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Genotype × environment interaction and stability of grain yield and selected quality traits in winter wheat in Central Asia

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Abstract: High grain yield and improved quality determine the commercial success of winter wheat (*Triticum aestivum* L.) varieties in Central Asia. This study was conducted to determine the effect of environment on grain yield, 1000-kernel weight (TKW), test weight (TWT), protein, and gluten content, and to identify superior wheat genotypes for yield and quality. Thirty winter wheat genotypes were evaluated in 3 years (2010–2012) over multiple locations. A genotype and genotype × environment interaction biplot analysis was used to determine the superior genotypes. There were significant effects of environment and genotype × environment interaction on yield and quality traits. The 30 wheat genotypes showed variations for grain yield (3.7–5.6 t ha^{-1}), TKW (33.6–42.4 g), TWT (753–797 g/L), protein (13.3%–14.8%), and gluten (27.2%–29.5%) content. There was a significant positive correlation between grain yield and TKW in three out of seven environments. There was no correlation of grain yield with TWT, protein, and gluten content with one exception. There were different sets of five most superior genotypes for individual traits. However, certain genotypes were superior based on grain yield and quality traits. Gozgon, Elomon, ID800994.W/Vee//Lagos-12, Jaikhun, and Kroshka were the five most superior genotypes for four quality traits. Elomon, Gozgon, Jaikhun, ID800994.W/Vee//Lagos-12, and Kiriya were the five most superior genotypes based on grain yield, TKW, TWT, protein, and gluten content. This study demonstrates success in wheat breeding for combined high yield and improved quality in winter wheat. This study provides information on the combined stability of high yield and improved quality of the internationally important winter wheat genotypes. Therefore, the results of this study could be valuable for national and international winter wheat breeding programs to develop new varieties with high stable grain yield and quality.

Key words: Genotype × environment interaction, gluten, grain yield, protein, quality, stability, *Triticum aestivum*, winter wheat

1. Introduction

High yield and improved quality are primary objectives of the winter bread wheat (*Triticum aestivum* L.) improvement programs in Central Asia. Breeders in the region often find it difficult to combine high yield and superior quality in winter wheat because of a negative correlation between these two traits and the intervening influence of the environment. This is reflected in the cultivation of old varieties such as Bezostaya 1, released in 1969, on considerable acreage despite the availability of newer varieties with substantial higher yield (Sharma et al., 2010). One of the important traits for which the older wheat varieties are being grown in Central Asia is stability of their quality traits. Therefore, the new wheat varieties must possess stability not only for grain yield but also for the traits related to quality.

There is a more complex influence of weather conditions on the quality parameters of winter wheat compared to spring wheat (Johansson and Svensson, 1998). Winter bread wheat growing environments in Central Asia are diverse (Sharma et al., 2014a) and there is a significant effect of environment and genotype × environment (GE) interaction on grain yield under both irrigated (Sharma et al., 2010) and rainfed (Sharma et al., 2012) conditions. Similar findings on the effect of GE interaction on wheat grain yield have been reported for the surrounding regions (Osmanzai and Sharma, 2008; Sakin et al., 2011; Sharma et al., 2014b). Previous studies have also reported a significant effect of GE interaction on quality-related traits in wheat (Kopell and Ingver, 2008; Zecevic et al., 2009; Sakin et al., 2011), suggesting difficulties in identification of genotypes with stable quality. A wheat-breeding program aims to develop genotypes with stability for high grain yield and

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quality. Such efforts face difficulties not only because of the great effect of environment on yield and quality but also due to the negative correlation of grain yield with one or more of the quality traits (Tayyar 2010; Sokoto et al., 2012).

1000-kernel weight (TKW), test weight (TWT), protein content, and gluten content are considered major quality-related traits of new varieties released in many developing countries including Central Asia. Previous studies have reported a positive correlation of grain yield with TKW (Sokoto, 2012) and TWT (Tayyar, 2010). Bilgin et al. (2010) found a weak negative correlation between grain yield and protein content. On the other hand, Tayyar (2010) and Sokoto et al. (2012) reported a nonsignificant correlation between grain yield and protein content. Tayyar (2010) found a negative correlation between grain yield and gluten content, whereas Sokoto et al. (2012) reported an inconsistent correlation between these two traits in two years. These findings from previous reports suggest that correlation between grain yield and quality may also depend on environment. This in turn could determine the effectiveness of selection for simultaneous improvement of grain yield and quality.

There is a lack of information on the effect of GE interaction on the quality of winter wheat in Central Asia. In order to develop winter wheat genotypes acceptable to farmers, the stability of the grain yield and quality traits must be determined. This study was conducted to find out the genotypic variation for grain yield and quality traits among a set of leading cultivars and advanced breeding lines of winter wheat, determine the GE interaction for grain yield and quality traits, and identify superior genotypes for yield and quality.

2. Materials and methods

A set of 30 winter wheat genotypes differing in their origin and genetic background was used in this study (Table 1). These included 19 advanced breeding lines from the International Winter Wheat Program (IWWIP), three released (Jaikhun, Saidaziz, and Kroshka) and three prospective (Hazrati Bashir, Elomon, and Gozgon) cultivars of Uzbekistan, and five genotypes from other sources. The field experiments were conducted at four diverse sites in Uzbekistan: Karshi (38°52′N, 65°48′E, 416 m above sea level (masl)), Kasbi (38°57′N, 65°24′E, 322 masl), Kibray (41°23′N, 69°27′E, 785 masl), and Namangan (41°00′N, 71°40′E, 476 masl).

The experiment at each site was conducted in a randomized complete block design in three replications using 10 m^2 plots. The experiments were managed under irrigated conditions at Karshi, Kibray, and Namangan, whereas the Kasbi site was rainfed. The field trials were planted between 15 and 30 October in each year, which is the optimal seeding time in the region. The experiments in Karshi and Namangan were fertilized with 200, 80, and 50 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. The experiment at the Kibray site was fertilized with 150, 60, and 25 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. At the Kasbi site, fertilizers were applied at the rate of 100, 50, and 25 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. The plots were kept free from weeds by hand weeding. In 2010, there was an incidence of yellow rust in the Karshi and Kibray sites, which was controlled by a single spray of fungicide Titul 390 (Schyolkovo Agrochim; a.i. propiconazole 390 g/L) at the rate of 0.5 L ha^{-1}. In the other years and sites, there were no incidences of diseases or pests in the experimental plots.

Heading days were recorded when approximately 50% of the plants in a plot had spikes fully emerged from the boot. At maturity, the plant height in each plot was measured from ground level to the tip of the spikes. After maturity, the plants in the plots were individually harvested and threshed. 1000 kernels were randomly counted from each plot's seed package and weighed to determine TKW. To determine TWT, two samples with a grain volume of 500 mL were used. Protein content was determined using the filter spectrometer Inframatic 8620 ASH (Perten, Sweden). Wet gluten content was determined using 25-g grain samples converted to flour.

2.1. Statistical analysis

First, analysis of variance (ANOVA) was calculated using Genstat 14.2 (2013) for each trial at each site. After confirming the homogeneity of variances (Gomez and Gomez, 1984), combined analysis of variance was conducted to test the significance of environment, genotype, and GE interaction. An individual year–site combination was considered as a unique and random environment, while a genotypic effect was analyzed as fixed. Genotype and genotype × environment (GGE) biplot analyses were conducted using GGE biplot software (Yan and Kang, 2002) to determine performance and stability for grain yield, TKW, TWT, protein content, and gluten content. The biplot analysis was used to identify genotypes superior for individual as well as for multiple traits. GGE biplot analysis has been widely used to determine performance stability in multilocation trials when identifying superior genotypes (Yan et al., 2007; Roozeboom et al., 2008; Sharma et al., 2010). Correlation coefficients (*r*) between traits were calculated in each environment.

3. Results

The seven environments were diverse, as suggested by a range of values for grain yield, quality traits, heading days, and plant height (Table 2). Grain yield ranged from 2.7 to 5.9 t ha^{-1}. 1000-kernel weight varied from 33.1 to 41.5 g. Test weight ranged from 759 to 784 g/L. Protein and gluten content varied from 12.8% to 15.5% and 26.7% to 30.5%, respectively.

Table 1. Name, origin, mean values, and superiority (rank based on GGE biplot analysis) across seven environments in Uzbekistan, 2010–2012.

Entry no.	Entry name / Pedigree	Origin	Grain yield (kg/ha)		1000-kernel weight (g)		Test weight (g/L)		Protein content (%)		Gluten content (%)	
			Mean	GGE rank‡	Mean	GGE rank	Mean	GGE rank	Mean	GGE rank	Mean	GGE rank
1	Hazrati Bashir	Uzb/IWWIP†	4.834	13	38.8	6	787	6	13.9	21	27.5	21
2	SW89-3218//Agri/Nac	IWWIP	4.996	7	38.9	7	758	29	13.8	28	28.7	14
3	ID800994.W/Vee//Lagos-12	IWWIP	4.733	18	37.8	13	781	9	14.4	4	29.5	7
4	Star/Bwd	IWWIP	4.702	17	36.7	16	758	22	14.1	14	28.5	10
5	MV17-3/Croc-1/*Ae. sq.* (205)//Kauz	IWWIP	4.795	19	33.6	30	758	28	13.8	8	28.2	15
6	Pelsart/3/ Dong87//Tjb368.251/Buc/4/Rsk/Nac	IWWIP	4.693	22	36.8	19	778	11	13.9	23	28.5	8
7	Elomon	Uzb/IWWIP	5.587	1	39.3	3	773	15	14.8	3	29.3	12
8	Kiriya	Ukraine	5.039	5	38.5	10	762	23	14.4	19	28.9	4
9	Experimental-1	Unknown	4.987	8	39.1	5	764	21	14.2	18	29.0	3
10	Experimental-2	Unknown	4.859	15	36.1	25	780	10	14.5	17	29.2	2
11	Kuyalnik	Ukraine	4.727	21	36.2	23	786	4	14.2	22	28.7	5
12	Victoriya	Ukraine	5.082	3	37.0	18	772	20	14.6	5	29.3	1
13	KS82142/Pastor	IWWIP	4.027	27	34.5	29	772	17	13.8	25	27.2	24
14	Bez/Nad//Kzm/3/Ptz Niska/UT1556-170	IWWIP	5.060	4	36.6	26	769	18	14.5	10	28.1	20
15	Gozgon	Uzb/IWWIP	5.490	2	38.7	8	791	3	14.7	12	29.2	6
16	Shi#4414/Crows"//GK Sagvari/CA805	IWWIP	4.862	9	37.7	14	764	24	14.2	13	28.1	25
17	F494J6.1111/Bonito	IWWIP	4.598	20	38.5	9	773	12	14.0	15	27.6	28
18	F134.71/Nac//Zombor	IWWIP	4.383	23	36.3	24	797	7	13.6	26	28.4	13
19	Pyn/Bau/3/Agri/Bjy//Vee	IWWIP	4.760	16	36.3	20	765	19	13.5	29	28.2	22
20	Pyn/Bau/3/Agri/Bjy//Vee	IWWIP	4.874	14	39.4	4	760	27	13.3	27	27.3	18
21	Pyn/Bau//Bonito	IWWIP	3.711	30	36.5	22	781	8	14.1	7	28.5	17
22	Agri/Bjy//Vee/3/Gun91/4/Cham6//1D13.1/Mlt	IWWIP	4.032	29	37.1	15	770	14	14.3	9	28.8	11
23	Mv17//Attila/Bcn	IWWIP	4.932	12	42.1	1	787	5	14.5	1	27.4	30
24	Vorona/HD2402//Albatross Odesskiy	IWWIP	4.873	10	36.6	27	753	30	14.2	11	27.4	26
25	Attila/3/Agri/Nac//Mlt	IWWIP	4.412	25	38.7	11	762	26	13.4	20	27.6	29
26	Attila/3/Agri/Nac//Mlt	IWWIP	4.303	26	37.2	17	762	25	13.7	30	27.8	27
27	Tast/Sprw//Zar/5/Yuandong 3/4/PPB8-68/ Chrc/3/Pyn//TAM101/Amigo	IWWIP	4.111	28	35.9	28	768	16	14.4	6	28.6	19
28	Jaikhun	Uzbekistan	5.089	6	42.4	2	791	2	14.0	24	29.0	16
29	Saidaziz	Uzbekistan	4.771	11	38.3	12	795	1	14.0	16	28.0	23
30	Kroshka	Russia	4.299	24	36.7	21	776	13	14.8	2	29.3	9
	$LSD_{0.05}$		0.902		2.9		26		0.9		1.6	
	CV (%)		11.9		4.8		2.1		3.8		3.6	

†Uzb = Uzbekistan and IWWIP = International Winter Wheat Improvement Program.

‡Rank is based on the GGE biplot analysis across the seven environments; 1 = most superior.

Table 2. Mean values for grain yield, grain quality, and agronomic traits in seven environments recorded for 30 winter wheat genotypes, Uzbekistan.

Environment (location and year)	Grain yield	1000-kernel weight	Test weight	Protein content	Gluten content	Heading days	Plant height
	(t ha^{-1})	(g)	(g/L)	(%)	(%)		(cm)
Karshi–2010	5.886	33.1	759	15.5	27.4	171	106
Namagan–2010	5.091	39.4	766	13.6	26.7	160	–†
Kibray–2010	4.409	41.5	765	13.3	26.3	165	100
Karshi–2011	5.936	35.3	783	14.4	29.0	159	97
Kibray–2011	4.033	38.1	784	14.2	29.2	171	93
Kasbi–2011	2.689	35.4	775	15.1	30.5	152	93
Karshi–2012	5.006	40.5	780	12.8	29.5	168	93
$LSD_{0.05}$	0.212	1.2	6	0.4	0.3	1	3

† = data not available.

Analyses of variance for individual traits showed a significant difference among the 30 genotypes for grain yield, TKW, TWT, protein content, gluten content, heading days, and plant height in each environment (ANOVA not presented). The combined ANOVA revealed a significant effect of environment for all traits (Table 3). The 30 genotypes differed significantly for each trait. Genotype × environment interaction was significant for each trait.

Correlation of grain yield with four quality-related traits differed in different environments (Table 4). Grain yield showed a significant positive correlation with TKW in three out of the seven environments. Grain yield was significantly positively correlated with protein content in one out the seven environments. Grain yield was not correlated with TWT and gluten content in any of the environments.

The 30 genotypes showed arrays of variation for grain yield in each environment (data not presented). The relative grain yield of the 30 genotypes changed greatly over the locations. However, certain genotypes consistently yielded high. Over the seven environments, Elomon (#7), Gozgon (#15), Jaikhun (#28), Victoriya (#12), and Bez/Nad//Kzm/3/Ptz Niska/UT1556-170 (#14) were the five highest yielding genotypes (Table 1). The GGE biplot analysis showed that Elomon (#7) and Gozgon (#15) were the most superior among the highest yielding genotypes based on both mean and stability of the grain yield (Figure 1).

There were arrays of variation for quality traits among the 30 genotypes, and their relative values changed over the environments (data not presented). Jaikhun (#28), Mv17//Attila/Bcn (#23), Pyn/Bau/3/Agri/Bjy//Vee (#20), Elomon (#7), and Nazorat-1 (#9) had the highest TKW values (Table 1). The GGE biplot analysis showed that Jaikhun (#28) and Mv17//Attila/Bcn (#23) were the most superior based on the mean and stability for TKW (Figure 2). Over the environments, F134.71/Nac//Zombor (#18),

Table 3. Analysis of variance for various traits of 30 wheat genotypes evaluated in seven environments, Uzbekistan.

Source of variation	df	Grain yield	1000-kernel weight	Test weight	Protein content	Gluten content	Heading days	Plant height	
								df	Mean square
Environment	6	115.79**	863.9**	8858**	83.65**	219.78**	4718.8**	5	2332.7**
Rep/environment	14	0.44	14.4	345	1.42	1.19	14.4	12	73.6
Genotype	29	3.61**	73.6**	3219**	3.47**	9.81**	77.1**	29	946.8**
Genotype × environment	174	0.95**	16.1**	923**	2.16**	8.41**	31.8**	145	41.3**
Residual	406	0.32	3.3	253	0.29	1.04	4.1	348	25.4

** = Significant at P = 0.01.

Table 4. Simple correlation coefficients between grain yield and quality-related traits studied in 30 winter bread wheat genotypes across seven environments, Uzbekistan.

Location and year	Grain yield	1000-kernel weight	Test weight	Protein content	Gluten content
Karshi–2011	5.936	–0.01	–0.12	–0.03	0.10
Karshi–2010	5.886	0.17	0.09	–0.08	–0.14
Namangan–2010	5.091	0.38*	–0.23	0.52**	0.25
Karshi–2012	5.006	0.09	–0.17	0.00	0.01
Kibray–2010	4.409	0.51**	0.01	0.23	0.30
Kibray–2011	4.033	0.48**	–0.04	0.10	0.02
Kasbi–2011	2.689	0.30	0.13	0.13	0.11

* and ** = correlation coefficients are significantly different from 0 at the 0.05 and 0.01 probability levels, respectively; N = 30.

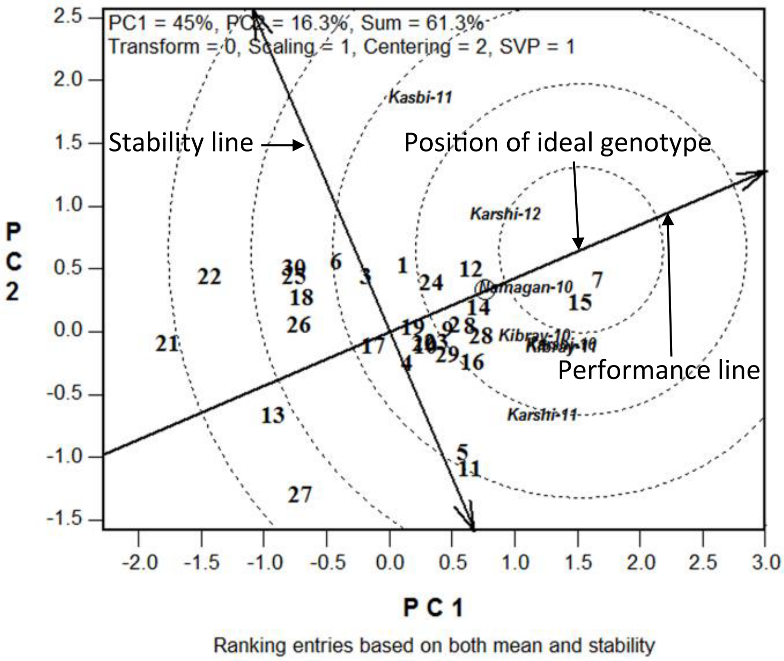

Figure 1. A GGE biplot of the grain yields of the 30 winter wheat genotypes evaluated across 7 environments in Uzbekistan. The names in italics are locations, with the last two numbers abbreviating the year (refer to Table 1 for the full names of the genotypes).

Saidaziz (#29), Jaikhun (#28), Gozgon (#15), and Hazrati Bashir (#1) had the highest TWT values (Table 1). The GGE biplot analysis demonstrated that Saidaziz (#29), Jaikhun (#28), and Gozgon (#15) were the most superior genotypes for TWT (Figure 3). Kroshka (#30), Elomon (#7), Gozgon (#15), Victoriya (#12), and Mv17//Attila/Bcn (#23) had the highest mean protein content across the environments (Table 1). Kroshka (#30), Mv17//Attila/Bcn (#23), and Elomon (#7) were the most superior genotypes based on the mean protein content and its stability (Figure 4). The five genotypes with the highest gluten content were ID800994.W/Vee//Lagos-12 (#3), Elomon (#7), Kroshka (#30), Victoriya (#12), and Nazorat-2 (#10) (Table 1). Based on the GGE biplot analysis, Victoriya (#12) and Experimental-2 (#10) were the most superior for gluten content (Figure 5). The GGE biplot analysis of multiple quality-related traits (TKW, TWT, protein content, and gluten content) across the seven environments showed that Gozgon (#15) and Elomon (#7) were the most superior genotypes (Figure 6). The GGE biplot analysis of the grain yield and the four quality traits also identified Gozgon (#15) and Elomon (#7) as the most superior genotypes (Figure 7).

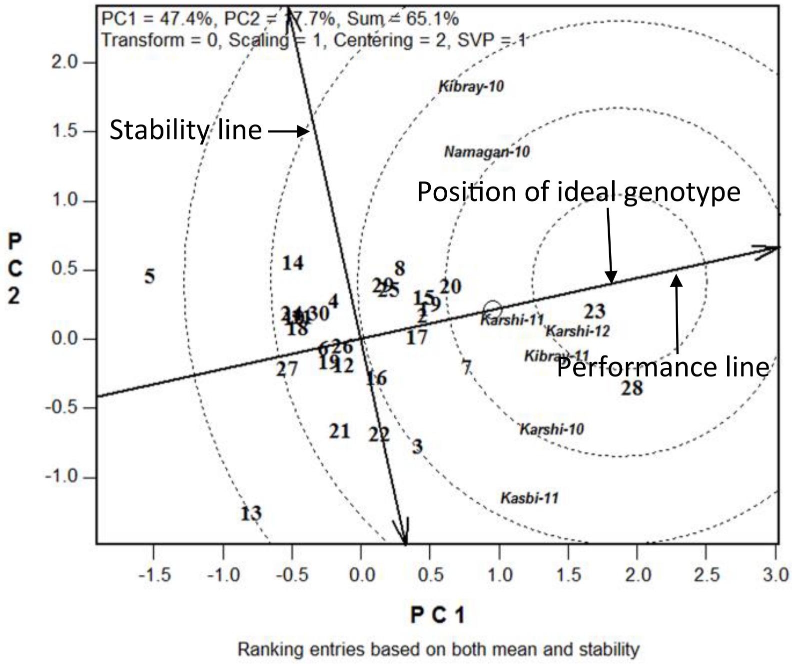

Figure 2. A GGE biplot of the 1000-kernel weights of the 30 winter wheat genotypes evaluated across 7 environments in Uzbekistan. The names in italics are locations, with the last two numbers abbreviating the year (refer to Table 1 for the full names of the genotypes).

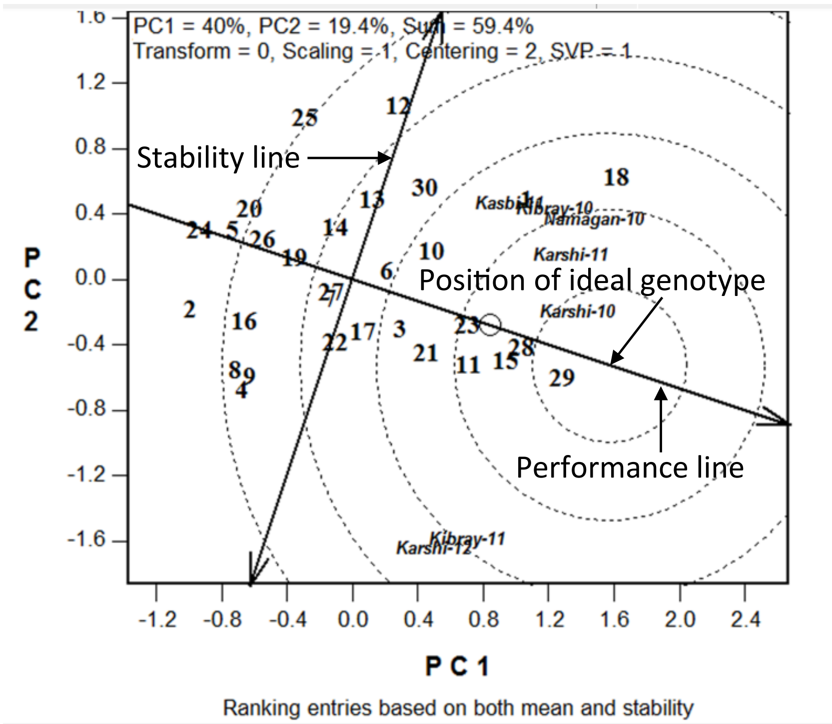

Figure 3. A GGE biplot of the test weights of the 30 winter wheat genotypes evaluated across 7 environments in Uzbekistan. The names in italics are locations, with the last two numbers abbreviating the year (refer to Table 1 for the full names of the genotypes).

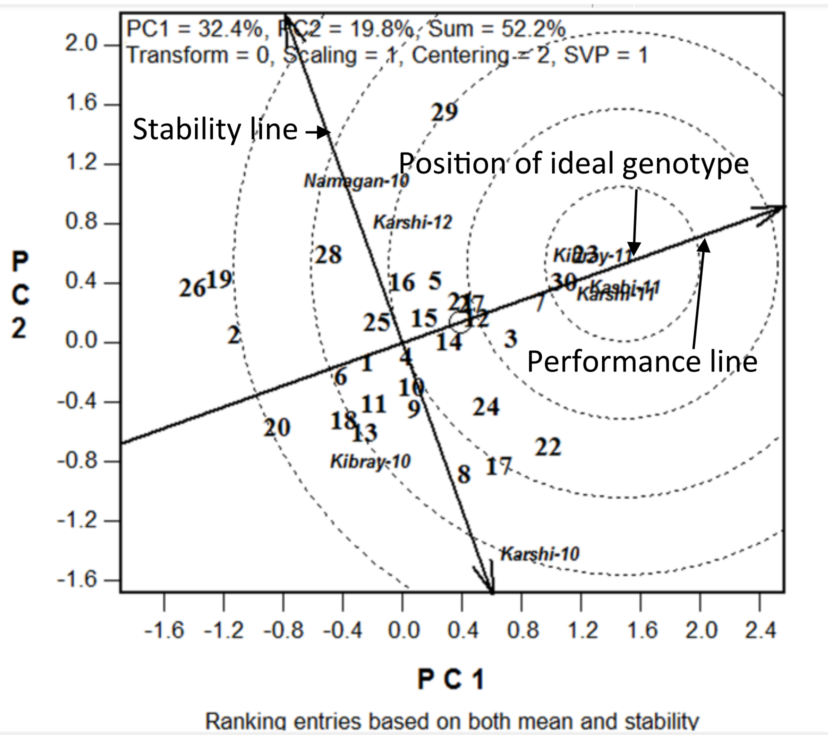

Figure 4. A GGE biplot of the protein contents of the 30 winter wheat genotypes evaluated across 7 environments in Uzbekistan. The names in italics are locations, with the last two numbers abbreviating the year (refer to Table 1 for the full names of the genotypes).

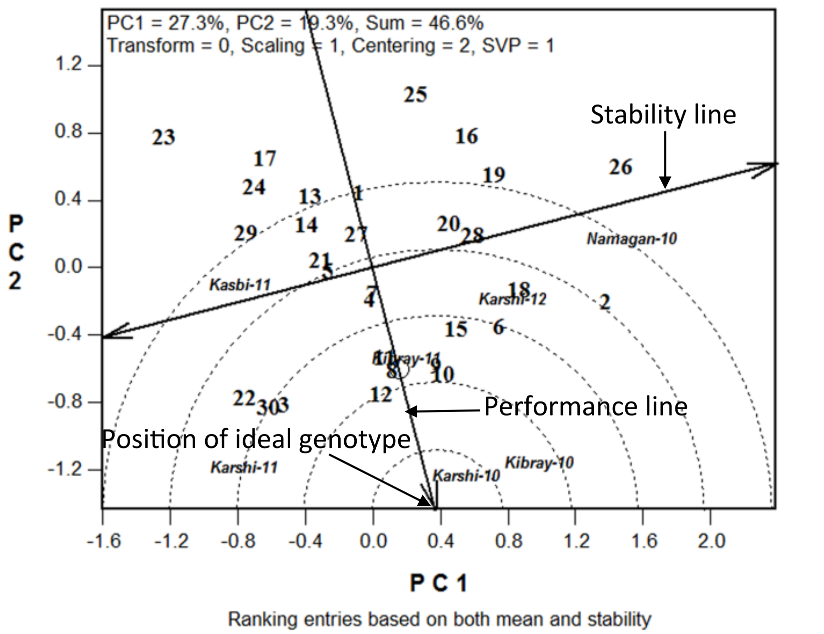

Figure 5. A GGE biplot of the gluten contents of the 30 winter wheat genotypes evaluated across 7 environments in Uzbekistan. The names in italics are locations, with the last two numbers abbreviating the year (refer to Table 1 for the full names of the genotypes).

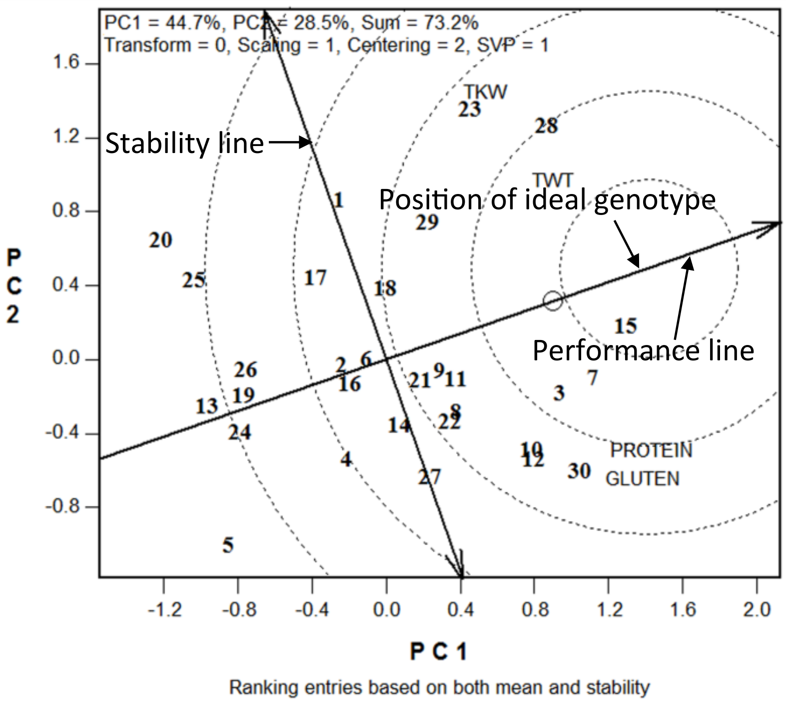

Figure 6. A GGE biplot based on the 1000-kernel weight (TKW), test weight (TWT), protein content, and gluten content of the 30 winter wheat genotypes evaluated across 7 environments in Uzbekistan. The names in italics are locations, with the last two numbers abbreviating the year (refer to Table 1 for the full names of the genotypes).

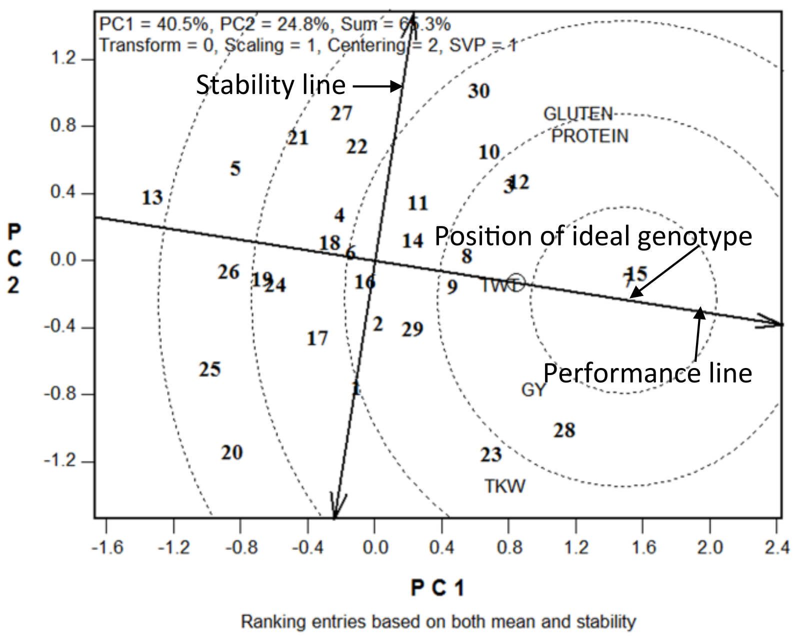

Figure 7. A GGE biplot based on the grain yield (GY), 1000-kernel weight (TKW), test weight (TWT), protein content, and gluten content of the 30 winter wheat genotypes evaluated across 7 environments in Uzbekistan. The names in italics are locations, with the last two numbers abbreviating the year (refer to Table 1 for the full names of the genotypes).

4. Discussion

Mean grain yield, quality-related traits, heading days, and plant height of the 30 genotypes differed significantly, suggesting that the seven environments represented a sufficient diversity to allow assessment of GE interaction and stability of performance for different traits. The presence of significant GE interaction for grain yield, TKW, TWT, protein, and gluten content suggested that relative differences among the genotypes for these traits changed over the environments. The environments with the highest (Karshi, 2010) and the lowest (Kasbi, 2011) grain yield had relatively lower values for TKW but the highest value for protein content (Table 2). These two environments had equal values for TWT but differed significantly for gluten content. This demonstrates the complex effect of environments on grain yield and quality-related traits. Previous studies have also reported significant GE interaction for grain yield and TKW in Central Asia (Sharma et al., 2013). The presence of GE interaction on quality-related traits (TWT, protein, and gluten content) in wheat has also been reported in Central Asia (Gómez-Becerra et al., 2010) and Turkey (Tayyar, 2010).

The range of values for grain yield suggested that the seven environments had different levels of productivity. This allowed examination of the correlation between grain yield and quality parameters under a range of productivity levels. There was no indication of association between mean grain yield in low and high productive environments with any of the four quality-related traits reported here. This suggests that it could be possible to maintain high yield and quality of wheat irrespective of the level of productivity of the environments. This finding is not in agreement with the study by Balla et al. (2011), who reported a linear decrease in protein content with increase in wheat yield. This difference could be due to the different sets of materials and environmental conditions used in the two studies.

The GGE biplot analysis allowed identification of superior genotypes for grain yield and each of the four quality-related traits. However, genotypic superiority based on the GGE biplot analysis, as shown by GGE rank, differed for grain yield and quality traits among the genotypes. The superior genotypes were not the same for the individual quality traits. However, a few genotypes were stable for quality-related traits. This is in agreement with the results published by Grausgruber et al. (2000), who reported the possibility of identifying wheat genotypes stable for multiple quality traits. Nevertheless, certain genotypes superior for grain yield were also superior for one or more of the quality-related traits. Elomon (#7), one of the most superior for grain yield, was also among the five most superior genotypes for TKW and protein content. Considering all four quality traits, Elomon (#7) ranked second. Similarly, Gozgon (#15) ranked second for grain yield superiority and was the most superior considering the four quality traits. Victoriya (#12) was among the five most superior genotypes for grain yield, protein, and gluten content. These results suggest that it could be possible to identify winter wheat genotypes superior for grain yield and quality traits. Two of the most superior genotypes (Elomon and Gozgon) for grain yield and quality are prospective cultivars under seed multiplication and limited commercial cultivation in Uzbekistan. They are expected to be released for large-scale commercial cultivation for the 2015–2016 winter wheat crop season. Gozgon was resistant to yellow rust during the epidemics of 2009, 2010, and 2013 in Central Asia (Sharma et al., 2013).

Both grain yield and quality-related traits in wheat are influenced by GE interactions, making it challenging to identify genotypes with superior and stable performance. However, our study presents genotypic variability for stability of grain yield and quality traits considered together. This finding is in agreement with the published reports by Grausgruber et al. (2000) and Peterson et al. (1998). Previous studies have reported selection for high grain yield and one or more superior quality parameters in fewer environments (Tayyar, 2010; Sokoto et al., 2012). However, multiple quality parameters were not included in those studies. The lack of negative correlation between grain yield and individual quality traits found in our study suggests that it could be possible to improve both grain yield and quality in winter wheat. However, the fact that not all genotypes superior for grain yield were necessarily also better for the individual quality traits suggests that some compromise would be required in selecting for both grain yield and quality. This might necessitate that the selection criteria for high, stable grain yield and improved, stable quality be flexible to allow balancing a modest deficiency in one or more of the quality traits with an obvious gain in yield. This strategy should be considered where food security is important; the opposite could be done when there is a premium price for high quality. This concept of a flexible selection scheme to allow balancing good qualities against moderate defects has been described as intuitive index selection by Simmonds (1981, p. 180).

Both the yield and the quality of bread wheat are important to meet the food and nutrition security of the growing population in Central Asia. This study confirms the complex effect of genotype × environment interactions on grain yield and quality-related traits. In the past, wheat breeders found it difficult to combine high yield and quality under diverse environment conditions. Our study shows that progress has been made in this direction in the wheat improvement programs. A few new wheat varieties and advanced breeding lines possess high, stable yield and improved, stable quality under different environmental conditions. Such superior genotypes could be considered as new varieties as well as improved parents in crossing programs by wheat breeders. Most of the superior genotypes for yield and quality originate from the International Winter Wheat Improvement Program and are distributed to countries in Central Asia and other regions. Therefore, the findings of this study are valuable for national and international winter wheat breeding programs.

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