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Identification of *Puccinia striiformis* f.sp. *tritici*. Characterization of Wheat Cultivars for Resistance, and Inheritance of Resistance to Stripe Rust in Kazakhstan Wheat Cultivars

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ABSTRACT

Stripe (yellow) rust, caused by *Puccinia striiformis* f.sp. *tritici*, is one of the major factors reducing the productivity of wheat crop. The region of Central Asia is one of the most important wheat areas in the world. As there was practically no breeding work in the past on stripe rust, most varieties released for commercial production are susceptible to the disease. This problem is especially important for Kazakhstan because of changing epidemic situations and the few resistant wheat cultivars. In order to effectively combat stripe rust, it is necessary to find donors of resistance and study genetics of resistance. Seedlings of winter wheat cultivars and advanced breeding lines from Central Asia were tested for resistance to five races of *P. striiformis* f.sp. *tritici* that are currently prevalent or were prevalent in the past in the USA. More virulent US races of *P. striiformis* f.sp. *tritici* for wheat germplasm from Central Asia were represented by PST-17 and PST-100. Cultivars 'Taza', 'Krasnovodopadskaya 25', and 'Ulugbek 600' have all-stage (also called seedling) resistance. The most effective resistant sources against stripe rust in this region are those of genes *Yr2*+, *Yr4*+, *Yr5*, *Yr10*, and *Yr15*. Resistance genes *Yr1*, *Yr6*, *Yr7*, *Yr8*, *Yr11*, *Yr12*, and *YrA* became ineffective in Kazakhstan were postulated in many cultivars. The most virulent pathotypes in Kazakhstan were 7E159, 15E159, 47E143 and 111E158, which are virulent to 9 or 10 *Yr*-genes of the 16 *Yr* genes studied. The use of these pathotypes for evaluating wheat germplasm for resistance could help to improve breeding for stripe rust resistance. The number of genes and characters of gene interaction conferring resistance to stripe rust of the most important wheat genotypes were determined. The genetic studies identified genes conferring resistance to stripe rust in commercial varieties. Based on genes in resistance donors, we should be able to develop cultivars possessing effective gene or combination of genes regarding to known virulent races of the pathogen.

Keywords: germplasm, stripe rust, resistance genes, virulence, wheat

INTRODUCTION

Wheat rusts are the major factors reducing the productivity of wheat crop. The FAO data indicate that annual yield losses from diseases may reach up to 10% of the world wheat production (Zhivotkov *et al.* 1989). Stripe, or yellow, rust of wheat, caused by *Puccinia striiformis* f.sp. *tritici*, is one of the most widespread and damaging diseases of wheat. Stripe rust infection can occur anytime from one-leaf stage to plant maturity provided plants are still green (Chen 2005). Stripe rust reduces the photosynthetic capacity, increases transpiration, and reduces the accumulation of organic matter, resulting in shrivelled grain with low quality. Stripe rust of wheat has been reported in more than 60 countries and on all continents except Antarctica. In most wheat producing areas, yield losses caused by stripe rust have ranged from 10 to 70% depending on susceptibility of the cultivar, earliness of the initial infection, rate of disease development, and duration of disease (Chen 2005).

The region of Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) is one of the most important wheat areas in the world. Wheat is grown on 15 million ha, including 5 million ha of winter or facultative wheat, and 10 million ha of spring wheat. In this area, wheat stripe rust over the past several years has been the major factor that reduces wheat yield and quality and caused considerable economic damage. In the late 1990s and early 2000s, yield losses accounted for 20-40% (Morgounov *et al.* 2004). As there was practically no breeding work in the past on stripe rust, the most varieties released for commercial production are susceptible to the disease. During the epidemic of 2001-2002, most high yielding widely grown cultivars such as 'Steklovidnaya 24', 'Progress' and 'Zhetisu' had severe stripe rust. In 2001 and 2002, the area affected by stripe rust was estimated to be as high as 1.5 million ha. In 2003 in the major wheat producing regions of Azerbaijan, Kyrgyzstan and South Kazakhstan, yield losses reached 30-50%. In Uzbekistan 50% of the wheat-growing areas were sprayed with fungicides in 2003.

The stripe rust pathogen is an obligate parasite. The capability of the pathogen for mutation and rapid generation turnover accelerates the development of races. The airborne spread of inoculum can reach over distances of hundreds of kilometres. Yahyaoui (2003) suggests that the main mechanisms of pathogen evolution in Central Asia are a sequence of mutations and genetic recombination.

More than 70 genes with official or temporary symbols for resistance to stripe rust have been reported (Chen 2005). Most of these genes are dominant, race-specific and therefore, do not provide durable resistance by themselves alone. It is necessary to identify new sources of resistance to the disease. Growing resistant cultivars offers an effective approach to reduce or eliminate fungicide application and to minimize yield losses from this disease (Roelfs *et al.* 1992; Bimb and Johnson 1997). Race-specific all-stage and non-race-specific high-temperature adult-plant (HTAP) resistan-

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ces are the two major types of stripe rust resistance, and the latter has been proven durable (Chen *et al.* 1998; Chen 2005). Adult-plant resistance also involves a slow rusting mechanism (Caldwell 1968) and is frequently based on additive interaction of slow rusting genes (Parlevliet 1988). Effective durable resistance is often based on additive interactions among slow rusting genes (Singh *et al.* 2003).

The development of donors and potential breeding lines resistant to stripe rust is a very important task. This objective is especially important for Kazakhstan because of changing epidemic situations and the chance occurrence of resistant wheat cultivars. In order to effectively combat stripe rust, it is necessary to study genetics of resistance in wheat and to find donors of resistance.

MATERIALS AND METHODS

Plant materials and evaluation for stripe rust resistance

The following wheat genotypes were used in this study: the differentials from CWARTN -Central and West Asia Yellow Rust Trap Nursery, including “World differentials”, “European differentials”, “Cobbity differentials”, “North American differentials”; advanced lines of winter wheat from different International Trials Nurseries CIMMYT and ICARDA; entries from national breeding programs of Kazakhstan, Kyrgyzstan and Uzbekistan; and segregating populations and homozygous lines, selected from progenies of crosses between adapted local cultivars and effective sources of resistance.

Experimental materials were grown in two locations of Central Asia differing in soil conditions, temperature and moisture in 2004-2008. The experimental station in Almalybak, Almaty region, located at the foothill zone. It is relatively well irrigated location, the wheat plants were irrigated three times during their development at a rate 600 m^3/ha. The altitude above the sea level is 785 m. The annual rainfall ranged from 332 to 644 mm in the three years. Nitrogen fertilizer were applied at a rate of 60 kg/ha and phosphate fertilizer at a rate 30 kg/ha. Irrigated location Gvardeysky, Research Institute for Biological Safety Problems (RIBSP) is situated in Zhambyl region, Kazakhstan in the desert-steppe zone, and therefore, the climate is extremely dry with great variation. The crop growth season, especially during maturity, is characterized by drought and dry winds. The total rainfall was 200-220 mm depending on the year. The plants were irrigated 3-4 times at a rate 650 m^3/ha. The soils in all testing locations are light, ranging from sandy loess to brown semi-desert soils to light silt loams. Each experiment consisted of three randomized replications.

Field trials were conducted by sowing seed of the entries in each autumn (20-25 September) of 2004-2007. The plots were inoculated in the spring at the tillering stage with a mixture of identified isolates representing the most prevailing races of the pathogen from Central Asia.

Seedling tests

Seedlings of winter wheat cultivars and advanced breeding lines from Central Asia, Russia, CIMMYT and ICARDA were tested under the controlled greenhouse conditions at Pullman, WA, USA for resistance to five races of *P. striiformis* f.sp. *tritici* that are currently prevalent or were prevalent in the past in the USA: (PST-100, PST-45, PST-43, PST-37, and PST-17). The seedling reactions of plants were evaluated at the two-leaf stage using methods described by Chen and Line (1992). For each plant, infection type (IT) based on 0-9 scale was recorded 20 days after inoculation.

The IT data of seedling reactions were analyzed using the method described by Konovalova *et al.* (1977). The decimal system of numbering was used for the designation of races. The base of this system is two types of sign: resistant type (R) signed as “0” and susceptible (S) as “1”. The first number was according to the international number, then followed by the number in the European set indicated by letter “E” between the two numbers. Virulences of the pathotypes were also studied using 16 *Yr* isogenic lines of AVS. Testing for postulating *Yr* genes in 20 winter wheat cultivars was conducted in the greenhouse using five pathotypes. Reactions of the cultivars to the pathotypes were compared with those of wheat genotypes with known *Yr*-genes (Gassner and Straib 1932).

Field response to stripe rust

Disease severity and adult plant response was recorded following McIntosh *et al.* 1995. Five infection types described as the following: 0 – immune (no uredia or other symptoms of disease infection); R – resistant (uredia minute, supported by distinct necrotic areas); MR – moderately resistant (uredia small to medium, in green islands surrounded by chlorotic tissue); MS – moderately susceptible (uredia medium in size, no necrotic but chlorotic areas may be present); and S – susceptible (uredia large, no necrosis but chlorosis may be evident). Cultivar ‘Morocco’ and local cultivar ‘Steklovidnaya 24’ was used as susceptible checks, for multiplication of the pathogen spores in the greenhouse and as spreaders in the field tests.

Genetic analysis based on the reaction data of F_1 and F_2 plants and F_3 families to infection was used for identifying the genes for resistance. The adult plant resistances were tested in the field by inoculating F_3 double rows (100 cm) with a mixture of virulent races using spreader rows. Observed and expected data were analyzed using the Chi-squared test (Serebrovsky 1970).

The selected wheat cultivars were crossed with susceptible cultivars to determine the number of resistance genes and were crossed with each other test cultivars to determine allelism of genes or their identity. The ratio of resistant versus susceptible plants in segregating populations was used to determine the mode of inheritance and the number of resistance genes.

Evaluation for agronomic traits was done each year in all selected materials by the most important traits of productivity (height of plant, tillers per plant, length of spike, number of kernels per spike, weight of kernels per spike, weight of kernel per plant, and weight 1000 kernels), heading date, lodging resistance, and quality of grain. Statistic analysis was done based on ANOVA.

RESULTS AND DISCUSSION

Seedling tests of wheat genotypes for resistance to US races of *P. striiformis* f.sp. *tritici*

Seedling tests for resistance to stripe rust were done for 15 wheat genotypes. Plants were grown and tested under controlled greenhouse conditions at Washington State University, USA. The reactions of the wheat genotypes to five races of *P. striiformis* f.sp. *tritici* are shown in **Table 1**. Resistance to race PST-100 was detected in cultivars Krasnovodopadskaya 25 and Ulugbek 600 (IT 2). Race PST-100 was virulent on cultivars ‘Almaly’, ‘Arap’, ‘Taza’, ‘Naz’, ‘Sapaly’, ‘Steklovidnaya 24’ and other commercial cultivars (IT 8). Resistance to race PST-45 was observed on cultivars ‘Taza’, ‘Krasnovodopadskaya 25’, ‘Ulugbek 600’ and ‘Sharora’ (IT 2). This race was virulent on genotypes ‘Almaly’, ‘Arap’, ‘Naz’, ‘Sapaly’, ‘Steklovidnaya 24’, ‘Sanzar 8’, ‘Adyr’, ‘MK-3796’, ‘BWKLDN’, ‘Knyazhna’ and ‘Umanka’ (IT 8). The similar reactions were observed when the genotypes were tested with races PST-43 and PST-37. Race PST-17 was virulent on most of tested genotypes except for ‘Ulugbek 600’ and ‘Sharora’, on which resistant reactions were detected (IT 2). Thus, the more harmful North American races of *P. striiformis* f.sp. *tritici* for wheat germplasm from Central Asia are represented by PST-17 and PST-100. Race PST-100 is virulent on North American differentials: ‘Lemhi’ (*Yr21*), ‘Heines VII’ (*Yr2*, *Yr25*, and *YrHVII*), ‘Produra’ (*YrPr1* and *Pr2*), ‘Yamhill’ (*Yr2*, *Yr4a*, *YrYam*), ‘Stephens’ (*Yr3a*, *YrS*, *YrSte*), ‘Lee’ (*Yr7*, *Yr22*, *Yr23*), ‘Fielder’ (*Yr6*, *Yr20*), ‘Express’ (*YrExp1*, *YrExp2*), Yr8/6*AVS (*Yr8*), Yr9/6*AVS (*Yr9*), ‘Clement’ (*Yr9*, *Yr25*, *YrCle*), and ‘Compair’ (*Yr8*, *Yr19*) (Chen 2005). Based on seedling tests, cultivars ‘Taza’, ‘Krasnovodopadskaya 25’, and ‘Ulugbek 600’ have all-stage resistance.

Races of *P. striiformis* f.sp. *tritici* in Kazakhstan resistance of wheat germplasm to Kazakhstan races

A total of 22 pathotypes of *P. striiformis* f.sp. *tritici* were identified from the stripe rust samples collected in 2006-2007 in Kazakhstan. The virulence patterns of the pathotypes ranged from avirulent on all differentials (0E0) to highly virulent (15E191, 71E175 and 111E158). Among the differentials, Spaldings Prolific had immune to all isolates, indicating that gene *YrSP* is highly effective against the Kazakhstan stripe rust population. The study of virulent pathotypes using isogenic lines of AVS indicated that the most virulent pathotypes were 7E159, 15E159, 47E143, 111E158, which are virulent to 9 or 10 *Yr*-genes out of 16 *Yr* genes studied (**Table 2**). Nine pathotypes, 7E159, 15E159 (a-8/1,5), 47E143, 7E223, 7E157, 111E158, 7E21, 4E144, and 6E145, were highly virulent. (Use a table to show virulent and avirulent reactions of all 20 pathotypes on differentials).

Five most virulent pathotypes were used to test wheat germplasms (**Table 3**). The high level of resistance to all 5 pathotypes was observed on L-19, L-572, L-796 (Kazakhstan), 'Aichureck' (Kyrgyzstan), and 'Ulugbek 600' (Uzbekistan).

The similarity of reaction to the pathogen allows assuming the presence of *YrSD*, *Yr2*, *Yr7* and *Yr24* or combination of these genes in 'Almaly' and 'Taza' (Kazakhstan). Resistance genes *Yr1*, *Yr6*, *Yr7*, *Yr8*, *Yr11*, *Yr12*, and *YrA* became ineffective in Kazakhstan were postulated in many cultivars. It is known that *Yr11* and *Yr12* are adult-plant resistance genes. But field responses to stripe rust among the differentials in Central and West Asia Yellow Rust Trap Nursery confirm their susceptibility in adult plant stage (CWARTN, 2005-2006).

Some of the wheat entries ('Zhalyn', L-102, L-809, 'Egemen', and 'Tungush' from Kazakhstan, and 'Umanka' from Russia) were resistant to the field collection but were susceptible to individual pathotypes. Susceptible reactions at the seedling stage were observed on commercial cultivars 'Steklovidnaya 24' (Kazakhstan), 'Alex', 'Ozoda' (Tajikistan) and 'Dostlik '(Uzbekistan).

Field response to stripe rust of wheat cultivars and differentials

The wheat entries from Central and West Asia Yellow Rust Trap Nursery (CWARTN) for *P. striiformis* f.sp. *tritici* in 2005-2006 were screened in field tests. This nursery was planted in the major locations where stripe rust occurs every

Table 1 Infection types of wheat genotypes grown in Central Asia produced by five North American races of *Puccinia striiformis* f.sp. *tritici.*

Wheat genotype	**Origin**	**Infection type of wheat genotypes produced by races/virulence formula**[*]				
		PST-100/ 1,3, 8-12, 16-20	**PST-45/ 1,3,12,13,15**	**PST-43/ 1,3,4,5,12,14**	**PST-37/ 1,3,6,8,9,10,11,12**	**PST-17/ 1,2,3,9,11**
Almaly	Kazakhstan	8	8	8	8	8
Arap	Kazakhstan	8	8	8	8	8
Taza	Kazakhstan	8	2	2	2	8
Naz	Kazakhstan	8	8	8	8	8
Sapaly	Kazakhstan	8	8	8	8	8
Steklovidnaya-24	Kazakhstan	8	8	8	8	8
Krasnovodopadskaya-25	Kazakhstan	2	2	2	2	8
Sanzar-8	Uzbekistan	8	8	8	8	8
Ulugbek-600 (Yr9)	Uzbekistan	2	2	2	2	2
Sharora	Tajikistan	8	2	2	2	2
Adyr	Kyrgyzstan	8	8	8	8	8
MK-3796 (Bez 2B/CGN//VR2)	CIMMYT	8	8	8	8	8
BWKLDN-95-(KASYON/GENA-RO.81//TEVEE-1 /ICW92-02.81. 1AP-2AP.OL-3AP-1AP-OAP	ICARDA	8	8	8	8	8
Umanka	Russia	8	8	8	8	8

[*] Based on Chen (2005): 1 Lemhi, 2 Chinese 166, 3 Heines VII, 4 Moro, 5 Paha, 6 Druchamp, 7 the *Yr5* line, 8 Produra, 9 Yamhil, 10 Stephens, 11 Lee, 12 Fielder, 13 Tyee, 14 Tres, 15 Hyak, 16 Express, 17 AVS/6**Yr8,* 18AVS/6**Yr9,* 19 Clement and 20 Compare.

Table 2 Virulences of *Puccinia striiformis* pathotypes detected in Kazakhstan in 2006-2007.

Pathotype	**Virulence formula (avirulent/virulent)**	**Parts of *Yr* genes, %**	
		R	**S**
0E0	Yr1, 5, 6, 7, 8, 10, 11, 12, 15, 17, 18, 24, 26, Sp, Sk / 9	87.50	12.50
7E21	Yr5, 9, 10, 15, 17, 24, 26, Sp / 1, 6, 7, 8, 11, 12, 18, Sk	50.00	50.00
4E144	Yr5, 9, 10, 15, 17, 24, 26, Sp / 1, 6, 7, 8, 11, 12, 18, Sk	50.00	50.00
5E136	Yr5, 6, 9, 10, 11, 12, 15, 17, 24, 26, Sp, Sk / 1, 7, 8, 18	75.00	25.00
6E145	Yr5, 9, 10, 15, 24, 26, Sp, Sk / 1, 6, 7, 8, 11, 12, 17, 18	50.00	50.00
7E3	Yr5, 6, 7, 8, 9, 10, 11, 12, 15, 17, 18, 24, 26, Sp, Sk / 1	93.75	6.25
7E63	Yr5, 7, 8, 9, 10, 12, 15, 17, 24, Sp, Sk / 1, 6, 11, 18, 26	68.75	31.25
7E148	Yr5, 6, 7, 9, 10, 11, 15, 17, 18, 24, 26, Sp, Sk / 1, 8, 12	81.25	18.75
7E151	Yr5, 8, 9, 10, 12, 15, 18, 24, 26, Sp, Sk / 1, 6, 7, 11, 17	68.75	31.25
7E159	Yr5, 10,15, 24, 26, Sp / 1, 6, 7, 8, 9, 11, 12, 17, 18, Sk	37.50	62.50
7E190	Yr5, 7, 9, 10, 12, 15, 17, 18, 24, 26, Sp, Sk / 1, 6, 8, 11	75.00	25.00
15E13	Yr5, 8, 9, 10, 11, 12, 15, 17, 18, 24, 26, Sp, Sk / 1, 6, 7	81.25	18.75
15E133	Yr5, 8, 9, 10, 15, 17, 24, 26, Sp, Sk / 1, 6, 7, 11, 12, 18	62.50	37.50
15E159 (a-8/1,5)	Yr5, 9, 10, 15, 24, 26, Sp / 1, 6, 7, 8, 11, 12, 17, 18, Sk	43.75	56.25
15E191	Yr5, 9, 10, 15, 18, 24, Sp, Sk / 1, 6, 7, 8, 11, 12, 17, 26	50.00	50.00
31E158	Yr5, 7, 10, 12, 15, 24, Sp, Sk / 1, 6, 8, 9, 11, 17, 18, 26	50.00	50.00
47E143	Yr5, 9, 10, 15, 24, 26, Sp / 1, 6, 7, 8, 11, 12, 17, 18, Sk	43.75	56.25
71E175	Yr5, 6, 7, 8, 9, 10, 12, 15, 17, 24, Sp / 1, 11, 18, 26, Sk	68.75	31.25
79E143	Yr5, 7, 9, 10, 12, 15, 24, 26, Sp, Sk / 1, 6, 8, 11, 17, 18	62.50	37.50
111E158	Yr5, 9, 10, 15, 24, 26, Sp / 1, 6, 7, 8, 11, 12, 17, 18, Sk	43.75	56.25
7E223	Yr 5, 9, 10, 15, 24, 26, Sp / 1, 6, 7, 8, 11, 12, 17, 18, Sk	43.75	56.25
7E157	Yr 5, 9, 10, 15, 17, 24, Sp / 1, 6, 7, 8, 11, 12, 18, 26, Sk	43.75	56.25

Table 3 Infection types on wheat cultivars growing in Central Asia and resistant genotypes to Kazakhstan races of Yellow Rust.

Entry, Origin*	**Wheat Infection type produced by races of Yellow Rust from Kazakhstan**					
	Field collection	**47E143**	**15E159**	**7E223**	**7E159**	**7E157**
Almaly, KZ	3	3	8	4	8	2
Zhalyn, KZ	2	2	2	2	2	8
Zhetisu, KZ	7	8	8	8	8	6
Egemen, KZ	2	2	8	8	8	6
Steklovidnaya 24, KZ	8	8	8	8	8	8
Taza, KZ	2	2	0	1	5	1
Tungysh, KZ	2	6	2	8	8	2
L-19, KZ	2	2	0	2	2	2
L-99, KZ	4	2	1	2	0	2
L-102, KZ	5	2	5	2	8	4
L -572, KZ	0	1	0	2	2	0
L-796, KZ	1	1	0	0	0	0
L -809, KZ	1	1	0	1	0	8
Ekinchi, AZ	8	2	2	6	2	2
Aichureck, KG	2	2	1	2	1	0
Alex, TJ	6	8	8	8	8	8
Ozoda, TJ	6	8	8	8	8	8
Dostlik, UZ	8	6	8	8	8	6
Ulugbek 600, UZ	2	2	0	2	2	2
Umanka, RU	2	8	6	8	8	4
Chinese 166 (*Yr1*)	8	8	8	8	8	8
Lee (*Yr7*)	8	8	8	8	8	8
Heines Kolben (*Yr6*)	8	8	8	8	8	8
Vilmorin 23 (*Yr3a*, *YrV23*)	6	6	8	2	2	0
Moro (*Yr10*, *YrMor*)	2	2	3	2	2	0
Strubes Dickkopf (*YrSD*, *Yr2*)	2	2	8	4	4	1
Suwon 92xOmar (*YrSU*, *YrPa1*)	2	1	3	2	2	1
Hybrid 46 (*Yr4b*, *YrH46*)	8	8	8	6	6	8
Reichersberg 42 *(Yr7*+)	8	6	8	8	8	1
Heines Peko *(Yr6*, *YrHP*)	6	8	8	6	6	6
Nord Desprez (*Yr3a*, *YrND*)	8	8	8	8	8	8
Compair (*Yr8*, *Yr19*)	8	8	8	8	8	8
Carstens V (*YrCV*)	1	1	1	2	2	2
Spaldings Prolific (*YrSp*, *Yr6*)	2	2	2	6	2	2
Heines VII (*Yr2*, *Yr11*, *Yr25*)	8	8	8	8	6	8
Yr1 Avocet S	8	8	8	8	8	8
Yr5 Avocet S	1	1	1	0	0	1
Yr6 Avocet S	8	8	8	8	8	6
Yr7 Avocet S	8	8	8	8	8	6
Yr8 Avocet S	8	8	8	8	8	6
Yr9 Avocet S	1	2	1	0	0	0
Yr10 Avocet S	2	2	3	0	0	0
Yr11 Avocet S	8	8	8	8	8	6
Yr12 Avocet S	8	8	8	6	6	6
Yr15 Avocet S	1	1	1	0	0	0
Yr17 Avocet S	1	6	6	8	8	0
Yr18 Avocet S	8	6	8	8	8	6
Yr24 Avocet S	2	3	6	2	2	2
Yr26 Avocet S	8	8	6	2	2	8
YrSp Avocet S	0	0	6	2	1	0
YrSk Avocet S	2	8	8	6	6	8
Jupateco R, *Yr18*	8	6	6	8	8	8
Avocet R (*YrA*)	8	8	8	8	8	6

*KZ – Kazakhstan, KG – Kyrgyzstan, AZ – Azerbaijan, TJ – Tadjikistan, UZ – Uzbekostan, RU – Russia

year. Under the natural infection conditions of Almaty region (Almalybak) and Zhambyl region (Gvardeysky), reactions of differentials and isogenic lines were similar (**Table 4**). The most effective resistant genotypes were those with resistance genes *Yr2*+, *Yr4*+, *Yr5*, *Yr10* or *Yr15*, which showed R-MR infection types. The entries with *Yr1* was susceptible, 60S-80S on 'Chinese 166' and 30S -80S on the isogenic line *Yr1*/6*Avocet S. 'Heines VII' had a high level of resistance, but cultivar 'Sonalika', that have *Yr2*, was not resistant. Similar reaction patterns were observed on carriers of *Yr3*: 'Vilmorin 23' (*Yr3a* and *YrV23*) was resistant, but 'Nord Desprez' (*Yr3a*, *YrND*) was susceptible. 'Hybrid 46' (*Yr4b* and *YrH46*) was moderately resistant (10MR) in 2005, but was highly resistant in previous years.

The high level of resistance (0) in many locations was consistently observed for *Yr5* – in the original source of this gene (*Triticum spelta album*) and in the isogenic line *Yr5*/6*Avocet S. Cultivar 'Heines Peko' (*Yr6* and *YrHP*) had variable reactions from MS-S (10S-30MS-90S) to high resistant (R), while the isogenic line *Yr6*/6*Avocet S was susceptible (60S-80S). 'Cranbrook' (*Yr7*) and 'Lee' (*Yr7*, *Yr22*, and *Yr23*) had susceptible reactions (20S-30S). However, 'Corella' (*Yr6*+*Yr7*) and 'Reichenberg 42' (*Yr7*) were resistant. The presence of genes *Yr8* and *Yr19* in 'Compair' had a MR reaction, but under severe stripe rust epidemic it was susceptible (20S-40S), especially in Otar. Isogenic line *Yr8*/6*Avocet S also showed high susceptibility (40-90S). The source of *Yr9*, 'Federation 4/Kavkaz', 'Clement' and the *Yr9*/6*Avocet isogenic line had moderately susceptible to susceptible reactions.

A consistent resistant reaction was observed on the *Yr10*/6*Avocet S and *Yr15*/6* Avocet S isogenic lines. The

Table 4 Field responses of the differentials in Central and West Asia Yellow Rust Trap Nursery (CWARTN, 2005-2006) to stripe rust.

Cultivar, entry (gene)	Almalybak, Almaty region	Otar, Zhambyl region
Chinese 166 (*Yr1*)	80S	70S
Vilmorin 23 (*Yr3a*, *YrV23*)	0	5R
Moro (*Yr10*, *YrMor*)	5R	5R
Clement (*Yr9*, *Yr25*, *YrCle*)	30S	30MS
Hybrid 46 (*Yr4b*, *YrH46*)	10MR	5R
Heines Peko (Yr6, YrHP)	5R	10S
Nord Desperz (*Yr3a*, *YrND*)	20MS	20S
Heines VII (*Yr2*, *YrHVII*, *Yr25*)	10MR	10R
Sonalika (*Yr2*)	50S	30S
Cranbrook (*Yr7*)	20S	30S
Lee (*Yr7*, *Yr22*, *Yr23*)	30S	30S
Corella (*Yr6+Yr7*)	0	5R
Reichenberg 42 (*Yr7*)	0	0
Compair (*Yr8*, *Yr19*)	5R	40S
Federation 4/Kavkaz (Yr9)	20MS	30MS
Yr1/6* Avocet S	60S	80S
Yr5/6* Avocet S	5R	5R
Yr6/6* Avocet S	40S	80S
Yr7/6* Avocet S	80S	80S
Yr8/6* Avocet S	30S	75S
Yr9/6* Avocet S	20S	20S
Yr10/6* Avocet S	0	5R
Yr11/6* Avocet S	25S	20S
Yr12/6* Avocet S	90S	60S
Yr15/6* Avocet S	5R	5R
Yr17/6* Avocet S	20MS	10MS
Yr18/6* Avocet S	40MS	60S
Avocet S	80S	60S
Oxley (*Yr6+APR*)	0	5R
Cook (*APR*)	0	5R
Anza (*Yr18+A*)	20MS	20S
Morocco (susceptible check)	100S	80S

Table 5 Field response of the USA differentials and commercial wheat cultivars from USA and Kazakhstan to Yellow and Leaf rusts (Almalybak, Almaty region, Kazakhstan, 2007)

Cultivar, entry (gene)	Heading date	Field response	
		Yellow rust	Leaf rust
Chinese 166 9(*Yr1)*	18.05.07	80S	10MS
Heinese VII (*Yr2*, *YrHVII*)	17.05.07	15MS	5MS
Moro (*Yr10*, *YrMor*)	25.05.07	0	50S
Paha (*YrPa1*, *YrPa2*, *YrPa3*)	23.05.07	10MS	30MS
Druchamp (*Yr3a*, *YrD*, *YrDru*)	24.05.07	0	10MS
Riebesel 47/51 (*Yr9+*)	27.05.07	5R	5R
Produra (*YrPr1*, *YrPr2*)	22.05.07	15MS	5MS
Yamhi11 (*Yr2*, *Yr4a*, *YrYam*)	14.05.07	5R	0
Stephens (*Yr3a*, *YrS*, *YrSte*)	24.05.07	0	5R
Lee (*Yr7*, *Yr22*, *Yr23*)	23.05.07	50S	5R
Fielder (*Yr6*, *YrFie*)	15.05.07	0	10MS
Tyee (*YrTye*)	14.05.07	5R	10MS
Tres (*YrTtr1*, *YrTre2*)	24.05.07	0	10MS
Hyak (*Yr17+*)	24.05.07	10MS	10MR
Express (*YrExp1*, *YrExp2*)	23.05.07	5R	5R
Yr8/ 6* Avocet S (*Yr8*)	19.05.07	15MS	5R
Yr9/ 6* Avocet S (*Yr9*)	16.05.07	50S	80S
Clement (*Yr9*, *YrCle*)	21.05.07	30S	20MS
Compair (*Yr8*, *Yr19*)	25.05.07	5R	0
Brundage 96 (adult plant resistance)	25.05.07	0	5MR
Finch (adult plant resistance)	29.05.07	0	0
Madsen (adult plant resistance)	24.05.07	0	0
Barbee (seedling resistance)	27.05.07	0	10MS
Bruehl (seedling resistance)	28.05.07	0	0
Daws (adult plant resistance)	23.05.07	0	5MR
Morocco (susceptible check)	17.05.07	100S	30S

Yr18/6*Avocet S isogenic line was more susceptible in comparison to cultivar 'Anza' (*YrA* and *Yr18*). Cultivar Cook with adult-plant resistance was resistant (IT 0). So, virulence to resistance genes *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, and *Yr9* have occurred in these regions. The predominant pathotypes in the population of *P. striiformis* f.sp. *tritici* were the races virulent to these genes.

Among the USA differentials, cultivars that were resistant to both stripe rust and leaf rust included 'Riebesel 47/51', 'Yamhill' and 'Stephens' (**Table 5**). The most resistant genotypes to stripe rust were 'Moro', 'Druchamp', 'Produra', 'Fielder', 'Tyee', 'Tres', 'Express', and 'Compair'. It was found that level of resistance of 'Heines VII' and 'Lee' was decrease in comparison with observation of 2006. All of wheat commercial varieties from USA ('Brundage 96', 'Finch Madsen', 'Barbee', 'Bruehl' and 'Daws') showed high resistance to both rust diseases and were included in the crosses to the national breeding programs for improvement of stripe rust resistance.

Inheritance of resistance to stripe rust in wheat genotypes

The study of the inheritance of resistance is very important for improving stripe rust resistance. Genetic analysis was done to determine inheritance of yellow rust resistance of important winter wheat varieties grown in the region. Resistant cultivars were crossed with susceptible check to determine inheritance of resistance. The cultivars with susceptible reaction 'Steklovidnaya-24' (S) and 'Morocco' (S) were used the susceptible parent and check, respectively.

Adult plants of parents, F_2 and families F_3 generations were tested under the field conditions for genetic analysis. Studies involved crossing resistant and susceptible cultivars and crossing various resistant parents with several sources of known genes for resistance for allelism tests (**Table 6**). Segregating ratios of resistant to susceptible F_2 plant and F_3 lines were used to estimate the number of genes segregating for resistance in the cross.

In the cross 'Almaly' x 'Steklovidnaya-24', the F_2 segregation was 15:1 ($P = 0.98$) for resistant and susceptible plants. The result indicated that resistance in 'Almaly' is controlled by two dominant genes. Similarly, the F_2 segregation of the cross 'Almaly' x 'Morocco' also fit to the 15:1 ratio, supporting the model of two dominant genes. Segregation in the F_3 lines from 'Almaly' x 'Steklovidnaya-24' provided the genotypic classification of individual F_2 plants based on response of progeny.

Allelism tests involved crosses between resistant parents and near isogenic lines and sources with known genes for resistance: *Yr2*+ ('Heines VII'), *Yr4*+ ('Hybrid 46'), *Yr10*/6*Avocet S, *Yr15*/6*Avocet S, *Yr18*/6*Avocet S, *Yr24*/6*Avocet S, *Yr26*/6*Avocet S (**Table 6**).

Segregation ratios in hybrids F_2 'Almaly' x *Yr2*+ were 249:7 that suggests the genetic control by two complimentary and two independent genes. This indicates that 'Almaly' does not have *Yr2* or other genes in 'Heines VII'.

In crosses 'Almaly' x *Yr18*/6*Avocet S and 'Almaly' x Avocet S, F_2 segregation ratios were 3:1 that indicate the genetic control by a dominant gene. In F_2 'Almaly' x *Yr10*/6*Avocet s and Adir x *Yr10*/6*Avocet s, no segregation was observed, suggesting that 'Almaly' and 'Adir' have *Yr10* or genes tightly linked to *Yr10*.

In order to select and develop valuable germplasms, breeding materials from different CIMMYT nurseries and local breeding programs were evaluated (**Table 7**). Based on data of multi-location trials, 24 entries with stable resistance to stripe rust including local germplasm ('Almaly', 'Arap', 'Taza', 'Lori-292', 'Sultan', 'Kupava', 'Khyazhna', 'Umanka' and 'Tilek') as well as entries from ICARDA (BWKLDN 95, BWKLDN 9, BWKLDN 33) and CIMMYT nurseries (FAWOON – MK-3744, MK-3745, MK-3796, MK-3797) were selected. These genotypes were intensively involved in crosses in national breeding programs on wheat improvement. Cultivars 'Naz', 'Ulugbek 600' and 'Anza' demonstrated moderate resistance and rated as having adequate resistance to the naturally occurred races of the pathogen.

Table 6 Segregation of adult plants of different wheat crosses to natural population of *Puccinia striiformis* fsp. *tritici*.

Crosses	**F_2 ratio R:S**		**χ2**	***P* value**	**Number of genes conferring resistance**	**F_3 ratio**
	Observed	**Expected**				
Almaly x Steklovidnaya 24	89:6	15:1	0.001	0.98	2 dominant duplicate genes	7R:8seg:1S*
Almaly x Morocco	128:6	15:1	0.72	0.40	2 dominant duplicate genes	7R:8seg:1S*
F_2 Almaly x *Yr2*+(Heines VII)	188:2	249:7	2.01	0.10-0.20	4 genes (2 complementary, 2 independent)	–
F_2Almaly x *Yr10*/6*Avocet S	150:0	–	–	–	Almaly has *Yr10* or a tightly linked gene to *Yr10*	–
F_2 Almaly x*Yr15*/6*Avocet S	185:13	15:1	0.03	0.95-0.90	2 dominant duplicate genes	7R:8seg:1S*
F_2 Almaly x *Yr18*/6*Avocet S	143:49	3:1	0.09	0.25-0.50	1 dominant gene	1R:2seg:1S*
F_2 Almaly x Avocet (S)	130:45	3:1	0.15	0.75-0.50	1 dominant gene	1R:2seg:1S*
F_2Adir x *Yr2*+(Heines VII)	223:16	15:1	0.09	0.80-0.75	2 dominant duplicate genes	7R:8seg:1S*
F_2 Adir x *Yr10*/6*Avocet S	144:0	–	–	–	Adir has *Yr10* or a gene tightly linked to *Yr10*	–
F_2 Adir x Avocet (S)	90:31	3:1	0.02	0.95-0.90	1 dominant gene	1R:2seg:1S*

[a] Reaction of parents given in **Table 3**

* = significant at 5% level of probability; - Not tested

Table 7 Field responses of wheat cultivars grown in Kazakhstan and Central Asia to stripe rust.

Cultivar	**Origin**	**Pedigree***	**Disease severity**
Almaly	Kazakhstan	R6862/50431/BEZ.1	0
Arap	Kazakhstan	R6997/Bez.1	5R
Taza	Kazakhstan	V170/KAVKAZ	5R
Krasnovodopadskaya 25	Kazakhstan	KRASNOVODOPADSKAYA49/BIMA/BEZ.1	40S
Zhetisu	Kazakhstan	ALMATINSKAYA P-K/KHARKOVSKAYA38	15MS
Stekljvidnaya24	Kazakhstan	(BOGARNAYA56/teplokluchevskaya-2)/rostovchanka	50S
Karlygash	Kazakhstan	(KYRGYZSKAYA-3/BEZ.1)/KAVKAZ	40MS
Yuzhnaya 12	Kazakhstan	KRASNOVODOPADSKAYA 25/(BEZ.1/ERITHROSPERMUM-7020)	30MS-MR
Sapaly	Kazakhstan	(BOGARNAYA56/ALBIDUM 114)/KRUPNOKOLOSAYA	30MS
Naz	Kazakhstan	(276402/BOGARNAYA56)/DNEPROVSKAYA521/DAKOTA	20MR
Sultan	Kazakhstan	K17368/ALBATROS ODESSKYI/ZARYA	5R
Kupava	Russia	KH 90AC21-10/KH3161A29-2901	5R
Knyazhna	Russia	AD-206/RUBIN//KH17t3	0
Umanka	Russia	KH 686H815/KH 1937H638	0
Bezostaya1	Russia	BEZ.4/(LUT.17/SKOROCPELKA2)	30MS
Skifyanka	Russia	Individual selection from SPARTANKA	50S
Bermet	Kyrgyzstan	(LUTESC.1454-11/ERITR.1022)/(LUT.1000/202-2)	10MS
Lori 292	Armenia	-	0
Nairi 149	Armenia	-	20MS
Sharora	Tajikistan	Ind. selection from VIR K-095667	40S
Ulugbek 600	Uzbekistan	-	20MR
Sanzar8	Uzbekistan	RED RIVER-68/RANYAYA-12	60S
Yanbash	Uzbekistan	SANZAR-85/K-17146	80S
BWKLDN #95	ICARDA	KASYON/GENARO.81//TEVEE-1 JCW92-0281.1AP-2AP-01-3AP-1AP-OAP	5R
BWKLDN#9	ICARDA	TEVEE-3/1HUHA-20 JCW92-0023-1ap-5ap-3ap-1ap-oap	0
BWKLDN#33	ICARDA	NS732/HER/4/2CH-542C/SKOROSPELKA//NEUZUCHT /3/NAC76/JCW92-0840-OAP-1AP-04-OBR-2AP-2AP-oap	5R
FAWWON MK-3732	CIMMYT	LOW26//LFN/SDY/E884-24/3/SERI/4/SERI	15S
FAWWON MK-3745	CIMMYT	ARG/R16//BEZ*2/3/AGRI/KSK/4/1D 13.1/MLT	5R
Anza**	USA	Lerma Rojo // Norin 10 /Brevor /4/ Yaktana 54 // Norin 10 /Brevor /3/3* Andes	20MR
Morocco (check)	Morocco	-	100S

*Pedigree – selection pathway, in some cultivars when their pedigree unknown; disease severity (percentage of rust infection on the plant); Plant response to disease (infection type) was recorded following McIntosh *et al.* (1995). Field response is mean of two replicates

** Pedigree by www//ars-grin.gov/cgi-bin/npgs/html/grin-acid.pl?Andres+40544+ped

CONCLUSIONS

The study of winter wheat germplasm from different nurseries allowed to evaluate the value of the lines for genetic and breeding programs directed on improvement of wheat stripe rust resistance in Kazakhstan. From the results obtained in our studies, it can be concluded that more virulent North American races of *P. striiformis*. f. sp. *tritici* for wheat germplasm from Central Asia were represented by PST-17 and PST-100. Cultivars 'Taza', 'Krasnovodopadskaya 25', and 'Ulugbek 600' have seedling resistance. The most effective resistant sources against stripe rust in this region are the genotypes possessing genes *Yr2+*, *Yr4+*, *Yr5*, *Yr10*, and *Yr15*. Among the USA differentials, genotypes that were resistant to stripe rust included 'Paha', 'Druchamp', 'Riebesel 47/51', 'Lee', 'Tres', 'Express', 'Clement', 'Heines VII' and 'Hybrid 46'. Resistance genes *Yr1*, *Yr6*, *Yr7*, *Yr8*, *Yr11*, *Yr12*, and *YrA* became ineffective in Kazakhstan were postulated in many cultivars. The study of virulent pathotypes using isogenic lines of AVS indicated that the most virulent pathotypes were 7E159, 15E159, 47E143 and 111E158, which are virulent to 9 or 10 *Yr*-genes out of 16 *Yr* genes studied. The use of these pathotypes for evaluating wheat germplasm for resistance could help to improve breeding for stripe rust resistance. The valuable sources of stripe rust resistance are L-19, L-572, L-796, 'Almaly', 'Taza', 'Zhalyn' (Kazakhstan), 'Aichurec '(Kyrgyzstan), 'Ulugbek 600' (Uzbekistan), and 'Ekinchi' (Azerbaijan).

The number of genes and character of gene interaction conferring resistance to stripe rust were determined for the most important wheat cultivars. Resistance of Almaly cultivar is controlled by at least by interactions of four genes. These genes can include *Yr2+*, *Yr10*, and *Yr18*, which are effective in Kazakhstan. It should be noted that this cultivar demonstrated resistance not only to stripe rust, but also to *P. triticina*, *Septoria nodorum* and *Pyrenophora tritici-repentis*. Thus, the studies of genetics of disease in local wheat cultivars allow knowing the genetic factors conferring resistance to *P. striiformis* f.sp. *tritici* in commercial varieties. Based on genetic studies of the resistant stocks, we should be able to develop cultivars possessing individual genes or combinations of genes conferring effective resistance against known virulent races of the stripe rust pathogen. Based on the data of multi-location trials, 24 entries with stable resistance to stripe rust including local germplasm as well as entries from ICARDA and CIMMYT nurseries were selected. These genotypes were intensively involved in crosses in national breeding programs for wheat improvement.

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