

# Identifying high yielding stable winter wheat genotypes for irrigated environments in Central and West Asia

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**Abstract** Improved winter wheat (*Triticum aestivum* L.) cultivars are needed for the diverse environments in Central and West Asia to improve rural livelihoods. This study was conducted to determine the performance of elite winter wheat breeding lines developed by the International Winter Wheat Improvement Program (IWWIP), to analyze their stability across diverse environments, and to identify superior genotypes that could be valuable for winter

wheat improvement or varietal release. One hundred and one advanced winter wheat breeding lines and four check cultivars were tested over a 5-year period (2004–2008). Grain yield and agronomic traits were analyzed. Stability and genotypic superiority for grain yield were determined using genotype and genotype × environment (GGE) biplot analysis. The experimental genotypes showed high levels of grain yield in each year, with mean values ranging from 3.9 to 6.7 t ha<sup>-1</sup>. A set of 25 experimental genotypes was identified. These were either equal or superior to the best check based on their high mean yield and stability across environments as assessed by the GGE biplot analysis. The more stable high yielding genotypes were ID800994.W/Falke, Agri/Nac//Attila, ID800994W/Vee//F900K/3/Pony/Opata, AU//YT542/N10B/3/II8260/4/JI/Hys/5/Yunnat Esskiy/6/KS82W409/Spn and F130-L-1-12/MV12. The superior genotypes also had acceptable maturity, plant height and 1,000-kernel weight. Among the superior lines, Agri/Nac//Attila and Shark/F4105W2.1 have already been proposed for release in Kyrgyzstan and Georgia, respectively. The findings provide information on wide adaptation of the internationally important winter wheat genotypes, and demonstrate that the IWWIP program is enriching the germplasm base in the region with superior winter wheat genotypes to the benefit of national and international winter wheat improvement programs.

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## Abbreviations

CIMMYT	International Maize and Wheat Improvement Center
ICARDA	International Center for Agricultural Research in the Dry Areas
IWWIP	International Winter Wheat Improvement Program
IWWYT	International Winter Wheat Yield Trial
TKW	1,000-kernel weight

## Introduction

Wheat (*Triticum aestivum* L.) 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 CIMMYT (van Ginkel and Rajaram 1993). Around 16.4 million hectares 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). One of the reasons for the low yields is continuous cultivation of old cultivars. To improve productivity of winter wheat, the International Winter Wheat Improvement Program (IWWIP), a cooperative breeding project between the Ministry of Agriculture and Rural Affairs of Turkey, the International Maize and Wheat Improvement Center (CIMMYT) and the International Center for Agricultural Research in the Dry Areas (ICARDA) was initiated in 1991 (cf. [www.iwwip.org](http://www.iwwip.org)). IWWIP distributes winter wheat observation nurseries and yield trials comprising high yielding advanced breeding lines to facilitate introduction and exchange of improved germplasm across the region for irrigated and dryland production conditions. This study includes winter wheat trials conducted under irrigated conditions.

Braun et al. (1998) outlined the priorities for winter wheat breeding in Central and West Asia. High and stable yield, wide adaptation, drought tolerance, grain quality, resistances to stripe rust (caused by *Puccinia striiformis*), leaf rust (*P. triticina*) and stem rust (*P. graminis tritici*), cold tolerance and winter hardiness are important traits needed in winter wheat

cultivars for the region (Braun et al. 1998; Morgounov et al. 2005). IWWIP, in collaboration with national partners, has been working to meet the winter wheat germplasm and cultivar needs, and successes were outlined by Morgounov et al. (2005). It is critical to study yield levels and stability of elite lines developed by IWWIP across the diverse environments in order to properly utilize them in winter wheat improvement programs and target the best for varietal release. An analysis of a limited number of accessions from IWWIP tested across nine environments in Turkey in 1 year suggested that a few genotypes had high and stable yields (Kaya et al. 2006). However, evaluation of winter wheat genotypes across diverse sites and several years is needed in order to identify spatially and temporally stable genotypes that could be recommended for release as new cultivars and/or for use in the breeding programs.

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 that higher yielding lines might not always be stable across environments (Sharma et al. 1987; Özgen 1991; Koemel et al. 2004), and hence would not be suitable for release as new, improved varieties. Therefore, this study was conducted to determine the range of variability and stability of grain yield of elite winter wheat genotypes developed by the IWWIP, and to identify superior lines that could more confidently be used in the winter wheat improvement programs in Central and West Asia, and possibly beyond.

## Materials and methods

Each year the international winter wheat yield trial for irrigated environments (IWWYT-IR) assembled by IWWIP, comprises 25 genotypes, including 20–21 new and promising breeding lines and four or five commercial checks. Two improved (Kinaci 97 and Katia 1), one old (Bezostaya 1) and one local cultivar were included as checks in each year. Sultan 95 (Agri/Nac) was used as a check in 2004, 2005 and 2006. Sultan 95, Kinaci 97 (Ymh/Tob//Mcd/3/Lira) and Katia 1 (Chebros/Bez) are high yielding, improved winter wheat cultivars, well adapted to the Central and West Asian production systems.

Bezostaya 1 is a widely adapted old cultivar. The local check was a popular winter wheat cultivar grown in individual countries and varied by country. This study included wheat genotypes tested in the 7th to 11th IWWYT-IR evaluated from 2004 to 2008. A total of 101 experimental genotypes were tested over these 5 years. The detailed information (i.e. pedigree, selection history and origin) on these genotypes are available at [www.iwwip.org](http://www.iwwip.org).

The IWWYT trials were conducted at 16, 11, 11, 10 and 16 sites in 2004, 2005, 2006, 2007 and 2008, respectively (see Table 1). In each year, the study was conducted during the main wheat-growing season (October to July) using a  $5 \times 5$  square lattice in two replicates. The trials were managed according to locally recommended wheat crop husbandry practices in the individual countries. Data were recorded on days to heading, plant height, grain yield and

**Table 1** Sites of winter wheat yield trials conducted in years, 2004–2008

Code	Country	State or city	Latitude	Longitude	Altitude (masl)
AFG01	Afghanistan	Kabul	34°27'N	69°07'E	1,835
AFG09	Afghanistan	Kunduz	36°10'N	68°85'E	400
AFG14	Afghanistan	Ghazni	33°32'N	68°09'E	2,183
AFG13	Afghanistan	Mazar-i-Sharif	36°38'N	66°56'E	477
AFG15	Afghanistan	Heart	34°18'N	62°16'E	1,096
AFG22	Afghanistan	Bamyan	34°43'N	67°49'E	2,550
ARM01	Armenia	Yerevan	40°10'N	44°17'E	850
AZR01	Azerbaijan	Tertter	40°20'N	46°55'E	239
BUL01	Bulgaria	Dobroudja	43°39'N	28°01'E	236
CHN08	China	Lanzhou	34°45'N	106°09'E	1,378
IRN01	Iran	Karaj	35°48'N	51°02'E	1,238
IRN02	Iran	Ardabil	33°15'N	48°17'E	1,350
IRN03	Iran	Mashad, Khorasan	36°13'N	59°37'E	985
IRN12	Iran	Khorasan	35°50'N	58°60'E	1,650
IRN17	Iran	Miandoab	36°58'N	46°09'E	1,371
KAZ01	Kazakhstan	Almaty	42°00'N	77°00'E	740
KAZ02	Kazakhstan	Saryagashsky	42°00'N	80°00'E	593
PAK04	Pakistan	Quetta	30°05'N	66°58'E	1,719
PAK05	Pakistan	Gilgit	34°36'N	70°76'E	1,300
PRT01	Portugal	Elvas	38°53'N	07°08'E	219
ROM01	Romania	Calarasi	44°24'N	26°31'E	67
RUS01	Russia	Krasnodar	45°01'N	38°57'E	37
SRB01	Serbia	Novi Sad	45°30'N	19°80'E	80
SYR01	Syria	Aleppo	36°01'N	36°56'E	362
TAJ01	Tajikistan	Gissar	38°38'N	67°31'E	928
TUR03	Turkey	Sakarya	40°47'N	30°25'E	36
TUR05	Turkey	Ankara-Haymana	39°30'N	32°30'E	1,000
TUR07	Turkey	Edirne	41°40'N	26°34'E	41
TUR08	Turkey	Erzurum	39°57'N	41°37'E	1,674
TUR09	Turkey	Eskisehir	39°50'N	30°10'E	760
TUR13	Turkey	Konya	37°50'N	32°40'E	1,010
TUR15	Turkey	Samsun	41°13'N	36°29'E	43
UKR01	Ukraine	Odessa	46°00'N	31°00'E	42
UZB02	Uzbekistan	Kibray	41°22'N	69°19'E	478

1,000-kernel weight (TKW) following standard procedures outlined by IWVIP.

The statistical analysis was conducted in each year using Genstat Discovery Edition 3 (Genstat 2007) software. Since experimental genotypes changed each year, all analyses were accomplished by year. Each year-site combination was considered a unique and random environment, while genotypic effect was analyzed as fixed. Genotype and genotype  $\times$  environment (GGE) biplots were conducted using GGE biplot software (Yan et al. 2000; Yan and Kang 2002) to determine grain yield stability and to identify superior genotypes. The GGE biplot presents the main genotype effect (G) and the genotype  $\times$  environment interaction (GE) of multi-environment tests. There is an option in the GGE biplot analysis that permits comparison among genotypes with a reference genotype. This method specifies the position of an “ideal” genotype, which will have the highest average value of all genotypes and be absolutely stable; that is, it expresses no genotype by environment interaction. A set of concentric circles are created using the ideal genotype at the concentric center. The ideal genotype is used as a reference to rank the other genotypes. A performance line passing through the origin of the biplot is used to determine mean performance of a genotype. The arrow on the performance line represents increasing mean performance. A stability line perpendicular to the performance line also passes through the origin of the biplot; the two arrows in opposite directions represent decreased stability. A genotype farther from the biplot origin on either side of the stability line represents relatively lower stability. This GGE biplot analysis has recently been widely used to determine performance stability in multilocation trials in order to identify superior genotypes (Sharma and Duveiller 2007; Yan et al. 2007; Roozeboom et al. 2008).

GGE biplot analysis was also used to examine relationships among sites across years using the four checks that were grown in different years. Each environment in the biplot is connected to the origin with a line, called the vector. The cosine of the angle between the vectors of two environments approximates the correlation coefficients between them. Two environments are positively or negatively correlated if the angles between their vectors are  $<90^\circ$  or  $>90^\circ$ , respectively. The two environments are independent if the angle between them is near  $90^\circ$ . The environments

with longer vectors are more discriminative of the genotypes; short vectors are less discriminative.

Rank correlation coefficients among genotypes across locations were also estimated to elucidate genotype  $\times$  environment interaction. Kinship coefficients among superior genotypes were estimated using ‘KIN’ software (Tinker and Mather 1993) to determine parental relationship among superior genotypes. A lower kinship coefficient value between two genotypes represents their genetic diversity, whereas a higher value shows similarity. Heritability for grain yield was estimated as the ratio of genotypic to phenotypic variance using the analysis of variance technique.

## Results

The wheat genotypes showed large variations for days to heading, plant height, grain yield and TKW in each of the 5 years (Table 2). Mean grain yields were significantly different over the years with actual values of 5.69, 5.10, 5.26, 4.29 and 6.13 t ha<sup>-1</sup> in 2004, 2005, 2006, 2007 and 2008, respectively. Relative differences among the common checks changed in the 5 years (individual data not presented). All checks showed the highest and the lowest grain yields in 2008 and 2007, respectively. The older check Bezostaya 1 showed significantly lower grain yield than the improved check Kinaci 97 in all 5 years. Bezostaya 1 also had the lowest grain yield among all genotypes in all years except 2007. Heritability estimates for grain yield were 0.60, 0.72, 0.63, 0.51 and 0.78 in 2004, 2005, 2006, 2007 and 2008, respectively. The mean rank correlation coefficients among sites were 0.03, 0.22, 0.20, 0.13 and  $-0.03$  in 2004, 2005, 2006, 2007 and 2008, respectively (Table 3). None of the sites showed a strong correlation with average grain yield across all locations in any of the 5 years.

GGE biplots for individual years represent a great deal of diversity among genotypes and among environments (Figs. 1–5). The values for principal components 1 (PC1) and 2 (PC2) were low to intermediate (35.6–52.6%); however, the relationship between the average tester axis abscissa and the genotypic means were high with actual values of 0.77, 0.98, 0.98, 0.75 and 0.97 in 2004, 2005, 2006, 2007 and 2008, respectively. This shows that despite

**Table 2** Superior winter wheat genotypes with the highest and most stable grain yields evaluated across sites, 2004–2008

Entry	Pedigree	CID	Selection history	Origin	Grain yield (t ha <sup>-1</sup> )	Plant height (cm)	Days to heading from Jan 1	1,000- kernel weight (g)
7-09 <sup>a</sup>	Shark/F41/05W2.1	CIT925169	-0SE-0YC-6YC-0YC	TCI	5.729*2, NS 2 <sup>b</sup>	88	140	47
7-13	TAM200*2/3/F60314.76/ MRL/Cno79	CMWW91M00277F	-0WM-050WM-6WM-05WM- 015WM-7WM-0WM	MX	5.854*2, NS 2	76	145	35
7-17	Agri/Nac/Kauz	CMSW92WM00231S	-0SE-0YC-0YC-*5YE-5YC-0YC	MX-TCI	5.876*2, NS 2	91	141	39
7-18	ID800994.W/Falke	SWM89Y165H	-3H-0PE-0YC-1YC-0YC-5YC-0YC	MXORTCI	6.070*2, NS 2	82	140	43
7-22	Vorona/Kauz//1D13.1/Mlt	CIT937111	-0SE-0YC-*3YE-3YC-0YC	TCI	6.126*2, NS 2	85	144	38
8-07	Griset-9	CIT925099	-0SE-0YC-3YC-0YC-4YC-0YC-5YC- 0YC	TCI	5.450*2, NS 2	91	131	40
8-12	Eskima-8	CIT925080	-0SE-0YC-7YC-0YC-2YC-0YC-3YC- 0YC	TCI	5.462*2, NS 2	90	129	41
8-15	Agri/Nac/Attila	CMSW92WM00232S	-0SE-0YC-5YE-0YC-4YK-0YK	ORMXTCI	5.493*2, NS 2	89	131	44
8-24	Star/Bwd	CMSW93WM0137	-0AP-0YC-7YE-0YC-2YC-0YC	MX-TCI	5.384*2, NS 2	85	129	46
8-25	Agri/Nac/Attila	CMSW92WM00232S	-0SE-0YC-5YE-0YC-4YK-0YK	MX-TCI	5.844*3, NS 1	89	131	44
9-06	F885K1.1/SXL	CIT932072	-0SE-0YC-*8YE-8YC-0YC-1YM-0YM	TCI	5.764*1, NS 3	94	147	31
9-08	ID800994 W/Vee//F900 K/3/ Pony/Opata	CIT945316	-030SE-0YC-4YE-0YC-2YM-0YM	TCI	5.928*2, NS 2	92	139	29
9-10	Griset-16	CIT925099	-0SE-0YC-3YC-0YC-4YC-0YC-1YM- 0YM	TCI	5.407*2, NS 2	94	145	36
9-14	Bilinmiyen96.40	F2.96.40	-0SE-0YC-3YE-0YC-1YM-0YM	TCI	5.385*2, NS 2	93	144	32
9-22	Bilinmiyen96.55	F2.96.55	-0SE-1YA-1YC-0YC-1YM-0YM	TCI	5.523*2, NS 2	96	142	32
10-05	Alpu-1/4/Kvz/Cut75/3/Ymh// 61.1.523/Drc	TCI951008	-0SE-0YC-0E-2YE-0YE-2YM-0YM	TCI	4.628*2, NS 2	85	133	37
10-10	Yubileinaya75/3/Agri/Bjy// Vee/4/Pyn/Bau	TCI952157	-0SE-0YC-0E-5YE-0YE-4YM-0YM	TCI	4.343*1, NS 3	81	128	39
10-18	AU//YT542/N10B/3/Π8260/4/ JI/Hys/5/Yunnat Esskiy/6/ KS82W409/Spn	TCI952009	-0SE-0YC-0E-1YE-0YE-1YM-0YM	TCI	4.805*1, NS 3	79	134	46
10-19	AU//YT542/N10B/3/Π8260/4/ JI/Hys/5/Yunnat Esskiy/6/ KS82W409/Spn	TCI952009	-0SE-0YC-0E-1YE-0YE-2YM-0YM	TCI	4.662*3, NS 1	81	129	44
10-24	CA8055/4/Rom Tast/Bon/3/ Dibo//SU92/C113645/5/ Agri/Bjy//VeeS	TCI951084	-0SE-0YC-0E-3YE-0YE-1YM-0YM	TCI	4.346*2, NS 2	78	135	37

Table 2 continued

Entry	Pedigree	CID	Selection history	Origin	Grain yield (t ha <sup>-1</sup> )	Plant height (cm)	Days to heading from Jan 1	1,000-kernel weight (g)
11-12	F130-L-1-12/MV12(Atila-12)	TCI961246	-0SE-0YC-2E-0E-2 K -0YK	TCI	6.381*3, NS 1	81	131	41
11-13	F130-L-1-12/MV12(Atila-12)	TCI961246	-0SE-0YC-2E-0E-3 K -0YK	TCI	6.511*3, NS 1	80	131	39
11-18	Vorana/Milan/Sha7/3/MV17	TCI972025	-0SE-0YC-0YE-4YE-0YE-1YE-0YE	TCI	6.658*3, NS 1	89	131	44
11-23	Agri/Bij/Vee/3/Akula/4/ F10S-1	TCI972515	-0SE-0YC-0YE-26YE-0YE-1YE-0YE	TCI	6.589*3, NS 1	88	130	43
11-24	Agri/Bij/Vee/3/Akula/4/ F10S-1	TCI972515	-0SE-0YC-0YE-3YE-0YE-1YE-0YE	TCI	6.414*3, NS 1	89	131	39

\* Followed by a number, represents the number of checks with significantly lower grain yield than the experimental line at  $P = 0.05$

<sup>a</sup> The numbers before and after '-' represent IWWT and entry number within a particular IWWT

<sup>b</sup> NS followed a number, represents the number of checks with grain yield non-significantly different from the experimental line at  $P = 0.05$

Table 3 Pairs among the 25 superior winter wheat genotypes with kinship coefficient greater than zero

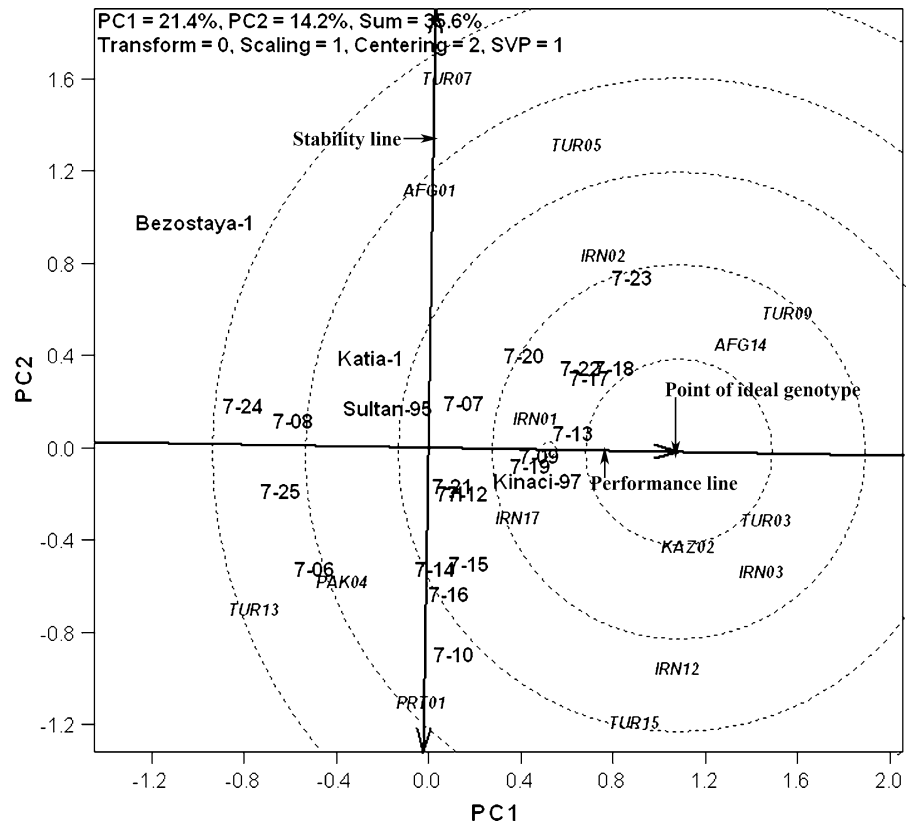
Genotype pair	Kinship coefficient
7-17/8-15	0.250
7-17/8-25	0.250
7-17/11-08	0.125
7-18/9-09	0.063
8-15/8-25	0.500
9-08/10-10	0.031
9-08/10-24	0.031
9-08/11-23	0.016
10-10/10-24	0.125
10-10/11-23	0.063
10-18/10-19	0.500
10-24/11-23	0.063
10-24/11-24	0.063
11-12/11-13	0.500
11-12/11-18	0.250
11-13/11-18	0.250
11-23/11-24	0.500

Lower values represent greater genetic diversity between the two lines being compared

low to intermediate values for PC1 and PC2, the biplots are valid.

Many experimental genotypes were higher in grain yield than one or more of the checks in each year (Table 2). GGE biplot analysis revealed that many high yielding experimental genotypes were also stable across environments in each year. Twenty-five such superior experimental genotypes, which were closer to the point of the ideal genotype in the biplots, are listed in Table 2. The experimental genotypes 7-09, 7-13, 7-17, 7-18 and 7-22 were closer to the point of the ideal genotypes for grain yield in 2004 (Fig. 1); genotypes 7-13, 7-17 and 7-18 were closer to the point of the ideal genotypes than all checks. Bezostaya 1 ranked last for grain yield among all genotypes by being farthest from the point of the ideal genotype. The experimental genotypes 8-07, 8-12, 8-15, 8-24 and 8-25 were superior for grain yield in 2005 by being closest to the point of the ideal genotype (Fig. 2). These five, as well as a few other, genotypes were also superior to all checks. Bezostaya 1 ranked 22nd among 25 genotypes for grain yield. Genotypes 9-06, 9-08, 9-10, 9-14 and 9-22 were superior experimental genotypes for grain yield in

**Fig. 1** GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 16 environments in 2004. The names in *italics* are locations, with the initial *three letters* abbreviating the country (see Tables 1 and 2 for full names of locations and genotypes, respectively)

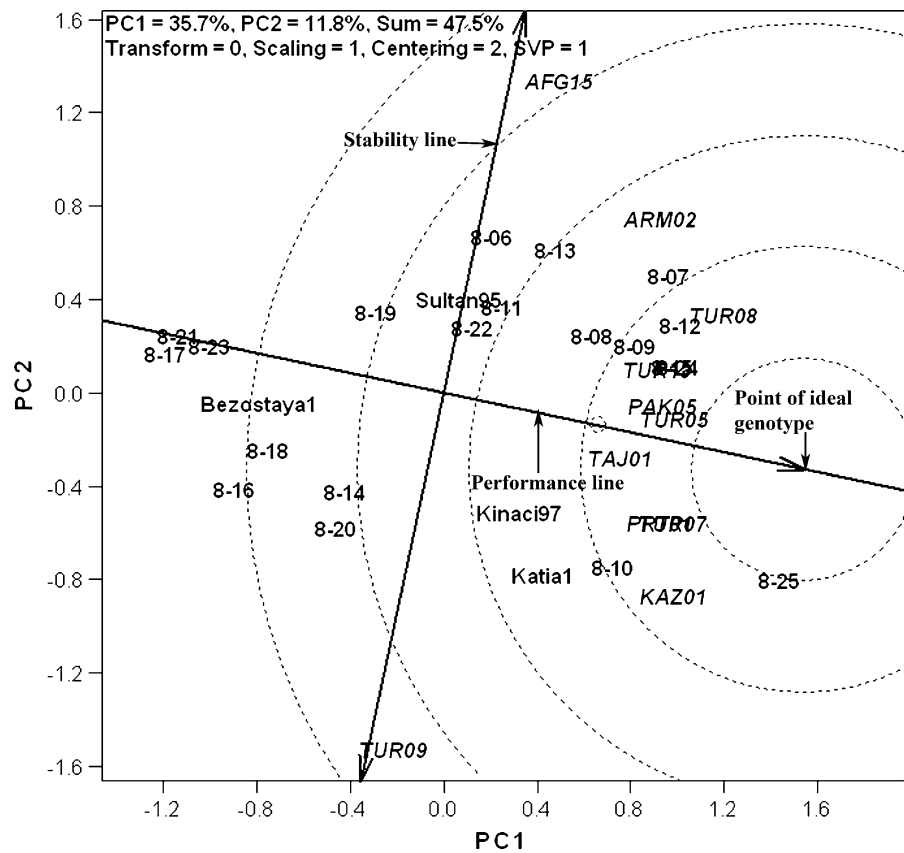


2006 by being near to the point of the ideal genotype (Fig. 3); 9-06 and 9-08 were superior over all the checks. Bezostaya 1 was placed farthest from the point of the ideal genotype. Genotypes 10-05, 10-10, 10-18, and 10-19 were the most superior genotypes for grain yield in 2007 (Fig. 4). They were closer to the point of the ideal genotype than all checks. Once again, Bezostaya 1 ranked last among all genotypes for grain yield superiority. Genotypes 11-12, 11-13 and 11-23 were the most superior for grain yield in 2008 by being closer to the point of the ideal genotype than all checks (Fig. 5). Bezostaya 1 ranked 24th and was superior for grain yield only to 11-19.

The 25 superior genotypes identified were genetically diverse as shown by dissimilar pedigrees (Table 2). There were only three sets (9-14/9-22, 11-12/11-13 and 11-23/11-24) of sister lines among the 25 superior genotypes. Kinship coefficient analysis showed that only 17 of the 300 pairs of genotypes had kinship coefficients  $>0.001$ , and eight pairs of genotypes showed kinship coefficients  $\geq 0.25$  (Table 3). The mean kinship coefficient was 0.014.

The 64 test environments assessed on the basis of grain yield of the common checks showed wide diversity among sites (Fig. 6). The environments, even within a country, often grouped differently as shown by the multiple sites in Turkey in each year (Figs. 1–6). All environments were discriminative for genotypes as shown by the position of the site-year combinations away from the biplot origin. However, environments greatly differed in their discriminative ability as shown by their different vector lengths. Frequently, a given site showed diversity in different years as represented by their position at different points and different vector lengths in the biplot. Two such examples are indicated by a black arrow ( $\downarrow$ ) and a circle ( $\circ$ ) on the biplot (Fig. 6). The site in Turkey T5 in 2004 (T5-4) with shorter vector length was less discriminative of genotypes than the same site in 2006 (T5-6). Besides, there was a negative association between T5-4 and T5-6. Another such example is shown for the site (T7) which differed in 5 years both in vector length and association.

**Fig. 2** GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 11 environments in 2005. The names in *italics* are locations, with the initial *three letters* abbreviating the country (see Tables 1 and 2 for full names of locations and genotypes, respectively)



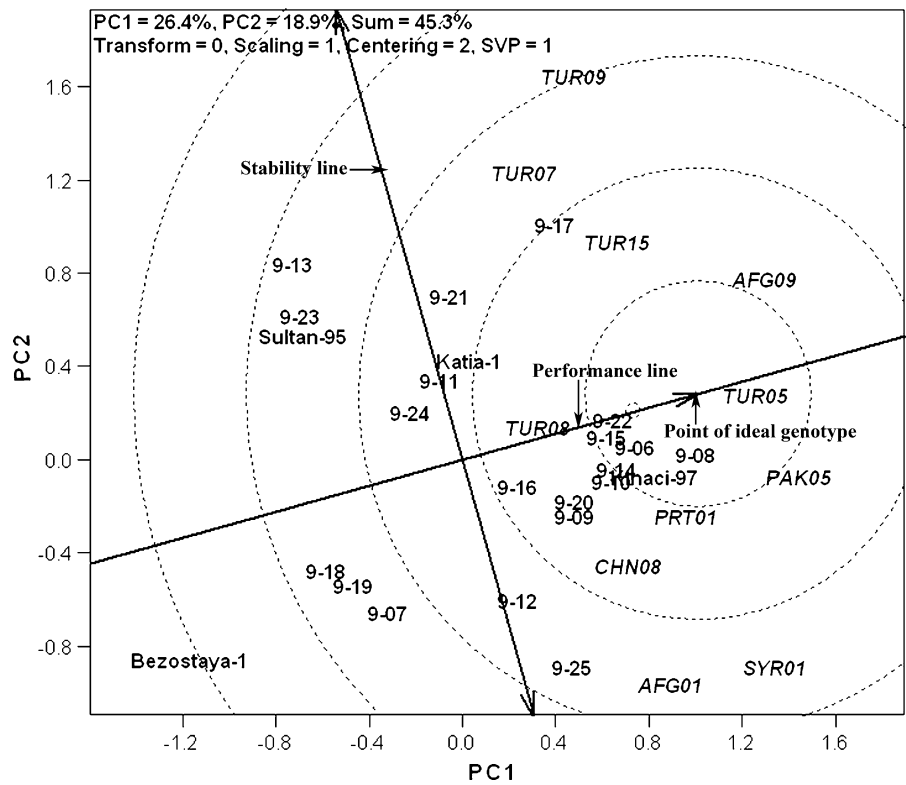
## Discussion

Mean grain yields of the wheat genotypes differed significantly over 5 years, demonstrating year-to-year variations in climatic conditions. Considering the diversity among test locations, wide year-to-year variations were expected. This was in agreement with previous findings using spring wheat (Trethowan et al. 2001, 2003; Lillemo et al. 2004, 2005). Such year to year disparity is also supported by the variation in average national wheat yields in the different countries, where the trials were conducted (FAO 2008). The low values for rank correlation coefficients among experimental sites in each year indicated that relative rankings of the genotypes for grain yield were not consistent across diverse environments. Therefore, the use of these diverse locations for testing IWWYT is justified in order to develop winter wheat genotypes with wide adaptation. Previous studies on spring wheat also found strong genotype  $\times$  environment interactions within

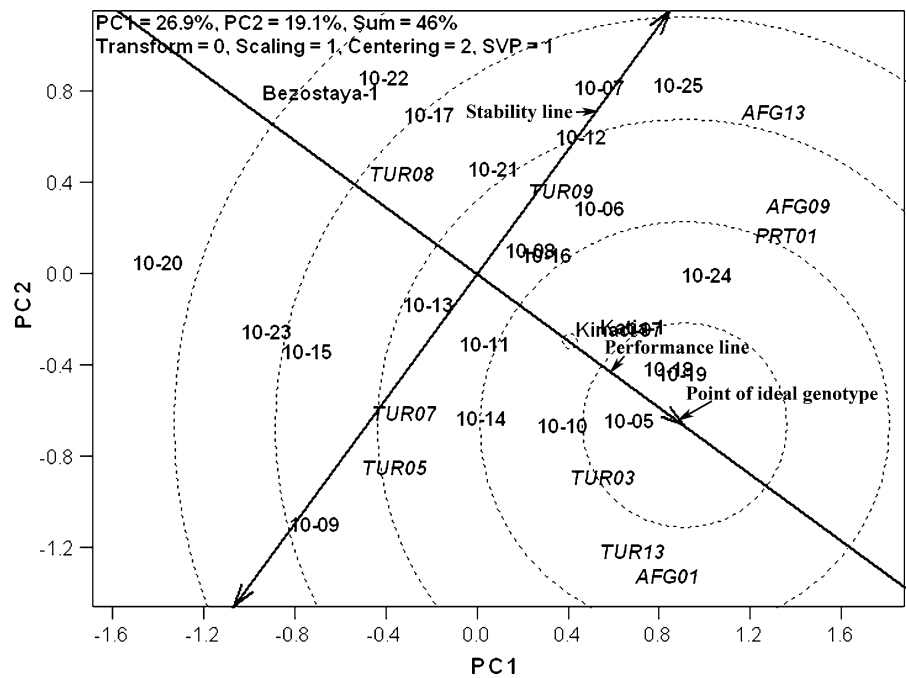
and between countries across the region (Singh et al. 2007). Despite changes in relative rankings of genotypes across locations, the intermediate-to-high estimates for heritability for grain yield show that the genotypic component constituted a greater portion than the environmental to total phenotypic variance. Therefore, selection for higher grain yield would be possible among the experimental lines tested in these IWWYT sets.

The test environments were highly diverse, and repeatedly the same site grouped differently in different years indicating site  $\times$  year interactions. There was no clear-cut grouping of environments based on grain yield of the checks. This suggests that the irrigated testing sites currently being used by IWWIP, and included in this study, are rational and very useful options that should continue in the future. This is also supported by the fact that all year-site combinations were discriminative of the genotypes, and frequently at different levels. This result differs from the findings of Lage et al. (2008) who identified

**Fig. 3** GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 11 environments in 2006. The names in *italics* are locations, with the initial *three letters* abbreviating the country (see Tables 1 and 2 for full names of locations and genotypes, respectively)



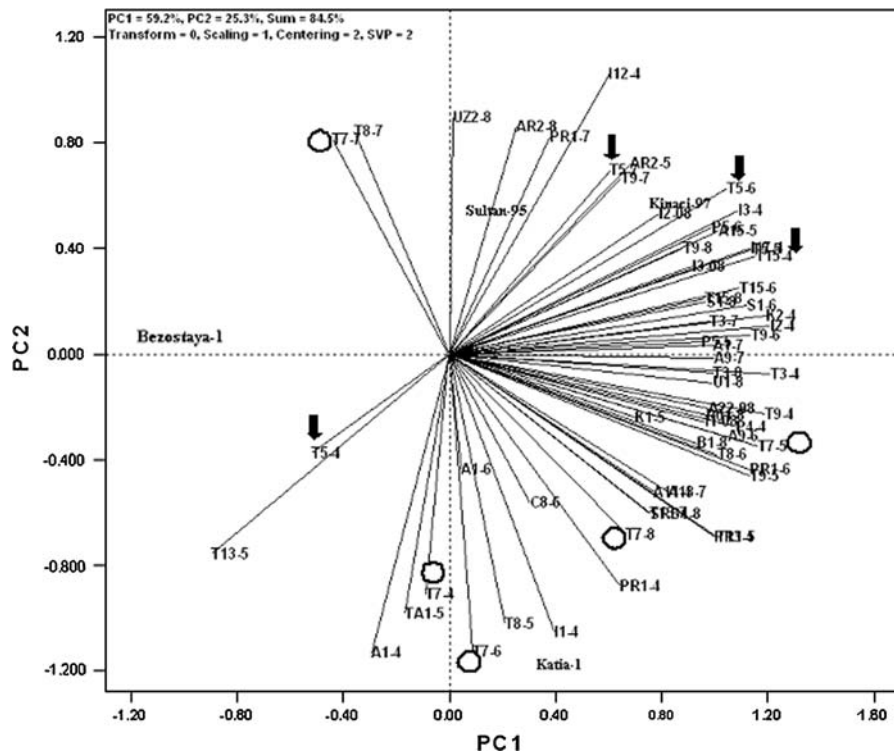
**Fig. 4** GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 10 environments in 2007. The names in *italics* are locations, with the initial *three letters* abbreviating the country (see Tables 1 and 2 for full names of the locations and genotypes, respectively)



key sites in Iran, Turkey and Mexico as predictor sites for regional yield testing in Central and West Asia. Our results showed weak rank correlation

coefficients among environments, dismissing any particular location as a reliable predictor site for the irrigated IWWT. The differences in findings were





**Fig. 6** Relationship among environments based on grain yield data for four checks (Bezostaya-1, Katia-1, Kinaci-97 and Sultan-95) evaluated across 64 sites over 5 years. The year-site combinations are represented by a *symbol* and site number in a country followed by year (4 = 2004, 5 = 2005, 6 = 2006, 7 = 2007 and 8 = 2008). Two examples of the same site

differing in relative performance in 2 years are shown by arrows (T5) and circles (T7). (A = Afghanistan, AR = Armenia, B = Bulgaria, C = China, I = Iran, K = Kazakhstan, P = Pakistan, PR = Portugal, R = Russia, S = Syria, SRB = Serbia, T = Turkey, TA = Tajikistan, U = Ukraine and UZ = Uzbekistan)

target countries in the region, as well as for improved quality traits (information available on [www.iwwip.org](http://www.iwwip.org)). Hence, the use of the superior genotypes identified in this study should provide additional benefits under disease epidemic conditions. There are a number of parents in the pedigrees of the superior genotypes that possess combinations of high yield and resistance to leaf rust and stripe rust (Singh et al. 2000). Such genotypes are especially valuable considering that leaf rust and stripe rust are the most important disease constraints in many of the target countries (Braun et al. 1998).

The wheat genotypes tested in the 7–11th IWWYT for irrigated conditions showed a wide range of variability for grain yield and other agronomic characters, with opportunities for selection of high yield and acceptable agronomic characters. The genotypes with significantly higher grain yields than the checks provide options for identifying improved

cultivars for the region. Since winter wheat hybridization programs are not well developed in several collaborating countries, the elite lines introduced through IWWIP are playing an important role for developing new cultivars. This is reflected through the release of several wheat varieties in the past 15 years (Morgounov et al. 2005). Recently, one of the 25 superior lines identified in this study (8-25, Table 2) was submitted for release as ‘Hans’ in Kyrgyzstan. Another superior line (7-09, Table 2) has been submitted for release as ‘Lomtagora-1’ in Georgia and as ‘Hanli’ in Turkey. These findings on cultivar identification demonstrate that national winter wheat programs are indeed selecting the outstanding lines from the IWWYT and that improved winter wheat genotypes are expanding the genetic base of winter wheat germplasm. These new cultivars along with many others identified in the past 10 years (Morgounov et al. 2005) may positively influence replacement

of older winter wheat cultivars and lead to an increase in wheat productivity.

There is only limited previous documentation on the performance stability of winter wheat genotypes in Central and West Asia (Kaya et al. 2006). Moreover, such information is lacking for the 101 elite lines that have been tested in the past 5 years. Even though this study has focused on yield trials conducted within and around the Central and West Asia region, these genotypes have been shared with winter wheat collaborators around the world. This study presents a comprehensive analysis of yield and stability of such a globally important large set of winter wheat genotypes for irrigated environments, and the information presented could benefit national and international winter wheat improvement programs in efficient dissemination and use of valuable germplasm.

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## References

- Braun HJ, Ekiz H, Eser V, Keser M (1998) Breeding priorities of winter wheat programs. In: Braun HJ, Altay F, Kronstad WE, Beniwal SPS, McNab A et al (eds) *Wheat: prospects for global improvement*. Kluwer, Dordrecht, pp 553–560
- CIMMYT (2005) Rapid progress in winter wheat breeding has large impact. [http://www.cimmyt.org/english/docs/ann\\_report/2004/publGoods/rapidProgress.htm](http://www.cimmyt.org/english/docs/ann_report/2004/publGoods/rapidProgress.htm) Verified 8 October, 2008
- FAO (2008) Statistical database. [www.fao.org](http://www.fao.org). Verified 14 October, 2008
- Genstat (2007) *Genstat for windows*. Discovery, 3rd edn. Lawes Agricultural Trust, Rothamsted Experimental Station, UK
- Kaya Y, Akcura M, Ayranci R, Taner S (2006) Pattern analysis of multi-environment trials in bread wheat. *Commun Biometry Crop Sci* 1:63–71
- Koemel JE, Guenzi AC, Carver BF, Payton ME (2004) Hybrid and pure line hard red winter wheat yield and stability. *Crop Sci* 40:107–113
- Lage J, Trethowan RM, Hernandez E (2008) Identification of site similarities in western and central Asia using CIMMYT international wheat yield data. *Plant Breeding* 127:350–354
- Lillemo MM, van Ginkel M, Trethowan RM, Hernandez E, Rajaram S (2004) Associations among international CIMMYT bread wheat yield testing locations in high rainfall areas and their implications for wheat breeding. *Crop Sci* 44:1163–1169
- Lillemo MM, van Ginkel M, Trethowan RM, Hernandez E, Crossa J (2005) Differential adaptation of CIMMYT bread wheat to global high temperature environments. *Crop Sci* 45:2443–2453
- Morgounov AI, Braun HJ, Ketata H, Paroda R (2005) International cooperation for winter wheat improvement in central Asia: results and perspectives. *Turk J Agric For* 29:137–142
- Özgen M (1991) Yield stability of winter wheat (*Triticum* sp.) cultivars and lines. *J Agron Crop Sci* 166:318–327
- Roozeboom KL, Schapaugh WT, Tuinstra MR, Vanderlip RL, Milliken GA (2008) Testing wheat in variable environments: genotype, environment, interaction effects, and grouping test locations. *Crop Sci* 48:317–330
- Sharma RC, Duveiller E (2007) Advancement toward new spot blotch resistant wheats in South Asia. *Crop Sci* 47:961–968
- Sharma RC, Smith EL, McNew RW (1987) Stability of harvest index and grain yield in winter wheat. *Crop Sci* 27:104–108
- Singh RP, Huerta-Espino J, Rajaram S (2000) Achieving near-immunity to leaf and stripe rusts in wheat by combining slow rusting resistance genes. *Acta Phytopathologica Entomologica Hungarica* 35:133–139
- Singh RP, Huerta-Espino J, Sharma R, Joshi AK, Trethowan RM (2007) High yielding spring bread wheat germplasm for global irrigated and rainfed production systems. *Euphytica* 157:351–363
- Tinker NA, Mather DE (1993) KIN: software for computing kinship coefficients. *J Heredity* 84:238
- Trethowan RM, Crossa J, van Ginkel M, Rajaram S (2001) Relationships among bread wheat international yield testing locations in dry areas. *Crop Sci* 41:1461–1469
- Trethowan RM, van Ginkel M, Ammar K, Crossa J et al (2003) Associations among twenty years of bread wheat yield evaluation environments. *Crop Sci* 43:1698–1711
- van Ginkel M, Rajaram S (1993) Breeding for durable resistance to diseases in wheat: an international perspective. In: Jacobs T, Parleviet J (eds) *Durability of disease resistance*. Kluwer, Dordrecht, pp 259–272
- Yan W, Kang MS (2002) *GGE Biplot analysis: a graphical tool for breeders, geneticists, and agronomists*. CRC Press, New York
- Yan W, Hunt LA, Sheng Q, Szlavnic Z (2000) Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Sci* 40:597–605
- Yan W, Kang MS, Ma B, Woods S, Cornelius PL (2007) GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Sci* 47:643–653