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Improved winter wheat genotypes for Central and West Asia

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Abstract High grain yield and resistance to stripe (yellow) rust are the most important traits for successful adoption of winter wheat varieties in Central and West Asia. This study was conducted to determine the stripe rust response and agronomic performance of a set of breeding lines recently developed by the International Winter Wheat Improvement Program (IWWIP). Replicated field studies were conducted in 2010 and 2011 using 38 experimental lines, one regional check (Konya) and one local check. Stripe rust scores were recorded at Karshi, Uzbekistan, and Karaj and Mashhad, Iran, in 2010. Grain yield was recorded at two sites each in Uzbekistan (Karshi and Kibray) and Iran (Karaj and Mashhad) and one site in Turkey (Eskisehir). The test lines showed variation for stripe rust severity, grain yield, 1,000-kernel weight, days to heading and plant height. Several stripe rust resistant genotypes were

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either higher yielding or equal to the local checks at different sites. Based on stripe rust resistance and yield performance in 2010, a set of 16 genotypes was selected and evaluated in 2011. All 16 were resistant at Almaty, Kazakhstan, and Dushanbe, Tajikistan, in 2011, whereas 9 of the 16 were resistant at Terter, Azerbaijan. The genotypes 'TCI-02-138, 'Solh', 'CMSS97M00541S', 'TCI -2-88(A)' and 'TCI-02-88(C)' were consistently resistant to stripe across all sites in both years. Several lines showed high grain yields and superior agronomic performance across four sites in Uzbekistan and one site in Tajikistan. One genotype has been released in Uzbekistan and another in Tajikistan.

Keywords: *Puccinia striiformis* f. sp. *tritici* · Resistance · Stripe rust · *Triticum aestivum* · Yellow rust

Introduction

Developing high yielding and stripe rust resistant varieties is an important objective of winter wheat (*Triticum aestivum* L.) improvement programs in Central and West Asia. Stripe (yellow) rust, caused by *Puccinia striiformis* f. sp. *tritici* (*Pst*), has been the most important disease constraint to winter wheat in the region over the last 12 years (Absattarova et al. 2002; Nazari et al. 2008; Sharma et al. 2009; Ziyaev et al. 2011). There have been five stripe rust epidemics in the Central Asian region since 1999 (Ziyaev et al. 2011). In a study on global incidence of wheat rusts over the past 40 years, Morgounov et al. (2012) reported significant increases in stripe rust severities between 2001 and 2010 in Central and West Asia. In 2009 and 2010, severe outbreaks occurred across Central and West Asia and North Africa (Hodson and Nazari 2010) suggesting that the disease needed attention at the international level. Substantial reductions in grain yield occurred throughout the region (Moghaddam et al. 2009; Ziyaev et al. 2011), with losses of 10–90 % being reported (Dzhunusova et al. 2009; Rahmatov et al. 2009; Sarbayev and Kydyrov 2009). Since the leading winter wheat varieties in the region are either susceptible or possess low levels of resistance to stripe rust (Sharma et al. 2009) fungicides are widely used to control the disease.

Despite previous reports from Central and West Asia on identification of stripe rust resistant genotypes, cultivation of susceptible varieties remains a common practice due to their high yield under irrigated conditions (Sharma et al. 2009; Ziyaev et al. 2011). Stripe rust on the susceptible, high yielding varieties are managed by fungicides. For any resistant variety to be extensively adopted and grown under irrigated management, it must possess a yield potential at least as high as the current susceptible varieties. Control of stripe rust with fungicides adds to costs of production, thus reducing the profit margins for growers. Moreover, during the epidemics of 2009 and 2010 fungicides did not provide complete control due to earlier than usual initial infection and long period of epidemics caused by highly favorable environments (Sharma et al. 2009; Hodson and Nazari 2010). Therefore, to manage the stripe rust problem there is an urgent need to identify stripe rust resistant winter wheat varieties with high grain yield and acceptable agronomic traits. The present study was conducted to determine stripe rust responses, grain yield levels and key agronomic traits in newly developed advanced breeding lines produced by the International Winter Wheat Improvement Program (IWWIP) in Central and West Asia. IWWIP is a cooperative project between the Ministry of Food, Agriculture and Livestock of Turkey, the International Maize and Wheat Improvement Center (CIMMYT) and the International Center for Agricultural Research in the Dry Areas (ICARDA), which started in 1991 (cf. www.iwwip.org). IWWIP utilizes a network of breeding stations in diverse environments of Turkey and Syria to develop high-yielding disease resistant germplasm targeting both irrigated and rainfed areas of Central and West Asia. Advanced lines are distributed to cooperators worldwide through a number of different international nurseries. For Central Asian breeding programs IWWIP is the main source of essential germplasm which is selected, advanced and promoted as new varieties. Therefore, identification of IWWIP germplasm with superior yield performance and resistance to rusts is of fundamental importance for wheat production gains in the region.

Materials and methods

Forty winter wheat genotypes, including 38 advanced breeding lines from IWWIP and two checks were included in 2010 (Table 1). The two checks at the five sites were Turkish cv. Konya and a local commercial cultivar that differed in each country (Krasnodar-99 in Uzbekistan, Toos in Mashhad, Shahriar in Karaj, and Alpu 2001 in Eskisehir). The five sites were Kibray and Karshi in Uzbekistan, Karaj and Mashhad in Iran and Eskisehir in Turkey (Fig. 1). The experiments were conducted in an alpha lattice design in three replicates using 7.5 m^2 plots managed under irrigated conditions. Local wheat cultivation practices were adopted at each site. Data recorded included stripe rust severities, days to heading, plant height, grain yield and 1,000-kernel weight (TKW). Stripe rust severities were recorded on three replications in Karshi and Mashhad and one replication in Karaj. For the replicated data means were presented. Genotypes showing terminal ratings ≤20 % stripe rust severity were classified as resistant. Leaf rust scores were recorded on the 40 genotypes sown in single replicate plots in Edirne and Adapazari, Turkey, in 2010 and 2011, respectively.

A set of 16 genotypes with good stripe rust resistance, high grain yield and acceptable agronomic traits was selected using data from the 2010 study, along with a widely grown variety as a control for specific sites (e. g. Krasnodar-99 in Uzbekistan and Navruz in Tajikistan), were evaluated at four regional sites (Karshi, Kibray, Gallaral and Namangan) in Uzbekistan in 2011. The 16 genotypes were also distributed to other countries in Central Asia and Azerbaijan.

The field trial at each site in 2011 was sown in a randomized complete block design with three replicates. Individual plot sizes were 25 m^2. The trials were planted at optimal seeding times, irrigated as necessary, and exposed to natural stripe rust infections. Data were recorded on days to heading, plant height, grain yield and TKW. Stripe rust data were recorded in Kazakhstan and Azerbaijan. Leaf rust severities were also scored in Kazakhstan.

An analysis of variance was made for each trial at each site using Genstat (2007) software. After confirming homogeneity of variances (Gomez and Gomez 1984), a combined analysis of variance was conducted to test the significances of genotypes and genotype × environment interactions. Significances of the differences between genotypes and local checks were tested using least significant difference. Genotype and genotype × environment (GGE) biplot analyses were conducted using GGE biplot software (Yan and Kang 2002) to determine specific and broad adaption for grain yield to identify superior genotypes. 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).

Results

Stripe rust severities were recorded at Karshi, Uzbekistan, and Karaj and Mashhad in Iran in 2010. Infection levels were high, allowing selection of resistant genotypes in Uzbekistan and Iran. Susceptible checks showed 90–100 % severities (Table 2). In 2011, all 40 genotypes showed low severities and moderately resistant reaction to leaf rust at Adapazari, Turkey.

There were arrays of variation in stripe rust scores at each of the three sites (Karshi, Karaj and Mashhad) where disease severities were high (Table 2) in 2010. Disease severities ranged from 0 to 100 % at Karshi and Karaj and 0 to 90 % at Mashhad. There were 25, 24 and 26 of the 38 experimental genotypes resistant to stripe rust at Karshi, Karaj and Mashhad, respectively (Table 2). There were 16 resistant genotypes common over the two sites in Iran. There were 13 resistant lines common among the three sites and six lines with no disease across three sites.

Forty genotypes in 2010 differed significantly for grain yield, TKW, days to heading and plant height (Table 3). The experimental sites differed significantly for grain yield and other traits. Mean grain yield of the five sites varied from 3.51 to 9.07 t ha^{-1}. There were arrays of variation for grain yields at the experimental lines in each of the five sites in 2010. Several genotypes produced significantly higher grain yields than the local checks at each site except Eskişehir (Table 2). The highest yields were above 10 t ha^{-1} in Karaj. The genotypes also varied for TKW, days to heading and plant height. Mean TKW, days to heading and plant height ranged from 33.6 to 46.4 g, 171 to 184 and 91 to 120 cm, respectively.

Four lines (#4, #10, #25 and #26) produced significantly higher grain yields than the local check in Karshi (Table 2). These four lines were also resistant (0 % severity) to stripe rust. Eleven lines produced significantly higher grain yields than the

Table 1 Winter wheat lines used in the study of stripe rust resistance and agronomic performance in Central and West Asia

Genotype	Pedigree (selection history)	Cross identification (CID)
1	6720.11//MDA38/WRM/3/69.148/YMH//HYS/4/ASP/BLT/5/GUN91/MNCH (0AP-4AP-6AP-0AP-4AP-0AP)	ICWH99302
2	HK1/6/NVSR3/5/BEZ/TVR/5/CFN/BEZ//SU92/CI13645/3NAI60 (0AP-0AP-0AP-5E-0E-2E-0E)	ICWH99158
3	6720.11//MDA38/WRM/3/69.148/YMH//HYS/4/ASP/BLT/5/GUN91/MNCH (0AP-4AP-6AP-0AP-4AP-0AP)	ICWH99302
4	VEE#8//JUP/BJY/3/F3.71/TRM/4/BCN/5/Kauz/6/163Hamidiye//VEE/Koel/6/TAM200/Kauz (030YE-0E-1E-0E-2E-0E)	TCI992192
5	PEHLIVAN/3/PANTHEON//CHUM18/SERI (0AP-0AP-2AP-0AP-5AP-0AP)	TCI-01-543
6	LRC/SERI/MEX-DW/BACA//VONA/3/ALTAY	TCI011549
7	JAGGER 'SIB'/3/LAGOS-7//GUIMATLI 2/17	TCI-02-1090
8	PEHLIVAN/3/ID#840335//PIN39/PEW (0AP-0AP-51AP-0AP-4AP-0AP)	TCI-02-25
9	GANSU-1//PTZ NISKA/UT1556-170 WRB860365 (0AP-0AP-25AP-0AP-3AP-0AP)	TCI-02-486
10	GANSU-1//PTZ NISKA/UT1556-170 WRB860365 (0AP-0AP-25AP-0AP-5AP-0AP)	TCI-02-486
11	DORADE-5/3/BOW"S"/GEN//SHAHI (0AP-0AP-6AP-0AP-3AP-0AP)	TCI-02-522
12	AMSEL/TUI//BLUEGIL-2//SHARK/F4105W2.1 (030YE-30E-10E-0E-5AP-0AP)	TCI012034
13	ZOLOTAVA/3/PYN/BAU//MILAN (030YE-30E-1E-0E-1AP-0AP)	CMSW01WM00459S
14	4WON-IR-257/5/YMH/HYS//HYS/TUR3055/3/DGA/4/VPM/MOS (0AP-0AP-5AP-0AP-3AP-0AP)	TCI-02-80
15	YMH/HYS//HYS/TUR3055/3/DGA/4/VPM/MOS/5/5/TAM200/KAUZ (-0AP-0AP-7AP-0AP-5A-0AP)	TCI-02-138
16	CADET/6/YUMAI13/5/NAI60/3/14.53/ODIN//CI13441/CANON (-0AP-0AP-1AP-0AP-5A-0AP)	TCI-02-417
17	PSK/NAC//SABALAN/3/TAM200/KAUZ (030YE-30E-2E-0E-1AP-0AP)	TCI011657
18	PANTHEON/BLUEGIL-2 (030YE-030YE-2E-0E)	TCI 001264
19	AGRI/NAC//KAUZ (0SE-0YC-10YE-0YC-2YC-0YC-1YM-0YM-0AP)	CMSW92WM00231S
20	VORONA/HD2402/6/VEE/TSI//GRK/3/NS55.03/5/C126.15/COFN/3/N10B/P14//P101/4/KRC67 (030YE-030YE-2E-0E-3AP-0AP)	TCI 001482
21	90ZHONG65/BUL5626.5.2 (0AP-0AP-40AP-0AP-1AP-0AP)	TCI-01-87
22	HK1/6/NVSR3/5/BEZ/TVR/5/CFN/BEZ//SU92/CI13645/3NAI60 (-0AP-0AP-0AP-4YE-0YE)	ICWH99158
23	HK1/6/NVSR3/5/BEZ/TVR/5/CFN/BEZ//SU92/CI13645/3NAI60 (-0AP-0AP-0AP-2YE-0YE-5AP-0AP)	ICWH99158
24	CATBIRD//CNO79*2/HE 1	A-29707
25	ZANDER//ATTILA/3*BCN (0SE-0YC-0YE-3YE-0YE-2YE-0YE)	CMSW97WM00514S
26	SOLH	
27	00247G6-106	
28	MILAN/KAUZ//HD29/2*WEAVER (020Y-030 M-040SY-020 M-27Y-010 M-0Y-0SY)	CMSS97M00541S
29	VEE#8//JUP/BJY/3/F3.71/TRM/4/BCN/5/KAUZ/6/163HAMIDIYE//VEE/KOEL/6/TAM200/KAUZ	TCI992192
30	PEHLIVAN/JAGGER	ICWH99130
31	CRR/TIA.2//FDL490/3/IRNERIA/MUKKAB HIB (0AP-0AP-34AP-0AP-2E-0E)	TCI-02-398
32	LUFER-1/ZERNOGRADKA8 (0AP-0AP-16AP-0AP-2E-0E)	TCI-02-449
33	LUFER-1/ZERNOGRADKA8 (0AP-0AP-14AP-0AP-1AP-0AP)	TCI-02-449
34	DORADE-5/3/BOW"S"/GEN//SHAHI (0AP-0AP-6AP-0AP-4AP-0AP)	TCI-02-522
35	DORADE-5//KS82117/MLT (0AP-0AP-4AP-0AP-1AP-0AP)	TCI-02-88(A)
36	DORADE-5//KS82117/MLT (0AP-0AP-4AP-0AP-3AP-0AP)	TCI-02-88(B)

Table 1 continued

Genotype	Pedigree (selection history)	Cross identification (CID)
37	FLAMURA85//F134.71/NAC/3/AGRI/NAC//KAUZ (0AP-0AP-37AP-0AP-4E-0E)	TCI-02-260
38	DORADE-5//KS82117/MLT (0AP-0AP-19AP-0AP-3AP-0AP)	TCI-02-88(C)
39	Konya	
40	Local check	

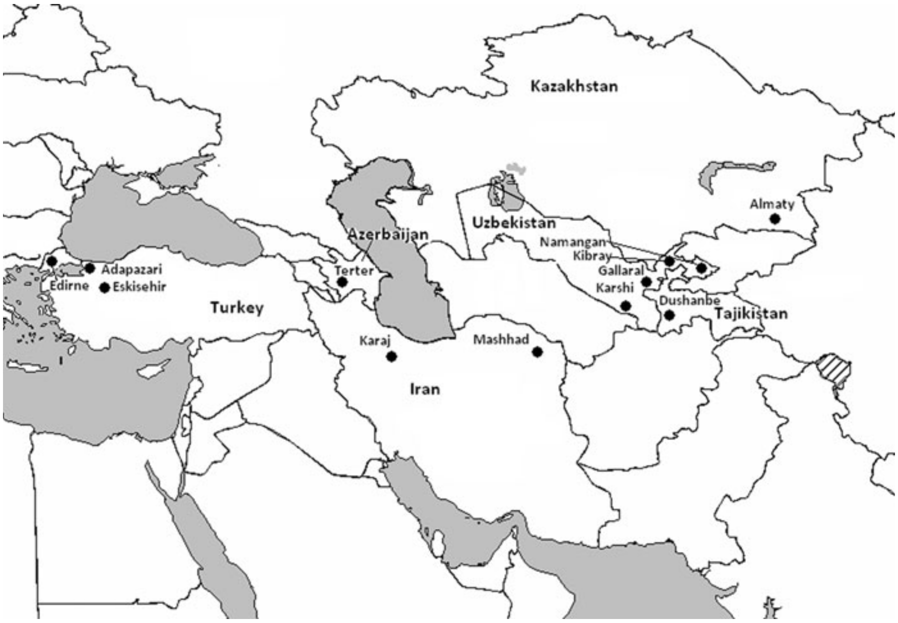

Fig. 1 Partial map of Central and West Asia showing sites where the field studies were conducted

local check in Karaj. Of those, seven (#7, #18, #25, #26, #35, #36 and #38) were resistant to stripe rust. Twelve lines had significantly higher grain yields than the local check in Mashhad; nine (#3, #11, #15, #26, #32, #33, #35, #36 and #38) were also resistant to stripe rust. Among the seven lines that produced significantly higher grain yields than the local checks at both sites in Iran, four (#26, #35, #36 and #38) were resistant to stripe rust at both sites. The only line (#26) producing significantly higher grain yield than the local checks at the three sites (Karshi, Karaj and Mashhad) was also resistant at each site. There were a few lines that had medium levels (30–60 %) of stripe rust severity and significantly higher grain yield than the check; for example, genotypes #3, #4 and #11 in Karaj, and #18, #27 and #34 in Mashhad. One genotype (#20) had relatively high stripe rust severity but produced a significantly higher yield than the check in Karaj. Correlation coefficients between grain yield and stripe rust severity were -0.57 ($p < 0.01$), -0.26 ($p = 0.10$) and -0.11 ($p = 0.49$) at Karshi, Karaj and Mashhad, respectively. A few highest yielding genotypes with stripe rust severities on them have been shown in Fig. 2.

The analysis of variance for individual sites in 2011 revealed significant effects of genotypes for grain yield, TKW, days to heading and plant height at each site (individual ANOVA not presented). The combined analysis of variance showed significant effects of locations, genotype and genotype × location interactions (Table 4). Coefficients of variation were 6.1, 4.2, 0.6 and 5.5 % for grain yield, TKW, days to heading and plant height, respectively.

All of the 16 genotypes selected for further testing in 2011 were stripe rust resistant (0 % severity) at Almaty, Kazakhstan, and Dushanbe, Tajikistan (Table 5); nine were resistant at Terter, Azerbaijan. Eleven of the 16 genotypes were also resistant to leaf

Table 2 Values for stripe rust severity, grain yield and other agronomic traits of 40 winter wheat genotypes in Central and West Asia, 2010

Genotype (Table 1)	Stripe rust severity (%)			Leaf rust score		Grain yield (t ha^{-1})					1,000-kernel weight (g)	Days to heading	Plant height (cm)
	Karshi	Karaj	Mashhad	Edirne[a]	Adapazari[a]	Karshi	Karaj	Mashhad	Kibray	Eskisehir			
1	80	80	7	60S	60MS-S[b]	6.06 a[¶]	9.34[a]	7.17[a]	4.49[a]	4.16[a]	33.6	176	98
2	3	40	10	20MR	30MS-S	6.25[a]	9.10[a]	7.13[a]	4.86[a]	3.54	37.7	176	90
3	73	40	20	100S	45MS-S	5.92[a]	9.70[c]	7.65[c]	4.88[a]	4.12[a]	35.0	177	98
4	0	30	40	10MR	20MR	7.08[c]	9.56[c]	7.38[a]	5.38[c]	3.47	41.2[a]	174	96
5	93	50	0	60S	30MS-S	5.08	8.78[a]	7.04[a]	3.91[a]	3.85[a]	44.5[a]	180	109
6	88	10	0	20S	20MR	4.37	8.58[a]	6.71[a]	1.94	4.04[a]	43.1[a]	174	120
7	90	0	30	60S	30MR-S	5.70[a]	9.62[c]	7.25[a]	3.68[a]	4.45[a]	36.9	173	108
8	87	0	40	100S	40MS-S	5.74[a]	9.05[a]	6.03[a]	3.68[a]	3.96[a]	44.4[a]	179	108
9	0	20	20	0	0	7.00[a]	7.67[a]	6.11[a]	4.68[a]	3.65	37.4	171	100
10	0	50	10	0	0	7.15[c]	8.26[a]	6.46[a]	4.65[a]	3.6	39.6	171	97
11	83	60	10	10MR	30MR-MS	5.48[a]	9.71[c]	7.80[c]	5.14[c]	3.97[a]	39.4	173	91
12	0	50	40	50S	40MS-S	6.48[a]	8.90[a]	7.03[a]	4.39[a]	3.67	37.4	172	95
13	0	70	20	10MR	30MR	6.74[a]	8.44[a]	6.34[a]	5.04[a]	2.99	46.8[c]	174	101
14	0	NA[b]	0	TR	10MR	6.56[a]	7.56[a]	6.86[a]	5.30[c]	3.46	40.1	176	98
15	0	0	0	TR	10MR	6.64[a]	8.61[a]	7.51[c]	4.90[a]	3.00	42.6[a]	172	106
16	0	0	10	5R	35MS-S	6.61[a]	8.84[a]	7.37[a]	4.55[a]	3.49	34.8	175	98
17	2	0	0	TR	25S	6.31[a]	9.49[a]	6.22[a]	3.93[a]	3.85[a]	42.6[a]	172	106
18	60	0	30	5R	30MR	6.66[a]	9.99[c]	7.84[c]	4.69[a]	3.44	34.7	176	94
19	0	20	30	20S	20MR-MS	6.31[a]	9.37[a]	6.30[a]	4.50[a]	3.92[a]	38.7	177	100
20	0	80	10	10S	30MS-S	6.47[a]	9.63[c]	6.91[a]	2.91	2.75	37.7	174	100
21	0	100	10	80S	50S	4.83	8.60[a]	7.34[a]	4.32[a]	3.06	37.0	172	98
22	30	0	10	70S	30S	6.61[a]	8.99[a]	6.95[a]	4.95[a]	3.69	37.1	177	83
23	3	0	10	50S	25MS-S	6.73[a]	8.94[a]	6.65[a]	4.44[a]	3.79	36.0	176	82
24	0	20	10	40S	30MS-S	6.44[a]	8.58[a]	7.39[a]	4.65[a]	3.52	35.0	172	97
25	0	0	30	40S	20MR-30S	7.18[c]	9.98[c]	7.34[a]	4.99[a]	3.23	37.4	174	108
26	0	0	0	0	50S	7.17[c]	10.20*	7.47*	3.21	2.72	39.5	173	98
27	77	0	30	0	50MR-S	5.79[a]	8.93[a]	7.70[c]	5.28[c]	2.77	43.8[a]	176	94
28	0	0	0	0	5MR	6.41[a]	8.23[a]	6.68[a]	4.22[a]	2.44	35.3	172	91
29	0	0	40	0	0	6.81[a]	8.66[a]	7.31[a]	2.34	3.44	42.0[a]	172	91
30	90	0	30	100S	30MS	5.99[a]	8.67[a]	6.99[a]	3.31[a]	3.84[a]	43.5[a]	179	103
31	0	80	30	0	0	5.41[a]	8.46[a]	6.09[a]	2.85	3.68	40.6[a]	180	109

Table 2 continued

Genotype (Table 1)	Stripe rust severity (%)			Leaf rust score		Grain yield (t ha^{-1})					1,000-kernel weight (g)	Days to heading	Plant height (cm)
	Karshi	Karaj	Mashhad	Edirne[a]	Adapazari[a]	Karshi	Karaj	Mashhad	Kibray	Eskisehir			
32	0	0	0	70S	30MS	5.90[a]	9.25[a]	7.44[c]	3.87[a]	3.6	40.1	178	110
33	0	0	0	80S	30MS	5.64[a]	9.03[a]	7.75[c]	2.51	3.48	38.3	177	108
34	67	40	30	50S	20MR	5.39[a]	9.38[a]	7.53[c]	4.42[a]	3.59	35.9	174	92
35	0	0	0	40S	20MR-MS	6.27[a]	10.19*	7.44[c]	3.86[a]	2.92	43.6[a]	181	108
36	40	0	0	50S	20MR-MS	6.51[a]	9.84*	7.72[c]	3.80[a]	2.90	43.4[a]	184	101
37	0	0	20	40S	20MR-S	5.89[a]	8.94[a]	6.26[a]	4.40[a]	3.83[a]	40.5[a]	181	111
38	0	0	20	80S	30MR-MS	6.74[a]	10.11*	8.56[c]	4.49[a]	3.05	46.5[c]	177	105
39	100	100	90	100S	80S	5.33[a]	8.65[a]	7.07[a]	4.82[a]	3.19	39.8	177	108
40	87	80	40	80S	35S	6.16	8.36	6.30	4.21	4.40	42.7	180	105
Mean						6.18	9.07	7.08	4.21	3.51	39.6	180	100
$LSD_{0.05}$						0.91	1.19	1.11	0.91	0.60	2.1	1	4
Correlation with stripe rust severity						−0.57**	−0.26	0.11					

Correlation coefficient significantly different from zero at $P = 0.01$ ¶Grain yield of the experimental lines followed by ‘a’ does not differ significantly from the local check at that site based on $LSD_{0.05}$

[a] Leaf rust scores recorded in Edirne and Adazapari in 2010 and 2011, respectively

[b] Data not available

[c] Grain yield of the experimental line significantly higher than local check at individual sites based on $LSD_{0.05}$

Table 3 Analysis of variance for various traits in winter wheat genotypes evaluated at five sites in 2010

Source of variation	Grain yield		1,000-kernel weight		Days to heading		Plant height	
	df	Mean square	df	Mean square	df	Mean square	df	Mean square
Loc	4	597.47**	3	989.4**	3	9261.1**	3	958.9**
Replication/location	10	0.44	6	5.0	6	2.7	8	24.8
Block/rep/loc	45	1.68**	30	30.4**	30	41.9**	36	160.5**
Genotype	39	1.52**	39	109.5**	39	56.3**	39	621.4**
Geno × loc	156	1.09**	113	20.7**	113	12.3	117	53.3**
Error	340	0.35	203	6.4	203	1.4	271	18.2
CV (%)		9.8		6.4		0.7		4.3

** Significant at $P = 0.01$

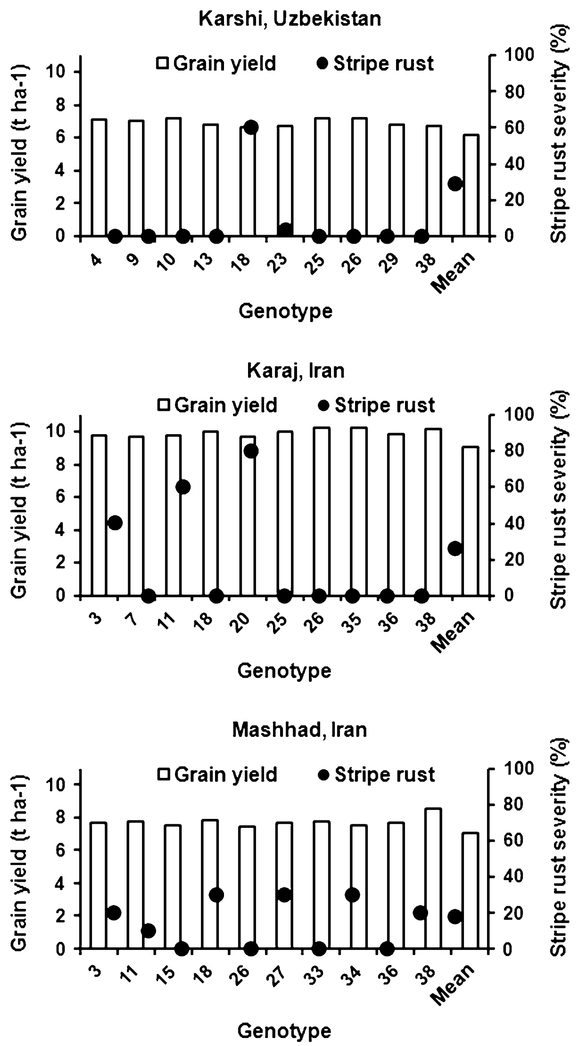

Fig. 2 Yield and stripe rust severities (*black spots*) of the best performing genotypes at three sites in Central and West Asia, 2010. Pedigree data are provided in Table 1

rust (0 % severity) at Almaty. Five (#9, #10, #14, #15 and #28) of the 16 selected genotypes were leaf rust resistant at the two sites in Turkey (Table 2) as well as in Kazakhstan (Table 5).

The five locations used in the study in 2011 showed variation for grain yield with site mean yields ranging from 2.53 to 5.56 t ha^{-1} (Table 5). The 16 selected genotypes showed variable grain yields, TKW, days to heading and plant height. At other locations, except four in Karshi, one in Gallaral and three in Namagan, all 16 genotypes gave grain yields significantly higher than, or equal to, the check. One or more genotypes were significantly higher yielding than the check in each site. Two genotypes (#13 and #38) showed significantly higher TKW than the check at three sites in Uzbekistan. Several genotypes had TKW equal to the check at each site. All of the 16 experimental genotypes headed earlier than the check by 2–5 days and had average plant height shorter than 94 cm compared to the check at 83 cm.

GGE biplot analysis for grain yield revealed a significant diversity among the 16 genotypes and among 10 environments (Fig. 3). Based on mean yield stability, the four genotypes closest to the point for ideal genotypes for grain yield were #4, #25, #24 and #38. Line #38 (DORADE-5//KS82117/MLT; -0AP-0AP-19AP-0AP-3AP-0AP), the overall highest yielding line across four locations in Uzbekistan, was named as cv. Amirbek, and submitted to the State Variety Testing Commission in Uzbekistan in 2011. This genotype also had significantly higher TKW than the check at three locations in Uzbekistan. Another genotype, #16 (CADET/6/YUMAI13/5/NAI60/3/14.53/ODIN//CI13441/CANON; -0AP-0AP-1AP-0AP-5A-0AP), among the highest yielding in

Table 4 Analysis of variance for various traits in winter wheat genotypes evaluated at five sites in 2011

Source of variation	df	Grain yield	1,000-kernel weight	Days to heading	Plant height
Location	4 (2)[a]	73.698**	274.8**	3726.0**	287.9**
Replication/location	10 (6)	0.777	2.7	5.1	36.3
Genotype	16	0.959**	124.7**	18.1**	153.8**
Genotype × location	64 (32)	0.563**	10.9**	6.8**	43.5**
Error	160 (96)	0.161	2.2	1.0	22.4

** Significant at $P = 0.01$

[a] Values in parentheses are degrees of freedom for 1,000-kernel weight, days to heading and plant height

Dushanbe, was submitted as cv. Chumon to the State Variety Testing Commission in Tajikistan in 2011.

The GGE biplot for specific adaptation showed that genotype #38 was superior to #4, #25 and #24 across four environments, viz. Mashhad in 2010, Karshi in 2010 and 2011 and Dushanbe in 2011, that grouped together (Fig. 4). Similarly, genotype #10 was superior to #16 in Namangan in 2011 and Kibray in 2010. Genotype #9 was superior to #12, #13, #14 and #23 across two sites.

Discussion

This study identified several winter wheat genotypes that were resistant to stripe rust in Iran and Uzbekistan in 2010. There was a severe outbreak of stripe rust in 2010 in Uzbekistan (Ziyaev et al. 2011). However, the fact, that stripe rust resistant lines were not always the same across the three sites in two countries or even across two sites within a country suggests that *P. striiformis* populations differed within and between the two countries. More importantly it shows that the resistance is specific and is unlikely to be durable. The 16 lines selected for stripe rust resistance in Iran and Uzbekistan in 2010 were also resistant in Kazakhstan and Tajikistan in 2011, but not all were resistant in Azerbaijan. This result indicates that *P. striiformis* population in Azerbaijan is different from those in Iran, Kazakhstan, Tajikistan and Uzbekistan. Similar variations in the pathogen population in Central and West Asia were earlier suggested by others (Yahyaoui 2002; Nazari et al. 2009). However, the previous studies were primarily based on data from trap nurseries consisting mostly of isogenic lines; our study involved advanced breeding lines selected for stripe rust resistance and agronomic performance at other locations.

There were several lines that possessed resistance to stripe rust as well as high grain yield at each site in 2010; a few had high yields across all three sites. A number of stripe rust resistant lines showing significantly higher grain yield than the local check at each of the three sites is a confirmation of the combination of high yield and resistance. With one exception, lines that produced significantly higher grain yields than the local checks were those with low to medium stripe rust severities. Based on low stripe rust severities and significantly higher grain yields than the local checks in 2010, five genotypes (#25, #26, #35, #36 and #38) were considered superior. Among them genotype #26 was highly resistant (0 % severity) and significantly higher yielding than the local check at the three sites where stripe rust was recorded. Genotype #38 was also among the highest yielding and with a high level of stripe rust resistance across three sites (Fig. 2). Previous studies had also identified stripe rust resistant germplasm in international winter wheat nurseries in different countries in the region (Dzhunusova et al. 2009; Rahmatov et al. 2009; Sarbayev and Kydyrov 2009), and several lines were released as resistant varieties (Morgounov et al. 2005, 2009). However, these varieties occupy only limited areas in the region because of multiple reasons, but including national policies on the number of varieties to be grown in a particular country. For example, more than 20 winter wheat varieties are grown across Uzbekistan to avoid substantial losses that might occur in the advent of pest outbreaks or disease epidemics. Therefore, more new varieties are needed. Most of the varieties released in the past were often based on stripe rust reaction in one country and not necessarily always under high disease pressure. This study has identified genotypes resistant to stripe rust under epidemic conditions in Uzbekistan and also under high disease severity in Iran in 2010, the year in which Hodson and Nazari (2010) reported

Table 5 Stripe rust severities, grain yields and other agronomic traits of winter wheat genotypes at different sites in 2011

Geno-type number	Stripe rust severity (%)			Leaf rust severity (%)	Grain yield (t ha^{-1})					1,000-kernel weight (g)				Days to heading[d]	Plant height (cm)[d]
	AL, KZ[b]	TT, AZ[b]	DU, TJ[b]	AL, KZ[b]	Karshi	Kibray	Gallaral	Nama-ngan	Dush-anbe	Karshi	Kibray	Naman-gan	Dush-anbe[b]		
4	0	20	20	0	6.23 a[c]	4.90	5.07	3.75	3.10[a]	37.0	33.9	28.4	32.6	169	85
9	0	90	10	0	5.60	5.61[a]	5.31	4.82[a]	1.84	35.5	31.5	34.1	34.7	170	87
10	0	90	0	0	5.87	5.14	4.27	4.97[a]	2.30	35.8	32.6	30.5	34.4	169	86
12	0	80	10	50	5.52	5.04	5.80[a]	4.57[a]	2.67	37.1	33.2	32.2	36.5	169	85
13	0	70	0	0	4.96	5.07	5.11	4.12	2.12	47.1[a]	41.2[a]	37.2[a]	38.1	169	88
14	0	60	0	0	5.45	4.88	5.01	4.43[a]	2.40	38.2	36.8	34.4[a]	38.1	171	87
15	0	0	0	0	5.15	5.17	5.93[a]	4.29	2.47	39.1	39.3[a]	33.6	31.1	169	89
16	0	5	0	90	5.24	5.26	5.27	4.57[a]	3.36[a]	34.6	31.5	27.0	31.0	171	90
19	0	20	0	0	5.37	4.21	5.29	3.89	2.74[a]	34.2	33.2	31.6	33.9	172	87
23	0	90	0	50	5.01	5.52	4.93	4.30	2.67	32.4	35.3	28.2	33.9	170	75
24	0	10	0	0	6.09	5.38	5.71[a]	4.82[a]	3.35[a]	30.3	29.8	28.4	31.7	171	88
25	0	80	0	50	5.69	4.76	4.52	4.56[a]	2.53	36.1	31.1	32.6	32.0	171	91
26	0	0	0	0	4.71	4.57	6.41[a]	4.03	2.58	37.1	35.8	30.9	37.1	169	86
28	0	0	0	0	6.03	4.99	5.44	4.43[a]	2.47	33.8	35.2	29.5	34.0	169	84
35	0	0	0	30	5.39	3.86	4.96	3.36	1.96	35.9	36.0	36.6[a]	36.7	172	92
38	0	0	0	0	6.55[a]	4.93	5.16	4.66[a]	2.20	48.1[a]	41.7[a]	43.5[a]	42.7	171	93
Check[e]	60	50	60	80	5.75	4.70	5.00	4.17	2.23	38.5	35.7	33.2	35.9	174	83
Mean					5.56	4.94	5.25	4.34	2.53	37.0	34.9	32.4	35.0	170	87
$LSD_{0.05}$					0.58	0.87	0.63	0.20	0.500	3.2	2.7	0.8		1	4

AL, KZ Almaty in Kazakhstan, *TT, AZ* Terter in Azerbaijan, *DU, TJ* Dushanbe in Tajikistan

[a] Grain yield and 1,000-kernel weight of the experimental line significantly higher than local check based on $LSD_{0.05}$

[b] Data from one replication

[c] Grain yield of the experimental lines followed by 'a' does not differ significantly from the local check based on $LSD_{0.05}$

[d] Mean value over Karshi, Kibray and Namangan

[e] Check included 'Krasnodar-99' in Uzbekistan and Kazakhstan, 'Navruz' in Tajikistan and 'Azamatly 95' in Azerbaijan

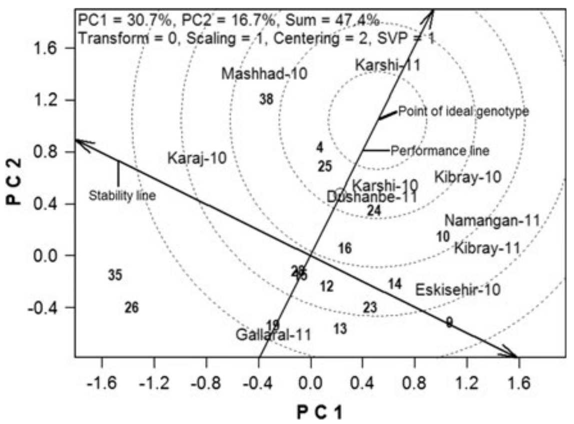

Fig. 3 GGE biplot showing superiority based on mean and stability of grain yield of 16 winter wheat genotypes evaluated across ten environments in Central and West Asia (see Table 1 for genotype names). The environments included six in Uzbekistan (Karshi and Kibray in 2010 and 2011 and Gallaral and Namangan in 2011), two in Iran (Karaj and Mashhad in 2010), one in Turkey (Eskisehir in 2010) and one in Tajikistan (Dushanbe in 2011)

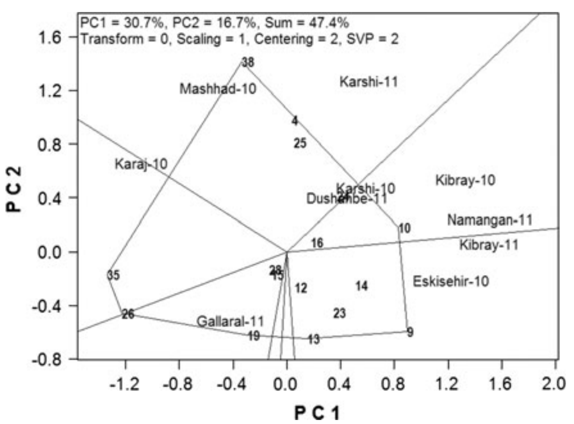

Fig. 4 GGE biplot showing specific adaptation for grain yield of 16 winter wheat genotypes evaluated across ten environments in Central and West Asia (see Table 1 for genotype names). The environments included six in Uzbekistan (Karshi and Kibray in 2010 and 2011 and Gallaral and Namangan in 2011), two in Iran (Karaj and Mashhad in 2010), one in Turkey (Eskisehir in 2010), and one in Tajikistan (Dushanbe in 2011)

serious outbreaks of stripe rust in many parts of Central and West Asia and North Africa.

All 16 genotypes selected for low stripe rust severities in Uzbekistan and Iran in 2010 were also resistant in Kazakhstan and Tajikistan in 2011 suggesting widespread effectiveness of the resistances and confirming the results of 2010. Furthermore, nine of the 16 genotypes were resistant in Azerbaijan in the Southern Caucasus, which underlines the effectiveness of these sources of stripe rust resistance in the region.

Several high yielding, stripe rust resistant genotypes selected in 2010 gave high yields in 2011 across four locations in Uzbekistan and one in Tajikistan. These high yields were obtained in the absence of the disease in Uzbekistan in 2011. This finding is significant suggesting that high yield potential relative to local checks in the presence of disease was maintained in the absence of disease. Such resistant genotypes, if grown by the farmers as new varieties, would help sustain productivity in years with and without stripe rust epidemics. Some progress in the right direction was achieved when national wheat improvement programs in Uzbekistan and Tajikistan each identified one new variety. Genotype #38 selected as new variety in Uzbekistan was resistant to stripe rust in Iran, Kazakhstan and Azerbaijan and was one of the superior genotypes identified in the GGE biplot analysis across 10 environments (Fig. 3).

The presence of a number of stripe rust resistant genotypes in this new set of advanced breeding lines suggests that resistance is being successfully combined with high yield in the IWWIP. In a previous study, Mosaad et al. (2008) reported stripe rust resistance in 60 % of 110 winter wheat varieties from Central Asia and adjoining countries. Those varieties were extensively used as parents in the IWWIP breeding program. Even though the germplasm included in the present set of materials had earlier been selected for resistance prior to distribution in the region, some were not resistant across all testing sites used in this study. However, identification of nine of the 38 (24 %) genotypes resistant across sites in West and Central Asia and the Caucasus shows that new sources of resistance are being made available to the national programs. Sharma et al. (2010, 2012) identified several high yielding genotypes in IWWIP yield trials tested throughout the region. However, the actual levels of stripe rust resistance of the superior genotypes were not clearly established. This study has identified several new high yielding winter wheat genotypes with resistance to stripe rust and acceptable agronomic traits. These genotypes are being further tested in the region for release as new cultivars, and could also be utilized as parents in national wheat improvement programs in Central and West Asia.

Since wheat germplasm developed by IWWIP is also shared by national wheat programs in Eastern Europe and South Asia, a few of the high yielding, stripe resistant lines of this study could also be valuable to the national programs in these regions.

The major global emphasis on wheat rust research at present is directed to race *Ug*99 of the stem rust pathogen, a potential threat to Central and West Asia because of its presence in Iran (http://www.seedquest.com/News/releases/2008/march/21996.htm). In a way this has resulted in neglect of the current serious problem of stripe rust being faced by the wheat growers in Central and West Asia and elsewhere. The findings of this study are therefore valuable in addressing the consequences of frequent stripe rust epidemics in the region over the past decade (Ziyaev et al. 2011), and especially in 2009 and 2010. Indeed the new varieties originating from IWWIP with excellent yield performance and resistance to stripe rust are available in the region. However, handicapped research, extension and seed production systems are not able to replace old susceptible varieties in a short time-frame. The Durable Rust Resistance Project targeting *Ug*99 (http://www.wheatrust.cornell.edu/) could be a model for coordinated efforts to enhance stripe rust resistance and promote resistant varieties. Through advocacy, financial support and affirmative action much has been achieved in international collaboration on pathogen surveillance, expansion of genetic resources, resistance genetics, and breeding for resistance in regards to the stem rust threat in a relatively short period of time (in practice, 2006–2012) in anticipation of potential *Ug99* threat. For stripe rust the yield losses already undermine the food security and affect the livelihood of rural and urban population. A similar program is urgently needed to reduce wheat vulnerability to stripe rust not only in Central and West Asia but also worldwide.

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