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Virulence of Wheat Leaf, Stem and Yellow Rust Pathotypes in Kazakhstan

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ABSTRACT

In Kazakhstan leaf rust (*Puccinia recondita f.sp. tritici*) is a common disease of wheat. Pathotypes virulent to some previously effective isogenic leaf rust (*Lr*) lines were isolated from the leaf rust population. The pathotypes (TKT/H, TKP/H, TTP/H, TRP/H, TTP/H) isolated from the commercial wheat and triticale varieties are highly virulent. The stem rust (*P. graminis f.sp. tritici*) population of 2006-2007 includes highly virulent pathotypes (TFK/R, TKT/C, TPS/H, TKH/RS, TDT/HS, TTH/KQ) that are hazardous to commercial wheat varieties in the republic. Some pathotypes affect all tested isogenic stem rust (*Sr*) lines and their nomenclatorial indices are similar to that of the pathotype Ug99 from Uganda, Africa (TTKS). In the south-eastern part of Kazakhstan winter wheat is often affected by yellow rust (*P. striiformis f.sp. tritici*). Recently the population of this fungus included the highly virulent pathotypes 7E159, 15E159, 47E143, 111E158 that affected 9-10 yellow rust (*Yr*) genes of resistance out of 16. Use of these leaf, stem and yellow rust pathotypes in assessment of new wheat variety resistance determines success of breeding for rust disease resistance in the region.

Keywords: disease, isogenic line, *Puccinia*, resistance gene, *Triticum aestivum*, variety

INTRODUCTION

The aim of this work was to study the pathotype structure and virulence of the local wheat leaf, stem and yellow rust population. The pathotypes of the diseases from different wheat growing regions of Kazakhstan were differentiated with use of leaf rust (*Lr*), stem rust (*Sr*) and yellow rust (*Yr*) isogenic lines.

Wheat is a major cereal in Kazakhstan and depending on the market conditions is grown on 12-14 million hectares, over 90% of the acreage being under spring wheat. Mainly the local and Russian spring and winter wheat varieties are sown under conditions of non-irrigated farming.

Recently wheat crops in Kazakhstan are often observed to be affected with rust species: leaf rust – *P. recondita f.sp. tritici*, stem rust – *P. graminis f.sp. tritici*, yellow rust – *P. striiformis f.sp. tritici*. For instance, leaf rust annually occurs in the northern region and depending on weather conditions of the year and other factors spreads from 400-500 thousands up to 4-5 million ha. The yield losses caused by the disease are 20-25% and more. In damp years this rust species develops on spring wheat in the east and west as well as on winter wheat in the south-east of the republic. In years 2006-2007 stem rust was recorded on spring wheat in the north of the republic and in some fields the rate of the disease progress was 20% through 80-100%. Due to the absence of the disease-resistant wheat varieties the crop productivity dropped abruptly in the areas severely affected with stem rust. Yellow rust occurs usually in the southern and south eastern Kazakhstan where winter wheat is mainly grown. In this region intensive spread of the pathogen was recorded on the irrigated crops in years 2000 and 2002 (Koishibayev *et al*. 2003).

Mass occurrence of rust species over the world is promoted both by the global climate change and by the other evolutionary and breeding-genetic factors. Emergence of new virulent races (pathotypes) of the diseases resulting in loss of wheat commercial varieties resistance is the main factor causing rust epiphytoties.

It was previously ascertained that the population of the wheat leaf rust agent in Kazakhstan is represented by a great number of races with the prevalence of race 77. Races 122, 192 often occur in all populations, there are also races 1, 15, 25, 58, 34, 42 and all of them have been differentiated with use of 8 tester varieties (Kulikova and Zhdanov 1984). In the regions of Russia adjacent to Kazakhstan decrease in race diversity of the pathogen from 12 physiological races in 70-ties to 3 in year 2001 has been observed. In years 1991, 1994 and 1996 the leaf rust population included only race 77 (Meshkova and Rosseva 2002).

Ug99 (Uganda, 1999), a new race of stem rust with pathotype structure TTKS identified in the Eastern Africa, migrates from the African continent to the Asian countries through the Arabian Peninsula and spreads rapidly on wheat varieties causing the disease epiphytoty (Pretorius *et al*. 2000; Wanyera *et al*. 2006). According to FAO information spread of this stem rust race is of special danger to the sates such as Afghanistan, Pakistan, Turkmenistan, Uzbekistan and Kazakhstan. All of them are large-scale wheat grain producers. The experts of this organization are warning that the disease may result in the marked drop of wheat productivity in these countries.

Yellow rust is a major problem in wheat production all over the globe and is known as an endemic disease in the Central and Western Asia and in the Transcaucasia. During the last decade yellow rust epiphytoties led to the marked losses in wheat grain production. The increasing frequency and aggressiveness of yellow rust epiphytoties during the recent years was observed due to formation of new physiologic races that are able to overpower the widely used wheat resistance sources (Yahyaoui *et al.* 2002; Yahyaoui 2003; Koishibayev 2002).

Periodic occurrence of new rust races is a disturbing fact for Kazakhstan where wheat is cultivated as an economically important crop. It is well known that the spores of rust fungi can cover long distances, sometimes even over the oceans. Rust species spread is related to the global progress of these diseases in the Central Asia. For instance, it

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has been demonstrated that in favorable years yellow and leaf rusts first appear in Uzbekistan, in 10-15 days these diseases are recorded in the southern part of Kazakhstan and in 20-30 days they appear in the piedmont area of the south-eastern part of the republic (Koishibayev *et al*. 2008). Therefore wheat rust species usually appear in Kazakhstan as a result of spore migration from other regions.

Analysis of published data demonstrates the urgency of the wheat rust population studies, therefore *P. recondita f.sp. tritici*, *P. graminis f.sp. tritici* and *P. striiformis f.sp. tritici* virulence evaluation is of great interest for plant pathology and wheat breading.

MATERIALS AND METHODS

Samples of wheat leaves with spores of leaf, stem and yellow rusts taken from the production and experimental fields of the crop in different regions of Kazakhstan in 2003-2008 served as an original material. The clones were isolated from these spores; after propagation they were used in race differentiation (pathotyping) and evaluation of their virulence. For this purpose the wheat seedlings were infected with rust uredospores and kept in the greenhouse under conditions favorable for the infections development (temperature +22…+24°C for stem and leaf rusts, +10…+12°C for yellow rust, illuminance – 10000-15000 lux, light period – 16 hours). Adult plant resistance and effectiveness of *Sr*-, *Lr*-, *Yr*-genes of resistance to the fungus population was studied in the field against the infectious background. Plant affection with leaf rust was typed according to Mains and Jackson (1926), with stem rust according to Stakman and Levine (1922), with yellow rust according to Gassner and Straib (1929). Intensity of the infection progress on plants was evaluated according to Peterson *et al.* (1948).

Under controlled conditions of the greenhouse leaf rust pathotyping was conducted with use of 16 isogenic lines of *Thatcher* wheat variety: *Lr* – 1, 2a, 2c, 3, 9, 16, 24, 26, 3ka, 11, 17, 30, 19, 20, 25 and 29. The last four lines are additional ones for conditions of Kazakhstan. With the help of the key for race identification the isogenic lines were sorted into four groups of four lines (Long and Kolmer 1989). According to combination of responses of resistant (*R*) and susceptible (*S*) plants each rust agent isolate was coded in letters. As a result each pathotype has a code including 4 consonants of English alphabet from B through T.

The structure of the stem rust population was determined according to identification system of Roelfs and Martens (1988) based on inoculation of isogenic *Sr*-lines with *P.graminis* spores that we had modified. According to this system the plant reaction is determined on 16 lines divided into 4 groups of four lines. The first group includes isogenic *Sr*-lines 5, 21, 9e, 7b; the second – 11, 6, 8a, 9g; the third group – 36, 9b, 30, 17. The fourth was the set of lines *Sr*24, *Sr*25, *Sr*27, *Sr*32 (Kazakhstani additional set). In some cases four lines more were added to the above mentioned: *Sr*23, *Sr*9f, *Sr*DP2 and *Sr*GT.

Seven varieties of the international set and 8 varieties of the European set (Konovalova *et al.* 1977) were used to differentiate yellow rust pathotypes. For race numeration the decimal system of designating physiological races was used. This system is based on the binary system of designating infection types when 0 means reaction of resistance and 1 means reaction of susceptibility for each variety. In race designation the first figure is the number from the international set, the second – from the European set with letter *E* (Johnson *et al.* 1972). Virulence of yellow rust pathotypes was determined with use of 16 isogenic *Yr*-lines *Avocet* estimating at the same time the part of resistant and susceptible lines with *Yr*-genes.

RESULTS AND DISCUSSION

Wheat leaf rust study

Leaf rust caused by *P. recondita f.sp. tritici*, an obligate fungus, is one of the most widespread diseases of wheat that results in considerable yield losses of this crop. Wheat breeding for resistance to this disease is complicated by the problems of race differentiation of the pathogen the population structure of which is often unsteady and diverse.

In the Research Institute for Biological Safety Problems (RIBSP), Kazakhstan, the race structure and virulence gene fund of cereal rusts is under study for many years; fungal spore spread is monitored, possible disease prognosis and resistance of wheat varieties to diseases is investigated.

New data in rust race differentiation demonstrate that at present the system of race designation with use of the standard differentiating varieties does not reflect the variability character of the pathogen population (Rsaliyev *et al.* 2005). This method of race identification does not provide information on the genetic characteristics of the pathogen. As a result the data are obtained that the rust population consists of one race, mainly of race 77 (Meshkova and Roseyeva 2002). Actually all principal varieties-differentiators (Malakoff, Carina, Brevit, Webster, Loros, Mediterranean, Hussar, Democrat) are heavily affected by new isolates of the leaf rust fungus. The additional differentiating varieties (Bezostaya 1, Kavkaz, Kharkovskaya 46, Agrus, Gabo, Transfer, Dmitrovka 5-12, Skorospelka 35) complicate the process of race identification and therefore are not used in plant pathology.

The North American system of *P. recondita f.sp. tritici* race identification proposed by Long and Kolmer (1989) allows identifying virulent genes that are dangerous for the cultivated varieties. When this system is used it is possible to add quickly a new line with an effective resistance gene or to withdraw additional varieties with genes that have become non-effective for breeding. According to our findings in Kazakhstan the isogenic lines *Lr*19, *Lr*20, *Lr*25 and *Lr*29 are effective for the most part of virulences that are available in the local leaf rust populations, so they may be used as additional differentiating varieties.

The conducted research with use of the new differentiation system of Kazakhstani leaf rust population made possible to determine the pathotypes structure of *P. recondita f.sp. tritici* on wheat, triticale and other plants. At the same time the assay of the samples revealed their marked difference in virulence.

In 2006-2008, 22 physiological races of *P. recondita f.sp. tritici* were differentiated, however only 12 pathotypes appear to be virulent to the isogenic *Lr*-lines. The pathotypes from Reke, Nureke, E-17, E-19 wheat varieties and triticale T-10 are characterized by specific virulence (over 75% of susceptible *Lr*-lines).

Some leaf rust pathotypes are low or medium virulent to *Lr*-lines. However among them there are isolates of the fungus that affect highly effective resistance genes. For instance, FQH/Q pathotypes virulent to *Lr*9- and *Lr*19-lines were isolated from T-3 triticale though the portion of isogenic lines susceptible to this pathotypes did not exceed 50%. The pathotypes virulent to *Lr*19 were isolated also from Omskaya 19, Omskaya 32 wheat varieties and T-14 triticale. The pathotype of the fungus affecting *Lr*25 resistance gene was not found (**Table 1**).

Analysis of the obtained data made possible to determine the frequency of occurrence of susceptible isogenic lines. The most part of pathotypes in Kazakhstani leaf rust population affects isogenic lines *Lr*1, *Lr*2a, *Lr*2c, *Lr*3, *Lr*16, *Lr*3ka, *Lr*17, *Lr*30, the occurrence of which varies between 70-85%. It should be noted that some resistance genes considered previously to be medium and highly effective in Kazakhstan are affected now. For instance, occurrence of lines *Lr*24, *Lr*26 and *Lr*29 susceptible to local pathotypes is 35, 65 and 60%, respectively.

Leaf rust pathotypes have been also isolated from *Bromus arvensis* L. and *Isopyrum fumarioides* L. that are alternate hosts of this fungus. On the plants of *B. arvensis* spores of *P. recondita* develop in uredostage, on the plants of *I. fumarioides* they develop in aecidiostage. Under favorable conditions the spores from these plants infect wheat as new pathotypes. Characteristic feature of the pathotypes from *B. arvensis* (RTN/G) and *I. fumarioides* (TRP/G) plants is their virulence to the effective genes *Lr*9 and *Lr*20.

Table 1 Pathotypes of wheat leaf rust in Kazakhstan and their virulence (2006-2008).

Host plant, variety	Pathotype	Susceptible isogenic *Lr*-lines	Percentage of susceptible *Lr*-lines
Saratovskaya 29	THT/C	1, 2a, 2c, 3, 16, 26, 3ka, 11, 17, 30, 29	68.8
Astana	TBK/C	1, 2a, 2c, 3, 11, 30, 17, 29	50.0
Bogarnaya 56	THP/G	1, 2a, 2c, 3, 16, 3ka, 17, 30, 20	56.3
Nureke, E-19	TKT/H	1, 2a, 2c, 3, 16, 24, 26, 3ka, 11, 17, 30, 20, 29	81.3
Reke, Nureke, E-17	TKP/H	1, 2a, 2c, 3, 16, 24, 26, 3ka, 17, 30, 20, 29	75.0
Karaspan, Triticale T-10	TTP/H	1, 2a, 2c, 3, 9, 16, 24, 26, 3ka, 17, 30, 20, 29	81.3
Triticale T-3	FQH/Q	2a, 2c, 3, 9, 3ka, 17, 19, 29	50.0
Triticale T-14	SHK/M	1, 2a, 2c, 16, 26, 11, 17, 30, 19, 29	62.5
E-779	KTP/C	2a, 2c, 3, 9, 16, 24, 26, 3ka, 17, 30, 29	68.8
Lr13	TRP/H	1, 2a, 2c, 3, 9, 16, 26, 3ka, 17, 30, 20, 29	75.0
Bromus arvensis L.	RTN/G	1, 2a, 3, 9, 16, 24, 26, 3ka, 17, 20	62.5
Isopirum fumarioides L.	TRP/G	1, 2a, 2c, 3, 9, 16, 26, 3ka, 17, 30, 20	68.8

Wheat stem rust study

Recently some cases of mass development of stem rust (*P. graminis f.sp. tritici* fungus is a causing agent), an especially dangerous wheat disease, were recorded in the main grain-growing regions of Kazakhstan. For instance, in years 2003-2005 the disease developed in aecidiostage on barberry (*Berberis vulgaris* L.), its alternate host, from which the spores usually proceed to cereal crops. Moreover, the disease agent was detected on common barley (*Hordeum vulgare* L.), barley grass (*Hordeum leporinum* Link.), bluegrass (*Poa pratensis* L.), couch grass (*Elytrigia repens* L.), desert wheatgrass (*Agropyron cristatum* L.) and Russian wild rye (*Elymus junceus* L.). However the disease did not move to the adjacent fields under spring wheat.

In 2006-2007 in the north of Kazakhstan (in Kostanaiskaya and Severo-Kazakhstanskaya oblasts) the first signs of stem rust were detected on spring wheat in late July and in early August it moved to the fields that were under this medium- and late-sown crop. The spread of the disease varied within 20-40%, in some fields this parameter reached 80-100%. At the same time stem rust was recorded on barley plants very seldom. Because of absence of the disease-resistant varieties of spring and winter wheat the productivity of these crops dropped abruptly in the areas of intensive development of this rust species.

We have determined the pathotype structure of the stem rust agent collection at the RIBSP as well as of the pathogens collected from the commercial and collection varieties of winter and spring wheat. The results of the differentiation demonstrate the difference between the races of the institute's collection, pathotypes collected in 2003-2004 and in 2006-2007 (**Table 2**).

The results of stem rust pathotyping show that the collection races of this fungus as well as specimens collected from the commercial wheat varieties in 2003-2004 are low virulent. None of the isolates affected the additional isogenic *Sr*-lines: 24, 25, 27, 32. *Sr*-lines 21, 11, 6, 9b, 30 have also appeared to be effective to the specimens collected in years 2003-2004. Races 17 (68.8%) and 21 (50.0%) were the most virulent in the institute's collection of the infectious material.

The stem rust agents isolated from the population in 2006-2007 are characterized by high virulence. All tested lines were affected by new isolates. Isogenic lines *Sr*5, *Sr*11, *Sr*24, *Sr*25, *Sr*27, and *Sr*36 that were effective previously demonstrated susceptibility to some isolates.

Among the studied pathotypes TFK/R, TKT/C, TPS/H, TKH/RS, TDT/HS, TTH/KQ are more virulent. They were isolated from the commercial wheat varieties and their virulence to *Sr*-lines reached 75%. Some pathotypes (TKT/C, TKH/RS, TTH/KQ) are similar to the pathotype from Africa Ug99 (TTKS) in their nomenclature index.

At present over 50 *Sr*-genes of wheat stem rust resistance are known. Before emergence of race Ug99 only three genes provided the absolute resistance of wheat varieties: *Sr*26, *Sr*27 and *Sr*31. This is due to the fact that these genes are of "non-wheat" origin: *Sr*26 originates from tall wheatgrass (*E. elongata* Nevski), *Sr*27 and *Sr*31 from cereal rye (Imperial and Petkus varieties respectively). In Kazakhstan and Western Siberia *Sr*5, *Sr*11, *Sr*24 and *Sr*25 were also effective. With emergence of new more virulent races of this fungus study of *Sr*-genes effectiveness to natural populations became the main task of the present-day phytopathology and breeding of cereals for immunity. According to our data in two regions of Kazakhstan *Sr*24, *Sr*33, *Sr*35,

Table 2 Virulence of wheat stem rust races and pathotypes in Kazakhstan.

Infection source, wheat variety	Pathotype	Susceptible *Sr*-lines	Percentage of susceptible *Sr*-lines
Collection physiological races (1989-2003)			
Race 11 (1990)	SHM/B	5, 21, 9e, 6, 9g, 36, 17	43.8
Race 17 (1990)	TRT/B	5, 21, 9e, 7b, 11, 6, 9g, 36, 9b, 30, 17	68.8
Race 21 (2003)	SFR/B	5, 21, 9e, 8a, 9g, 36, 9b, 17	50.0
Race 34 (1990)	NCF/B	5, 9e, 9g, 30, 17	31.3
Race 117 (1989)	HHC/B	21, 7b, 6, 9g, 17	31.3
Pathotypes of 2003-2004			
Tselinnaya jubileinaya	MBM/B	5, 7b, 36, 17	25.0
Omskaya 35	DCC/B	9e, 9g	12.5
Niva 2	LCM/B	5, 9g, 36, 17	25.0
Bezenchukskaya 139	PFL/B	5, 9e, 7b, 8a, 9g	31.3
CID 88	CFC/B	7b, 8a, 9g	18.8
Pathotypes of 2006-2007			
Shortandinskaya 95	TFK/R	5, 21, 9e, 7b, 8a, 9g, 9b, 30, 17, 24, 25, 32	75.0
Saratovskaya 29	TKT/C	5, 21, 9e, 7b, 6, 8a, 9g, 36, 9b, 30, 17, 32	75.0
Bogarnaya 56	TPS/H	5, 21, 9e, 7b, 11, 8a, 9g, 36, 9b, 30, 25, 32	75.0
Omskaya 19	TKH/RS	5, 21, 9e, 7b, 11, 8a, 9g, 9b, 17, 24, 25, 32, 23, 9f, DP2	75.0
Bezenchukskaya 139	TDT/HS	5, 21, 9e, 7b, 8a, 9g, 36, 9b, 30, 17, 25, 32, 23, 9f, DP2	75.0
Damsinskaya 90	TTH/KQ	5, 21, 9e, 7b, 11, 6, 8a, 9g, 9b,17, 25, 27, 32, 23, 9f	75.0
K-84107	TCP/HQ	5, 21, 9e, 7b, 9g, 36, 30, 17, 25, 32, 23, 9f	60.0
K-84112	PCP/CQ	5, 9e, 7b, 9g, 36, 30, 17, 32, 23, 9f	50.0

*Sr*36 and *Sr*Dp2 are highly effective genes of resistance to the natural population of stem rust. It is known that gene *Sr*24 has been isolated from Agent wheat variety developed with use of tall wheatgrass (*E. elongata*), *Sr*33 from goat grass (*Aegilops tauschii* Coss.), *Sr*35 from einkorn wheat (*Triticum monococcum* L.), *Sr*36 from Timopheevi wheat (*T. timopheevi* Zhuk.), *Sr*Dp2 from turgid wheat (*T. turgidum* L.), Golden Ball variety (McIntosh *et al.* 1995).

Isogenic lines *Sr*9b, *Sr*11, *Sr*22, *Sr*29, *Sr*30 and *Sr*Gt demonstrated resistance in Zhambylskaya oblast (south-east of the country). However these lines were heavily affected in Akmolinskaya oblast (north) thus revealing high virulence of the stem rust population in the north of Kazakhstan.

We have evaluated the effectiveness of *Sr*-lines to 19 pathotypes of the disease agent in the greenhouse. The research has demonstrated that *Sr*7b, *Sr*9e and *Sr*9g are absolutely non-effective, i.e. these lines are affected by all tested pathotypes. An absolutely effective gene of resistance to new pathotypes of stem rust has not been detected. High effectiveness to the most part of the agent pathotypes was demonstrated by *Sr*6, *Sr*24, *Sr*27 and *Sr*Gt (Gamut).

So, the results of the studies show that *Sr*24, *Sr*33, *Sr*35, *Sr*36 and the new gene *Sr*Dp2 are effective to the natural population of wheat stem rust in the grain-producing regions of Kazakhstan. The use of sources of the above-mentioned *Sr*-genes ensures the successful breeding of wheat for stem rust immunity.

Wheat yellow rust study

The structure of the yellow rust population in Kazakhstan is determined with use of the international and European sets of differentiating varieties. Analysis of the yellow rust pathogen specimens collected in years 1995-2004 on the wheat production fields, experimental plots of collection varieties and from affected wild grasses in the grain-producing regions of Kazakhstan allowed to differentiate the races of this fungus. Six of them (7E150, 7E156, 7E159, 15E148, 15E159, 39E158) were the most widespread races on susceptible winter wheat varieties (Rsaliyev 2005).

The study of the yellow rust population structure in 2006-2007 resulted in detection of 20 pathotypes of the fungus. The pathotypes demonstrating both absolute avirulence (0E0) and high virulence (15E191, 71E175, 111E158) to the differentiating varieties were detected. Among the varieties-differentiators absolute immunity to the tested yellow rust isolates was demonstrated by Spaldings Prolific wheat variety. Perhaps, resistance gene *Yr*Sp of this variety is highly effective to Kazakhstani population of the fungus because another gene of this variety *Yr*6 has lost its effectiveness long time ago. This fact is also observed in manifestation of susceptible reaction to almost all isolates of Heines Kolben variety protected by gene *Yr*6. High resistance to the tested isolates was demonstrated by Moro, Strubes Dickkopf, Suwon 92xOmar varieties included into the international set. Further study of the selected pathotypes with use of Avocet isogenic *Yr*-lines has shown that the existing nomenclature of yellow rust races does not provide full information about virulence of each pathotype. For instance, pathotype 0E0 avirulent to the differentiating varieties affects two isogenic lines of resistance including *Yr*6 that is medium effective in the Central Asia. 7E159, 15E159, 47E143, 111E158 appeared to be the most highly effective pathotypes affecting 9-10 *Yr*-genes of 16. It should be noted that the rust pathotypes either virulent to 50% and more isogenic lines or affecting effective resistance genes may be referred to as highly virulent and respectively as especially dangerous races. The results of our experiments (**Table 3**) had shown that in 2006-2007 Kazakhstani population of yellow rust included 9 highly virulent pathotypes. Knowledge of the race-specific resistance of new wheat varieties and lines to these pathotypes makes successful the wheat breeding for yellow rust resistance in the region.

The next step was to ascertain the sources of formation of differentiated pathotypes. For this purpose affinity of the selected pathotypes in Kazakhstan in different years was studied and the obtained experimental results were compared with the published data (Absattarova *et al.* 2001; Volkova 2003; Yahyaoui *et al.* 2002; El-Shamy 2006; Stanka Mikhova 1989). The populations of the yellow rust agent in many regions and countries are characterized by diversity of physiological races and pathotypes.

Comparative analysis of the yellow rust population structure in Kazakhstan revealed the identity of 9 pathotypes in 2004-2007. Pathotypes 7E159, 15E159, 39E158 were detected in early studies. They were a basis for synthetic yellow rust population in determining resistance of wheat varieties against the infectious background. As it was supposed some Kazakhstani pathotypes of yellow rust were identical with pathotypes from Uzbekistan. However in most cases Kazakhstani races of yellow rust differ from races of other countries and regions of the Central and Western Asia (**Table 4**).

Yellow rust resistance of commercial wheat varieties was evaluated with use of nine pathotypes widespread in Kazakhstan in recent years. Prevailing pathotypes 15E159, 31E158 and 39E159 manifested high virulence to all varieties. New pathotypes 79E143 and 111E158 are also viru-

Table 3 Characterization of virulence of wheat yellow rust pathotypes (2006-2007).

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

* *R*: resistance, *S*: susceptible

Table 4 Occurrence of the wheat yellow rust pathotypes.

Kazakhstan		Kazakhstan,	Azerbaijan (2003)	Iran, Lebanon,	Egypt (2006) [D]	Bulgaria (1989)
2004-2005	2006-2007	Uzbekistan (2001) [A]	[B]	Syria (2002) [C]		[E]
6E145	6E145	0E0	4E0	230E	0E6	2E0
7E148	7E148	5E0	4E16	230E134	6E16	6E0
7E159	7E159	6E16	5E0	230E150	70E26	6E16
15E159	15E159	7E140	5E16	172E146	134E158	38E16
31E158	31E158	7E148	6E0	198E150	198E150	41E136
39E158	39E158	7E156	6E16		238E190	41E168
71E175	71E175	28E2	7E0			104E169
79E143	79E143	38E16	7E16			108E173
111E158	111E158	39E158				198E150
15E128	0E0	41E136				230E150
47E159	4E144	41E168				
47E223	7E151	98E150				
55E144	7E190	104E137				
70E130	15E133	104E169				
71E135	15E191	108E173				
79E205	47E143	134E158				

A: Absattarova *et al.* 2001, B: Volkova 2003, C: Yahyaoui *et al.* 2002, D: El-Shamy 2006, E: Stanka Mikhova 1989

Table 5 Resistance of wheat varieties to some pathotypes of yellow rust.

Variety	Type and rate of plant affection by yellow rust pathotypes, points/%									
	6E145	7E148	7E159	15E159	31E158	39E159	71E175	79E143	111E158	Average
Bezostaya 1	3/10	2/5	2/5	4/5	4/5	4/5	2/5	3/20	3/10	3,0/7,8
Bogarnaya 56	3/20	3/10	3/10	4/20	4/20	4/20	3/5	3/10	4/20	3,4/15,0
Saratovskaya 29	4/20	3/20	3/5	4/10	4/20	4/5	3/10	4/5	4/5	3,7/11,1
Morocco	2/5	2/5	4/20	4/5	4/10	4/5	3/5	3/10	3/5	3,0/7,8

lent under favorable conditions. Some pathotypes were avirulent to Bezostaya 1 variety with a complex of resistance genes (*Yr*1, *Yr*4, *Yr*9, *Yr*18). Pathotypes 6E145 and 7E148 failed to overcome the protective reaction of universally susceptible variety Morocco.

Bogarnaya 56 (winter wheat) and Saratovskaya 29 (spring wheat) appeared to be the most susceptible among all varieties tested in the greenhouse. These varieties are used as controls in study of race-specific resistance of collection varieties and their resistance in the phase of seedlings since Morocco does not manifest adequate reaction to inoculation with spores of wheat yellow rust (**Table 5**).

Dynamics of the disease progress on the yellow rust differentiating varieties was studied in the field against the infectious background. Wheat varieties that are used as *P. striiformis f.sp. tritici* differentiators in the USA (Chen 2007) and Avocet isogenic lines with *Yr*-genes (McIntosh *et al.* 1995) have been evaluated. Yellow rust was actively developing on Lemhi, Chinese 166, Heinese VII, Lee, Fielder, Hyar and Avocet *Yr*1, *Yr*8, *Yr*12, *Yr*18 lines in booting and heading phases of plant growth thus demonstrating non-effectiveness of their resistance genes to the local

Table 6 Effectiveness of yellow rust differentiators in Kazakhstan.

Variety, line	Resistance gene	Plant resistance in phases, points/%			Manifestation in	Effectiveness**
		Tillering	Booting	Heading	onthogenesis*	
Lemhi	*Yr*21	0	2/5	3/50	JR	L
Chinese 166	*Yr*1	2/5	3/40	3/70	JR	L
Heinese VII	*Yr*2, *Yr*HVII	1/5	2/5	2/40	JR	L
Moro	*Yr*10, *Yr*Mor	2/10	2/20	2/20	JR	H+
Paha	*Yr*Pa1, *Yr*Pa2, *Yr*Pa3	0	0	0	JR	H+++
Druchamp	*Yr*3a, Dru1, Dru2	0	0	0	JR	H+++
Produra	*Yr*Pr1, Pr2 (durum)	0	0	0	JR	H+++
Yamhill	*Yr*2, *Yr*4a, *Yr*Yam	0	0	2/10	JR	H++
Lee	*Yr*7, *Yr*22, *Yr*23	3/10	3/60	3/80	-	L
Fielder	*Yr*6, *Yr*Fie	3/5	4/70	4/90	JR	L
Tyer	*Yr*Tye	0	0	2/40	JR	H+
Tres	*Yr*Tr1, *Yr*Tr2	1/5	2/10	2/20	JR	H+
Hyar	*Yr*17, *Yr*Tye	3/10	4/70	4/80	JR	L
Express	*Yr*HTAP	0	2/5	3/40	JR	M
Compair	*Yr*8, *Yr*19	0	0	3/40	JR	L
Avocet /*Yr*1	*Yr*1	3/5	4/60	4/100	JR	L
Avocet /*Yr*5	*Yr*5	0	0	0	JR	H+++
Avocet /*Yr*8	*Yr*8	3/5	4/40	4/80	APR	L
Avocet /*Yr*9	*Yr*9	0	2/5	2/40	JR	H++
Avocet /*Yr*10	*Yr*10	0	0	0	JR	H+++
Avocet /*Yr*12	*Yr*12	0	3/40	4/70	APR	L
Avocet /*Yr*15	*Yr*15	0	0	0	JR	H+++
Avocet /*Yr*18	*Yr*18	0	3/40	4/70	JR	L
Avocet /*Yr*24	*Yr*24	0	0	1/5	-	H++
Avocet /*Yr*26	*Yr*26	0	1/5	2/5	-	H+
Avocet /*Yr*Sp	*Yr*Sp	0	0	1/5	-	H++

* JR: juvenile resistance, APR: adult plant resistance
** L: low, M: moderate, H: high, +: intensity

population in Kazakhstan (**Table 6**).

Resistance genes of the American differentiating varieties Paha, Druchamp, Produra, as well as *Yr*5, *Yr*10, *Yr*15 from Avocet variety are highly effective. Resistance of Moro, Yamhill, Tyer, Tres and Avocet *Yr*9, *Yr*24, *Yr*26 and *Yr*Sp lines varies depending on weather conditions of the year. In the years with conditions unfavorable for plant diseases yellow rust did not develop on these varieties and lines in spite of inoculation but in damp summers infection rate on leaves reached 20-40%.

CONCLUSIONS

Differentiation of Kazakhstani wheat leaf rust population resulted in isolation and propagation of 22 pathotypes with different virulence to isogenic *Lr*-lines and commercial varieties. High virulence (over 75% of susceptible *Lr*-lines) is characteristic for pathotypes TKT/H, TKP/H, TTP/H, TRP/H, TTP/H isolated from wheat and triticale varieties.

There are leaf rust isolates affecting highly effective resistance genes *Lr*9 and *Lr*19, but a fungus pathotype with virulence to *Lr*25 has not been found in the local population. Resistance genes *Lr*24, *Lr*26 and *Lr*29 that were considered to be moderate effective in Kazakhstan turned to be susceptible to some local fungus isolates.

Kazakhstani stem rust population of years 2006-2007 includes highly virulent pathotypes (TFK/R, TKT/C, TPS/H, TKH/RS, TDT/HS, TTH/KQ) that are of danger to the wheat commercial varieties in the republic. Some pathotypes affect all tested isogenic *Sr*-lines and their nomenclature indices are similar to the index of Ug99 pathotype (TTKS) from Africa.

*Sr*24, *Sr*33, *Sr*35, *Sr*36 and *Sr*Dp2 are effective genes of wheat resistance to the natural stem rust population in the grain-producing regions of Kazakhstan. Use of sources of these *Sr*-genes can provide success in wheat breeding for the disease immunity in the republic.

Rust pathotypes either virulent to 50% and more isogenic lines or affecting effective resistance genes may be referred to as highly virulent and respectively as especially dangerous races. In 2006-2007 20 pathotypes of yellow rust were isolated in Kazakhstan. Pathotypes 7E159, 15E159, 47E143, 111E158 affecting 9-10 *Yr*-genes of 16 were the most highly virulent. Their usage in resistance evaluation of new wheat varieties can determine success of the breeding for the disease resistance in the region. Some pathotypes of the agent from Kazakhstan and Uzbekistan were identical but many Kazakhstani races of *P. striiformis* differ from races of other regions and countries.

American differentiating varieties Paha, Druchamp, Produra, as well as *Yr*5, *Yr*10, *Yr*15 from Avocet variety are highly effective. Resistance of Moro, Yamhill, Tyer, Tres and Avocet *Yr*9, *Yr*24, *Yr*26 and *Yr*Sp lines varies depending on weather conditions of the year.

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