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High Yielding Stable Wheat Genotypes for the Diverse Environments in Afghanistan

Mahmood Osmanzai and Ram C. Sharma
CIMMYT, P.O. Box 5291, Kabul, Afghanistan

Abstract: This study was conducted to determine performance of elite spring wheat (*Triticum aestivum* L.) breeding lines developed by the International Maize and Wheat Improvement Center (CIMMYT), Mexico, examine genotype×environment (GE) interaction and identify superior wheat genotypes across diverse environments in Afghanistan. Forty nine breeding lines and one local check cultivar were tested across 7, 6 and 6 sites in 2005, 2006 and 2007, respectively. Grain yield, days to heading, plant height and agronomic scores were analyzed. Stability and genotype superiority for grain yield was determined using regression and genotype and genotype×environment (GGE) biplot analyses. The experimental genotypes showed high levels (4.5 to 5.7 t ha^{-1}) of grain yield in each year. There were significant GE interactions for grain yield in each year. There were experimental genotypes in each year that produced significantly higher grain yield than the check. Regression analysis showed that stability parameters were significant and differed among genotypes, however, couldn't explicitly identify the most superior lines in relative term. GGE-biplot analysis showed that among highest yielding lines, Chum18/7*Bcn, CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilh, Croc_1/Ae.sq.(224)//Opata/3/Kauz*2/ Bow//Kauz/4/NL683, PBW343//Car422/Ana and Milan/Otus//Attila/3*Bcn were the five most superior genotypes for grain yield. These genotypes also had acceptable to superior agronomic traits. The findings of this study provide additional information on stability of the internationally important wheat genotypes tested across diverse environments in Afghanistan. These genotypes are also adapted to other developing countries; hence this information could be useful for international and national wheat improvement programs.

Key words: Grain yield, performance, stability, *Triticum aestivum*, wheat

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INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is a major staple of poor farmers in the West Asia including Afghanistan. Wheat growing environments in the region are diverse ranging from hot lowland to temperate mountains. The diverse environmental conditions are suitable for growing spring, facultative and winter type wheats. These environments represent more than one mega-environment for wheat cultivation defined by CIMMYT (Van Ginkel and Rajaram, 1993). Around 2.5 million hectares of wheat is grown in Afghanistan (FAO, 2006). Timely planted wheat in fall matures in 150 to 190 days in different parts of Afghanistan. The winter, facultative and irrigated spring types are planted in fall (October to December), but the seeding of rainfed spring wheat is mostly delayed till spring (February- March).

Due to diverse environmental conditions, genotype×environment (GE) interactions are of major concern to wheat breeders for developing improved cultivars for Afghanistan and other countries in the region. In order for a cultivar to be commercially successful, it must perform well across the range

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Corresponding Author: Ram C. Sharma, P.O. Box 5186, Kathmandu, Nepal
Tel: 0097714219262 Fax: 0097714229804

of environments in which the cultivar may be grown. The presence of GE interactions reduces the correlation between phenotype and genotype and makes it difficult to judge the genetic potential of a genotype. Wheat breeders grow performance tests at different sites (locations) in different years in the target area and data obtained from these tests are used to determine the magnitude of GE interactions and stability. Stability of a cultivar refers to its consistency in performance across environments and is affected by the presence of GE interactions. In the presence of significant GE interactions, stability parameters are estimated to determine the superiority of individual genotypes across the range of environments.

The traditional stability analysis models for estimating the magnitude of GE interactions involved an analysis of variance approach in which a significant GE interaction is partitioned into components using regression analysis. This regression method and their modifications have been explained by previous researchers and are still being widely used by cereal breeders (Sharma *et al*., 1987; Koemel *et al*., 2004; Fuentes *et al*., 2005). However, this method often results into subjective judgment for choosing a cultivar among the best ones. Recently, a genotype and genotype×environment (GGE) biplot analysis was proposed by Yan and Kang (2002) to determine stability and to identify superior genotypes. GGE biplot is a method of graphical analysis of multi-environment data (Yan and Kang, 2000). It is different from regular biplot that simultaneously displays both genotypes and environments (Yan and Kang, 2002). The GGE biplot is a biplot that displays the main genotype effect (G) and the Genotype×Environment interaction (GE) of multi-environment tests. It is constructed by plotting the first two principal components (PC1 and PC2, also referred to as primary and secondary effects, respectively) derived from singular value decomposition of the environment-centered data. A specific option in GGE biplot analysis allows comparison among a set of genotypes with a reference genotype. This method defines the position of an ideal cultivar, 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 generated using the ideal cultivar as the concentric center. The ideal cultivar 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 is also passing through the origin of the biplot; the two arrows in opposite directions represent instability. A genotype farther form the biplot origin on either side on the stability line represents relatively lower stability. A genotype closer to the performance line is considered more stable than the one placed farther.

The present experiment involved a study of GE interactions for grain yield in a set of spring wheat (*Triticum aestivum* L.) genotypes in diverse wheat growing environments in Afghanistan. The objectives of this study were to determine the range of variability for grain yield in a set of wheat developed at CIMMYT as the elite bread wheat genotypes, to estimate GE interactions and stability for grain yield and to identify superior wheat genotypes.

MATERIALS AND METHODS

This study was conducted in Afghanistan in 2005-2007 wheat growing seasons. This study involved different sets of 49 advanced wheat breeding lines developed by CIMMYT, Mexico for testing in the 25, 26 and 27th international elite spring wheat yield trials (ESWYT) and one local improved wheat cultivar in each of the three years. Hence, a total of 147 experimental genotypes and a local commercial cultivar of wheat were tested in the multiple sites in Afghanistan. The detailed pedigrees and data on these wheat genotypes can be obtained on http://www.cimmyt.org/wpgd/Cycles.aspx by entering the year, name of the trial and traits of interest. The trials were conducted at seven, six and six sites in 2005, 2006 and 2007, respectively. These sites widely differ in terms of geographic position, altitude, temperatures and precipitations (Table 1).

Table 1: Site description and climatic data of experimental sites in Afghanistan where the experiments were conducted

				Mean temperature (°C)			
Stations	Latitude (N)	Longitude (E)	Altitude (m)	Maximum	Minimum	Annual rainfall (mm)	Frost free days
Baghlan	36° 42’ N	67° 13’ E	510	26.6	-2.4	413	249
Bolan	34° 31’ N	70° 14’ E	789	32.0	7.4	200	262
Darulaman	34°28’ N	69°09’ E	1841	26.5	0.0	550	238
Dehdadi	36°65’ N	66°96’ E	378	33.1	1.1	200	253
Kunduz	36°43’ N	68°51’ E	455	31.5	0.0	348	258
Shishambagh	34°25’ N	70°27’ E	552	40.6	2.0	243	274
Urdokhan	39°11’ N	68°13’ E	964	28.9	-0.6	367	226

The study was conducted during the wheat-growing season (Nov. to June) in 2004-2005 (2005), 2005-2006 (2006) and 2006-2007 (2007), using a randomized alpha lattice design in two replicates. Plot size of 5.0×1.5 m was seeded with six rows using 0.20 m spacing. The trials were sown in a timely fashion using the standard seeding rate (120 kg ha^{-1}). Fertilizers were mixed into the soil prior to seeding using 120, 60 and 40 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. The other trial management practices were consistent with good crop husbandry recommended in the region.

Days to heading was recorded from January 1 when spikes of approximately 50% of the plants in a plot were fully emerged from the boot. At maturity, plant height in each plot was measured from ground level to the tip of the spikes. Agronomic scores were recorded visually based on overall appearance of the standing crop in each plot on a scale of 1 to 5, where 1 and 5 signify the poorest and the best, respectively. After maturity, plots were individually harvested, threshed and grain yield was recorded.

Since the values for agronomic scores were between 1 and 5, data transformation was accomplished for this trait using square-root method as outlined by Gomez and Gomez (1984). The transformed data were used for analysis but means have been reported after reverting the values to the original scale. The statistical analysis included an analysis of variance for each environment and a combined analysis across environments. After confirming the homogeneity of variance (Gomez and Gomez, 1984), a combined analysis of variance was also conducted. Each year-site combination was considered a unique and random environment, while genotypic effect was analyzed as fixed. The significance of F-ratios was tested according to the procedure outlined by McIntosh (1983) for analysis of combined experiments. The mean squares for GE interactions were partitioned into heterogeneity between regressions and remainder component using the procedure outlined by Sharma *et al*. (1987). GGE biplot analyses for grain yield were conducted using GGE biplot software (Yan and Kang, 2002) to determine stability and to identify superior genotypes for grain yield.

RESULTS

Weather conditions in 2006 were drier compared to 2005 and 2007 wheat growing seasons. This resulted in lower grain yield in 2006 than the 2005 and 2007 (Table 2). On the other hand, the cool and wet conditions during 2005 and 2007 in Afghanistan favored higher severity of leaf and yellow rust in these two years compared to 2006. In general, the grain yield levels in the trial could be considered high comparing to the average 1.5 t ha^{-1} national wheat yield in Afghanistan.

Genotype and environment effects were significant for grain yield, days to heading, plant height and agronomic score in each of the three years (Table 3). Genotype×environment interaction was significant for grain yield, plant height and agronomic scores in each year. The two components of GE interactions, heterogeneity between regressions and the remainder component, were significant for grain yield, which confirmed the presence of GE interactions (Sharma *et al*., 1987). The heterogeneity mean squares were significant for grain yield when tested against remainder mean squares. This suggested that there were differences in regression coefficient values among genotypes.

Table 2: Range of values for various traits in wheat genotypes included in the study

	Grain yield (t ha^{-1})			Grain yield (% of check)			Days to heading			Plant height (cm)			Agronomic score (1-5)		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Maximum	5.661a†	4.502a	5.371a	119a	123a	115a	105a	133a	129a	98a	101a	95a	4.5a	4.0a	4.3a
Minimum	4.257c	2.909c	4.044c	90c	79c	87c	98a	125a	123a	85bc	75c	85b	2.5c	2.3c	3.0c
Check	4.745b	3.670b	4.660b	100b	100b	100b	100a	128a	126a	92ab	85bc	85b	3.8b	3.1b	3.5b

†Means within a column for a trait in the same year followed by different letters are significantly different from one another based on Duncan's New Multiple Range Test at $p = 0.05$

Table 3: Analysis of variance for grain yield for 50 wheat genotypes in three years, Afghanistan

	2005		2006		2007	
Source of variation	df	Mean square	df	Mean square	df	Mean square
Grain yield						
Environment (Env)	6	251.1**	5	134.6**	5	180.3**
Rep (Env)	7	4.2**	6	1.7	6	3.4
Block (Rep Env)	126	1.0	108	0.6	108	0.7
Genotype	49	0.9	49	0.7**	49	0.8**
Genotype×Environment	294	0.5**	244	0.5**	244	0.8**
Heterogeneity between regressions	(49)	1.2**	(49)	1.3**	(49)	2.07**
Remainder	(245)	0.4**	(195)	0.3**	(195)	0.49**
Error	217	0.2	187	0.1	187	0.26
Days to heading						
Environment (Env)	6	12644.7**	5	50058.2**	5	25300.9**
Rep (Env)	7	45.1	6	25.9	6	38.5
Block (Rep Env)	72	18.1	63	11.0	99	8.5
Genotype	49	13.8**	49	21.0**	49	17.6**
Genotype×Environment	160	3.0	160	3.8	236	2.8
Error	219	2.4	179	3.2	155	2.6
Plant height						
Environment (Env)	6	11406.6**	5	12316.3**	5	12796.5**
Rep (Env)	7	3.1	6	60.1	6	99.1
Block (Rep Env)	63	92.9	72	82.5	63	82.8
Genotype	49	85.2**	49	138.6**	40	49.4**
Genotype×Environment	160	22.6**	160	18.7**	160	8.8*
Error	179	13.0	219	7.3	179	13.5
Agronomic score						
Environment (Env)	5	106.	5	30.9	5	10.
Rep (Env)	6	4.3	6	0.2	6	1.1
Block (Rep Env)	72	0.8	72	1.2	99	1.2
Genotype	49	1.4**	49	2.6**	49	1.8**
Genotype×Environment	160	0.6**	160	1.0**	236	0.6*
Error	219	0.2	219	0.3	155	0.4

*, ** Significant at $p = 0.05$ and $p = 0.01$, respectively

The wheat genotypes showed a range of values for grain yield, days to heading, plant height and agronomic score in each year (Table 2). The level of grain yield was high in each of the three years. The highest and lowest yielding genotypes had significantly higher and lower grain yield, respectively, than the local check. The highest yielding experimental genotype didn't differ significantly for days to heading compared to the check in three years. The highest yielding genotype was significantly taller than the check in 2006 and 2007. The highest yielding genotype had significantly superior agronomic score than the check in three years. The lowest yielding genotype had significantly inferior agronomic score than the check.

Several wheat genotypes showed significantly higher grain yield than the local check in each year with actual increases ranging from 11 to 23% (Table 4). Most of these high yielding genotypes had days to heading, plant height and agronomic scores comparable to the check. There were nine high yielding genotypes that had significantly superior agronomic scores than the check.

Table 4: Mean values for various traits of the wheat genotypes producing significant higher grain yield than the local commercial cultivars in multi-location trials in Afghanistan, 2005-2007

Trial and Entry ID No.	Entry No.	Pedigree	Grain yield (t ha^{-1})	Check (%)	b †
ESWYT25-05	5	SW89.5181/Kauz	5.350	113^{*+}	1.14*
ESWYT25-18	18	Croc_1/Ae.sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL 683	5.411	114^{*+}	1.10**
ESWYT25-27	27	Chum18/7*Bcn	5.198	110^{*+}	1.12*
ESWYT25-30	30	Vee/Snb//Buc/Pvn/3/Parus	5.261	111^{*+}	1.11*
ESWYT25-34	34	PBW343//Car422/Ana	5.661	119^{*+}	1.18**
ESWYT25-43	43	SKauz/Bav92	5.574	117^{*+}	1.20**
ESWYT26-07	107	Rayon F89	4.288	117^{*+}	1.15*
ESWYT26-08	108	Seri/Rayon	4.361	119^{*+}	1.22**
ESWYT26-27	127	Croc_1/Ae. sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL	4.275	116^{*+}	1.19**
ESWYT26-30	130	Chum18/7*Bcn	4.502	123^{*+}	1.23**
ESWYT27-16	216	Pastor/3/Vorona/Cno79//Kauz	4.271	116^{*+}	1.14*
ESWYT27-17	217	Weaver/3/Sapi/Teal//Hui/4/Croc_1/Ae.sq.(213)//Pgo/5/SKauz*2/Srma	5.188	111^{*+}	1.13*
ESWYT27-18	218	CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilhi	5.371	115^{*+}	1.16**
ESWYT27-19	219	CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilhi	5.203	112^{*+}	1.12*
ESWYT27-31	231	Cal/NH//H567.71/3/SeriI/4/Cal/NH//H567.71/5/2*Kauz/6/Pastor	5.300	114^{*+}	1.17**
ESWYT27-39	239	WH542/2*Pastor	5.187	111^{*+}	1.13*
ESWYT27-41	241	Milan/Otus//Attila/3*Bcn	5.209	112^{*+}	1.14*

Trial and Entry ID No.	Entry No.	Pedigree	s^2d‡	Days to heading	Plant height (cm)	Agronomic score (1-5) ¶
ESWYT25-05	5	SW89.5181/Kauz	0.081**	100^{NS}	93^{NS}	4.2^{*+}
ESWYT25-18	18	Croc_1/Ae.sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL 683	0.045**	102^{NS}	92^{NS}	3.7^{NS}
ESWYT25-27	27	Chum18/7*Bcn	0.059**	102^{NS}	85^{NS}	3.0^{NS}
ESWYT25-30	30	Vee/Snb//Buc/Pvn/3/Parus	0.042**	103^{NS}	90^{NS}	4.0^{*+}
ESWYT25-34	34	PBW343//Car422/Ana	0.060**	103^{NS}	93^{NS}	3.5^{NS}
ESWYT25-43	43	SKauz/Bav92	0.048**	105^{NS}	92^{NS}	3.5^{NS}
ESWYT26-07	107	Rayon F89	0.057**	121^{NS}	75^{*+}	4.0^{*+}
ESWYT26-08	108	Seri/Rayon	0.049**	122^{NS}	82^{NS}	4.0^{*+}
ESWYT26-27	127	Croc_1/Ae. sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL	0.076**	130*-	81^{NS}	2.7*-
ESWYT26-30	130	Chum18/7*Bcn	0.071**	118^{NS}	74^{*+}	3.3^{NS}
ESWYT27-16	216	Pastor/3/Vorona/Cno79//Kauz	0.058**	130*-	88^{NS}	3.7^{NS}
ESWYT27-17	217	Weaver/3/Sapi/Teal//Hui/4/Croc_1/Ae.sq.(213)//Pgo/5/SKauz*2/Srma	0.065**	115^{NS}	87^{NS}	4.3^{*+}
ESWYT27-18	218	CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilhi	0.077**	122^{NS}	87^{NS}	4.0^{*+}
ESWYT27-19	219	CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilhi	0.054**	115^{NS}	87^{NS}	4.0^{*+}
ESWYT27-31	231	Cal/NH//H567.71/3/SeriI/4/Cal/NH//H567.71/5/2*Kauz/6/Pastor	0.060**	115^{NS}	90^{NS}	4.0^{*+}
ESWYT27-39	239	WH542/2*Pastor	0.055**	128*-	90^{NS}	4.0^{*+}
ESWYT27-41	241	Milan/Otus//Attila/3*Bcn	0.063**	118^{NS}	90^{NS}	3.7^{NS}

†b = linear regression coefficient. ‡s^2d = deviation from linear regression. ¶1 = poorest and 5 = best, NS = Non-significantly different from the local check based on $LSD_{0.05}$, *, ** Significantly higher than the check at P = 0.05 and P = 0.01, respectively, $^{*+}$ Significantly superior to the local check based on $LSD_{0.05}$, *-Significantly inferior to the local check based on $LSD_{0.05}$.

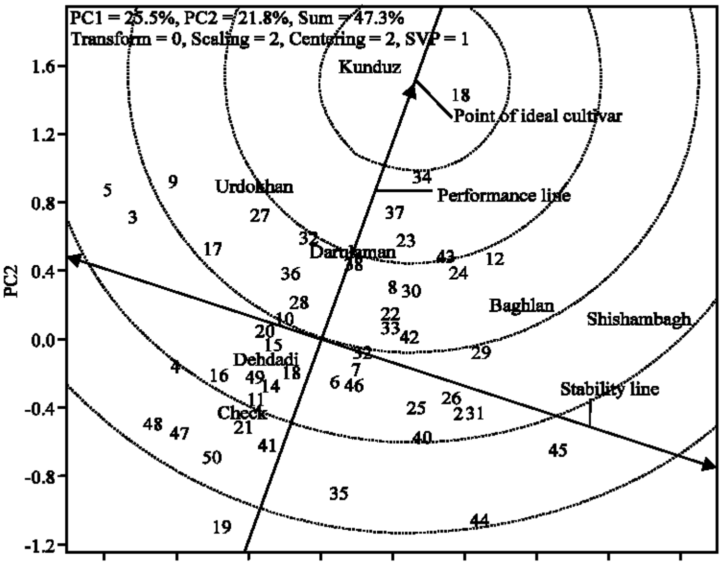

Fig. 1: GGE biplot showing a comparison of 50 wheat genotypes with an ideal cultivar for grain yield tested on-station across 7 environments in 2005, Afghanistan (Refer to Table 4 for name of the outstanding genotypes)

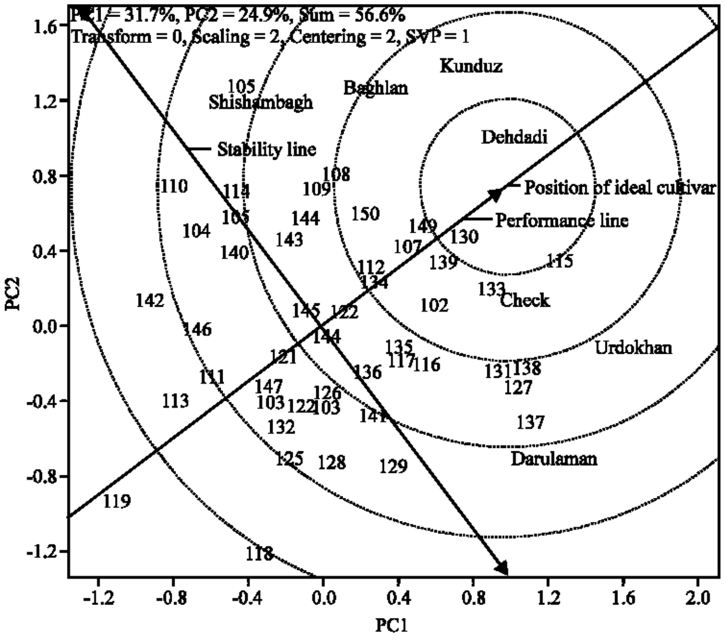

Fig. 2: GGE biplot showing a comparison of 50 wheat genotypes with an ideal cultivar for grain yield tested on-station across 6 environments in 2006, Afghanistan (Table 4 for name of the outstanding genotypes)

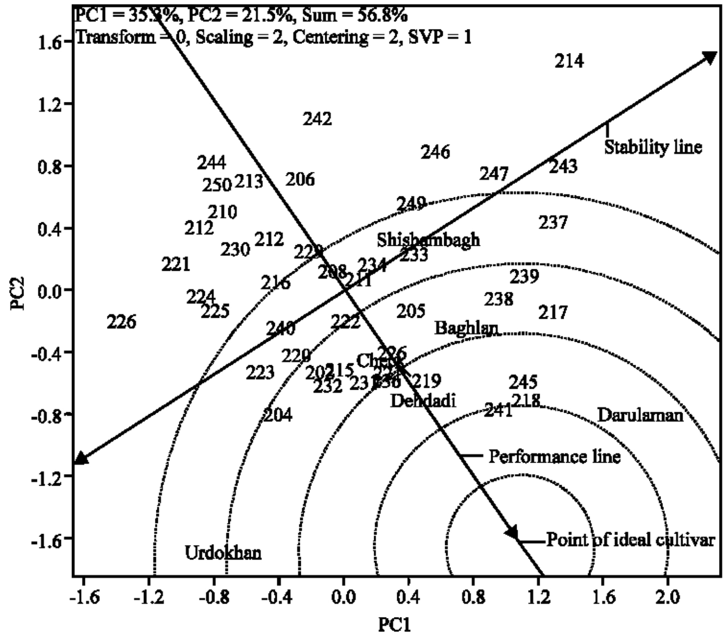

Fig. 3: GGE biplot showing a comparison of 50 wheat genotypes with an ideal cultivar for grain yield tested on-station across 6 environments in 2007, Afghanistan (Table 4 for name of the outstanding genotypes)

Based on regression analysis, linear regression coefficient and deviation from linear regression for grain yield were significant for all genotypes (Table 4). However, the biplot analysis revealed that only a few genotypes were stable across the diverse sites in Afghanistan. All high yielding genotypes shown in Table 4 were not stable. On the other hand, there were other genotypes, with somewhat lower grain yield, that were stable. Based on the results from the GGE biplot analysis, PBW343//Car422/Ana (No. 34) and Croc_1/Ae.sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL683 (No. 18) were the most stable among the highest yielding genotypes in 2005 by being closer to the position of the ideal cultivar (Fig. 1). The highest yielder Chum18/7*Bcn (No. 130) was also the most stable among the highest yielding genotypes in 2006 as it was closest to the position of the ideal cultivar (Fig. 2). CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilhi (No. 218) and Milan/Otus//Attila/3*Bcn (No. 241) were the most stable among the highest yielding genotypes in 2007 (Fig. 3).

DISCUSSION

Mean grain yield of the wheat genotypes differed across locations, which may be due to differing environmental conditions over sites. The sites themselves differ greatly in key attributes, such as geographic location, temperature and rainfall that affect performance (Table 1). The diversity among site was also reflected in significant location effect in each of the three years.

The wheat genotypes represented a range of variability for grain yield and other agronomic characters (Table 2), with opportunities for selecting wheat genotypes for high yield and acceptable agronomic characters. The genotypes with significantly higher grain yield than the check provide wide option for directly identifying improved genotypes for Afghanistan. Since there is no hybridization program *per se* for wheat improvement in Afghanistan, the exotic introduced varieties are the major source of identifying superior varieties. This study provides a number of such genotypes that could be considered for further evaluation and release in Afghanistan.

This study identified 16 wheat genotypes with significantly higher yield than the check (Table 4). However, based on the regression analysis method (Koemel *et al*., 2004), none of the high yielding genotypes were ideally stable for all the environments in Afghanistan. This shows that the relative performance of high yielding genotypes differed among environments due to their site specific superior performance. This is comprehensible considering the wide diversity among test environments (Table 1).

The GGE biplot analysis identified superior genotypes in each of the three years. There were five wheat genotypes that could be considered stable across the environments for high grain yield. All of these genotypes could be valuable for wheat improvement program in Afghanistan and in the region attempting to develop high yielding wheat varieties for similar environments. PBW343//Car422/Ana (No. 34) and Croc_1/Ae.sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL683 (No. 18) in 2005 (Fig. 1), Chum18/7*Bcn (No. 130) in 2006 (Fig. 2) and Milan/Otus//Attila/3*Bcn (No. 241) and CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilh (No. 218) in 2007 could be considered the most superior among the high yielding genotypes by being closer to the position of an ideal cultivar. Croc_1/Ae.sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL683, is a derivative of synthetic wheat suggesting that superior genotype is now available from the wide hybridization program of CIMMYT (Mujeeb-Kazi *et al*., 1996; van Ginkel and Ogbonnaya, 2007). A number of these genotypes involved in the pedigrees of the above outstanding wheat genotypes carry high levels of resistance to leaf and yellow rust (Singh *et al*., 2000, 2005, 2007).

There is little previous documentation of GE interactions for grain yield of wheat in Afghanistan. The presence of the strong GE interactions suggests that wheat growing environments in Afghanistan represent diversity and testing international nurseries under these conditions could help identify widely adapted genotypes. Since Afghanistan is located in the junction of South and Central Asia, the findings of this study could be valuable for similar environments of these two regions where livelihood of millions of resource poor farmers depend on wheat cultivation. Diversity in widely adapted wheat cultivars is needed for diverse environments in both these regions (Morgounov *et al*., 2005; Ortiz-Ferrara *et al*., 2007).

CONCLUSION

Exotic wheat genotypes tested under the diverse environments in Afghanistan showed significant variation for grain yield, days to heading, plant height and agronomic scores. There were experimental lines that outyielded the check and were also more stable, indicating that superior germplasm is being introduced through the international collaborative work. Five genotypes, Chum18/7*Bcn, Milan/Otus//Attila/3*Bcn, Croc_1/Ae.sq.(224)//Opata/3/Kauz*2/Bow//Kauz/4/NL683, PBW343//Car422/Ana and CS/Th.sc.//3*Pvn/3/Mirlo/Buc/4/Milan/5/Tilh were highly desirable in terms of high mean yield and stability, which could be valuable for other regions of the world. This underscores continuous development and dissemination of superior wheat germplasm across continents in terms of saving resources.

The GGE biplot approach used in this study could help breeders to release the most appropriate cultivar with more confidence than using other stability methods. The visual combination of superior performance and stability presented in the GGE biplot is an advantage in releasing a cultivar.

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