype Gcn//Stj/Mrb3 with *b*-value closer to 1 was the most stable and genotypes Lgt3/4/Bcr/3/Ch1//Gta/Stk, 71-7-3-5 and 'Zardak' with the lowest *b*-values were adapted to marginal environments, whereas the genotypes Mrb3/Mna-1, Mna-1/Rfm-7 and Syrian-4 with the highest *b*-values were adapted to favorable environments (**Table 4**). Based on Francis and Kannenberg's (1978) stability parameter (CV), genotypes Mrb3/Mna-1, Gcn//Stj/Mrb3 and Mna-1/Rfm-7 were considered to be stable as verified by GGE biplot analysis (**Fig. 1**). These genotypes with the lowest CV had highest yielding performance, whereas genotypes Syrian-4 and 71-7-3-5 with the highest CV values had high grain yield.

The values of regression coefficients across bread wheat genotypes also varied from 0.37 to 1.69. Among bread wheat genotypes PATO/CAL/3/7C//BB/CNO/5/… as the highest responsive genotype to environments had high specific adaptation as shown by GGE biplot (**Fig. 2**), while the 'Sardari' and WW33G/vee"s'//Mrn/4/HD2172/… had the lowest responsive to environments and were widely adapted genotypes. The remaining bread wheat genotypes had average responsive. Corresponding to Finlay and Wilkinson's (1963) method, genotype Ghafghaz//F9.10/Maya"s" with coefficient regression (*b*) value close to 1 was stable and genotypes PATO/CAL/3/7C//BB/CNO/5/…, Momchil/Katya1 and 'Azar-2' with values higher than 1 were more adapted to favorable environments and remaining genotypes with lowest *b*-values were adapted to unfavorable environments.

According to Francis and Kannenberg's (1978) stability parameter (CV), the genotypes 'Azar-2', 'Sardari' and Momchil/Katya1 were considered as the most stable genotypes over environments as supported by GGE biplot (**Fig. 2**). These genotypes with the lowest CV had ranks 6, 7 and 2 in yield performance, respectively. PATO/CAL/3/7C//BB/CNO/5/… with rank of one in yielding performance had the highest CV value. Regarding the simultaneous interpretation of stability and yield performance constitute a common strategy in breeding programs, the results of this study verified that the use of stability is associated with recommendations for high yielding performance genotypes.

Discriminating power vs. representativeness of on-farm testing sites

The concept of the ideal testing location is characterized by the combined ability of locations to discriminate among genotypes included in the study and to be representative of other locations in the overall locations of interest (Yan and Kang 2003; Yan and Tinker 2006). The discriminating ability of locations is most easily visualized by counting the number of rings separating the location from the origin of the biplot display. The more rings separating the location from the origin of the graph, the more discriminating the location is (Yan and Tinker 2006). The representativeness of locations is visualized by the angle formed between the location vectors and the dark line running across the display (average environment axis) and passing through the origin.

Table 5 Yield and statistical performance of testing sites in durum and bread wheat crops.

Location	Durum wheat			Bread wheat		
	Mean yield	*b*j	CVj	Mean yield	*b*j	CVj
Islamabad	952 b	0.279	18.3	1354 b	0.737	76.6
Sarfirozabad	2558 a	2.472	34.8	2487 a	2.348	65.9
Ravansar	1585 b	0.508	27.2	1310 b	0.718	47.9
Bistoon	2781 a	1.477	34.9	1252 b	0.23	40.7
Harsin	1116 b	0.264	13.1	1155 b	0.967	12.7

*Means followed by similar letters are not significant at $P < 0.05$ according to Duncan's multiple range test

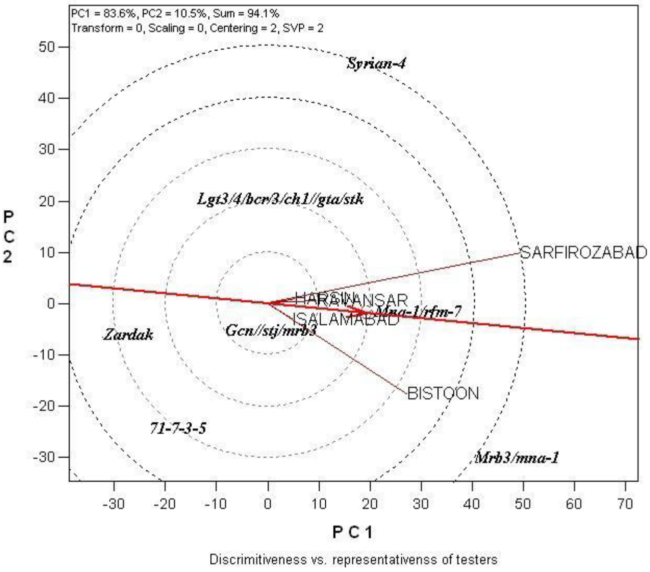

Fig. 3 Genotype plus genotype × location (GGL) interaction biplot display of the discriminating power versus representativeness of on-farm testing sites in promising durum wheat genotypes. Sites are in capital letters and genotypes are in italic.

The smaller the resulting angle, the more representative the location of other sites in the area of interest (Yan and Tinker 2006). For durum wheat on-farm trial, Sarfirozabad was the most discriminating location (**Fig. 3**). Bistoon had average discriminating ability, but Ravansar followed by Islamabad and Harsin were the least discriminating ability (**Fig. 3**). The most representative location was Ravansar followed by Sarfirozabad = Harsin (**Fig. 3**). However, the excellent discriminating ability of Sarfirozabad suggested it as a good choice. Additional work on durum wheat at each location would add clarification to these results.

For bread wheat, Sarfirozabad followed by Islamabad were the most discriminating locations (**Fig. 4**). The most representative location was Harsin followed by Sarfirozabad. The Sarfirozabad appeared to be a good location for testing bread wheat due to its excellent discriminating ability and representativeness. Across both on-farm trials (durum and bread wheat), there was some consistency in the clustering of locations into groupings. Sarfirozabad was the most discriminating location while the Harsin location was the least discriminating one. However, the other locations were not consistence in discriminating and representativeness. One of the more interesting and consistent findings was the value of Sarfirozabad as an ideal testing location. It was one of the most discriminating and, generally, most representative location for each of crops.

In addition to GGE biplot, univariate analysis may be useful to describe testing sites. However, when different genotypes are tested in a range of specific environments, test environments, like test genotypes, may be considered for better understanding of GE interaction (Mohammadi and Amri 2009). A good test site for screening genotypes must allow sufficient efficiency of selection through the expression of good genotypes. Thus, environments with high *b*j values exhibit high genotypic selectivity and may be considered as good test sites for detecting and selecting good genotypes (Isik and Kleinschmit 2005; Mohammadi *et al.* 2008).

In durum wheat on-farm trial, Sarfirozabad followed by Bistoon exhibited the highest values for genotypic selectivity (**Table 5**), indicating that these locations are good testing sites for genotype discrimination. This can be verified by GGL biplot analysis (**Fig. 3**). Harsin location followed by Islamabad and Ravansar had the least genotypic selectivity (**Table 5**). In the case of bread wheat on-farm trial, the Sarfirozabad had the highest genotypic selectivity while the Bistoon had the least one. The remaining testing sites had an average genotypic selectivity. Test locations with a low genotypic selectivity do not encourage good genotypes and, at the same time, they have a tendency to upgrade poor genotypes. Therefore, such sites are not desirable and may be misleading as test site. Results in the both on-farm trials showed that Sarfirozabad with the highest *b*j-value was the best site for genotype selectivity. These results also can be supported by the results of GGL biplot analysis. Test of sites based on coefficient of variation (CVj) showed that Harsin, in both on-farm trials, had the lowest CVj and the least variability for genotypic responses, unlike Sarfirozabad and Bistoon (in durum wheat) and Islamabad and Sarfirozabad (in bread wheat) (**Table 5**).

Correlation among testing locations

On a biplot display, the cosine of the angle between the vectors (i.e., lines that connect the locations to the biplot origin) of two locations approximates the correlation between the two locations in ranking the genotypes: the smaller the resulting angle, the more highly correlated the locations (Yan and Kang 2003; Yan and Tinker 2006). An angle of 0° indicates a correlation of +1, an angle of 90°a correlation of 0, and an angle of 180° represents a correlation of -1.

Based on the biplot analysis and correlation coefficient values (**Table 6**), environmental groupings were identified, which represented groupings of locations within the target region where tested plant materials behaved similarly. This concept of identifying similar testing locations has been used for a number of species (Gauch and Zobel 1997; Yan *et al.* 2000; Trethowan *et al.* 2003; Navabi *et al.* 2006).

Table 6 Correlation among testing sites in durum wheat (below diagonal) and bread wheat (above diagonal) crops (n=7).

	Isalamabad	Sarfirozabad	Ravansar	Bistoon	Harsin
Isalamabad		-0.02	-0.21	0.26	0.21
Sarfirozabad	0.46		0.55	-0.08	0.87*
Ravansar	0.05	0.59		-0.21	0.57
Bistoon	0.58	0.72	0.50		0.28
Harsin	0.30	0.72	0.06	0.53	

* Significant at 5% level of probability according to Duncan's multiple range test

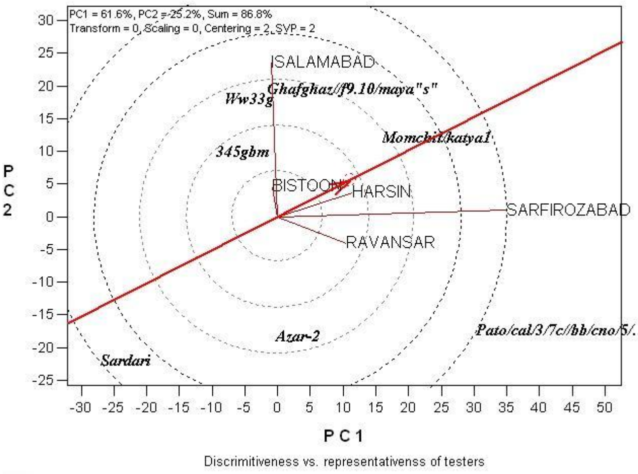

Fig. 4 Genotype plus genotype × location (GGL) interaction biplot display of the discriminating power versus representativeness of on-farm testing sites in promising bread wheat genotypes. Sites are in capital letters and genotypes are in italic.

Fig. 3 also shows relationship among testing locations. Although positive correlation was found among testing locations in durum wheat, the most prominent relations can be identified among Sarfirozabad, Ravansar and Harsin locations as well as between Isalamabad and Bistoon. In bread wheat (**Fig. 4**), Islamabad and Bistoon were highly correlated and were separated from the other highly correlated locations, which shows that in ranking of bread wheat genotypes these two groups are not similar. Correlation coefficients among the testing locations (**Table 6**) can further verify these results and indicate the biplot correctly displays relationships among the statistics measures. However, exact match is not to be expected, because the biplot describes the interrelationships among all environments on the basis of overall pattern of the data whereas correlation coefficients only describe the relationship between two environments (Yan and Rajcan 2002).

'Which-Won-Where' patterns

Visualization of the "which-won-where" patterns of MET data is important for studying the possible existence of different environmental groups in a region (Gauch and Zobel 1997; Yan *et al.* 2000, 2001). The polygon view of a biplot is the best way to visualize the interaction patterns between genotypes and environments and to effectively interpret a biplot (Yan and Kang 2003). A line that starts from the biplot origin and perpendicularly intersects a polygon side represents the set of hypothetical environments in which the two genotypes defining that side perform equally; the relative ranking of the two genotypes would be reversed in environments on opposite sides of the line. Therefore, the perpendicular lines to the polygon sides divide the biplot into sectors, each having its own winning genotype (Yan 2002). **Fig. 5** shows that all the durum wheat testing sites fell into a single sector; this indicates that a single genotype had the highest yield in all environments (Yan *et al.* 2007). The vertex genotypes in durum wheat trials were Mrb3/Mna-1, Syrain-4, 'Zardak', Lgt3/4/Bcr/3/Ch1//Gta/Stk and 71-7-5-1. The vertex genotype for each sector is the one that gave the highest yield for the environments that fall within that sector. Another important feature of **Fig. 5** is that it indicates environmental groupings, which suggests the possible existence of different mega-environments. Thus, based on bi-plot analysis of durum wheat trial, all locations made up a single mega-environment, where the Mrb3/Mna-1 had the highest yielding performance in this mega-environment.

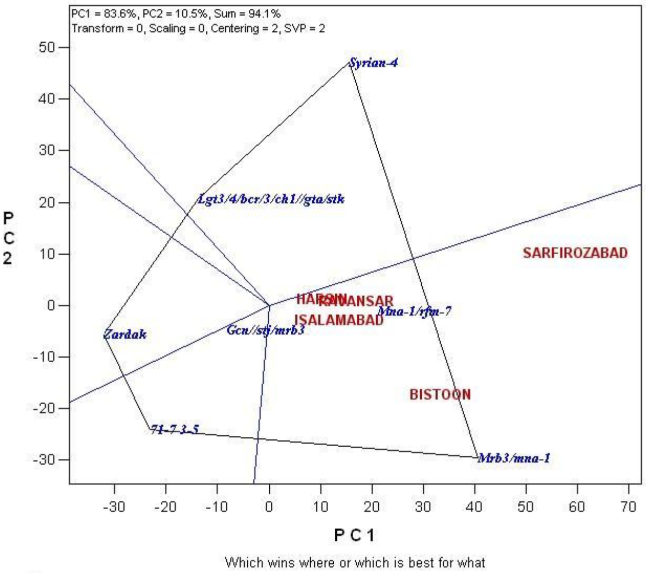

Fig. 5 The "which-won-where" view of the GGL biplot to show which durum wheat genotypes best in which farmers' fields testing sites.

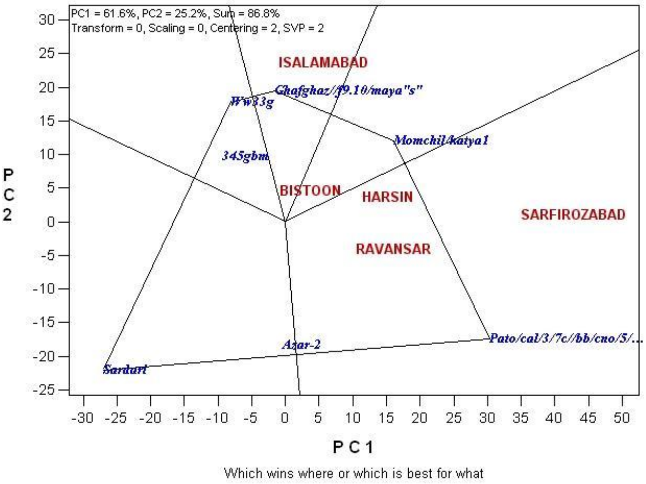

Fig. 6 The "which-won-where" view of the GGL biplot to show which durum wheat genotypes best in which farmers' fields testing sites.

In the which-won-where view of the GGE biplot based on the bread wheat data, the on-farm testing sites fell into two sectors with different winning genotypes (**Fig. 6**). Specifically, PATO/CAL/3/7C//BB/CNO/5/CAL//CNO was the highest yielding genotype in Sarfirozabad, Harsin and Ravansar, and Ghafghaz//F9.10/Maya"s" was the highest yielding genotype in the other two locations (Islamabad and Bistoon). This crossover GE suggests that the target environments may be divided into different mega-environments. Since a mega-environment is defined as a group of locations that consistently share the best set of genotypes or cultivars across years (Yan and Rajcan 2002), data from several years are essential to decide whether or not the target region can be divided into different mega-environments. Repeatable environmental grouping is necessary, but not sufficient, for declaring different mega-environments (Yan and Rajcan 2002).

CONCLUDING REMARKS

One of the most interesting and consistent findings was the value of Sarfirozabad as an ideal testing location. It was one of the most discriminating and, generally, most representative location for each of on-farm trials. The on-farm GGL biplot analysis and the unvariate statistics (*b* and CV) gave similar results in identifying superior genotypes and grouping testing sites. These methods also helped identify some of the least discriminating locations and those that were the least representative of test locations. GGL biplot methodology was a useful tool for identifying locations that optimized genotype performance and for making better use of limited resources available for the testing program. In this study, the durum wheat ('Zardak') and bread wheat ('Sardari' and 'Azar-2') checks were outyielded by promising genotypes in farmers' fields. The results showed that yield improvements and stability are achieved by growing the promising lines on farmers' fields under rainfed conditions.

However, in the highlands of Iran, there is a need to develop better-adapted and higher-yielding genotypes. In developing countries, such as Iran, genotypes have mostly been selected in favorable environments and then introduced agronomic management packages (e.g., mineral fertilizer, pesticides, irrigation) designed to significantly improve the growing environment. However, the results of less than two decades of breeding efforts jointly with between the ICARDA and DARI, led to the release of stable bread and durum wheat genotypes with high-yielding ability in minimum input conditions.

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