Genetic protection of wheat from rusts and development of resistant varieties in Russia and Ukraine

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Abstract Leaf rust represents the major threat to wheat production in Russia and Ukraine. It has been present for many years and epidemics occur in different regions on both winter and spring wheat. In some regions there is evidence of more frequent epidemics, probably due to higher precipitation as a result of climate change. There is evidence that the virulence of the leaf rust population in Ukraine and European Russia and on winter wheat and spring wheat is similar. The pathogen population structure in Western Siberia is also similar to the European part, although there are some significant differences based on the genes employed in different regions. Ukrainian wheat breeders mostly rely on major resistance genes from wide crosses and have succeeded in developing resistant varieties. The North Caucasus winter wheat breeding programs apply the strategy of deploying varieties with different types of resistance and genes. This approach resulted in decreased leaf rust incidence in the region. Genes *Lr23* and *Lr19* deployed in spring wheat in the Volga region were rapidly overcome by the pathogen. There are continuing efforts to incorporate resistance from wild species. The first leaf rust resistant spring wheat varieties released in Western Siberia possessed gene *LrTR* which protected the crop for 10-15 years, but was eventually broken in 2007. Slow rusting is being utilized in several breeding programs in Russia and Ukraine, but has not become a major strategy.

Introduction

Wheat has been cultivated on the territory of Russia and Ukraine since ancient times (Merezhko 2001) and as the human population expanded, so did the wheat area. The diet of Slavic people is historically based on cereals. Average per capita wheat consumption in 2003-2005 was 247 kg in the Russian Federation and 226 kg in Ukraine compared to 113 kg in the USA (Dixon et al. 2009). The last 100-150 years witnessed a gradual change from primarily rye bread consumption to wheat bread. In 1900 rye covered 24 m ha of the 106 m ha of arable land in Russia and wheat was cultivated on 11 m ha (Zhuchenko 2004). During 2000-2008 the wheat area in Russia varied between 20.06 and 26.7 m ha (Table 1) whereas the rye area did not exceed 3.7 m ha and has continued to decline over the last 2-3 years (http://faostat.fao.org). In addition to high domestic consumption the importance of wheat for the national economies in both Russia and Ukraine is also substantiated by export potential. An estimated 24 m ha of arable land in Russia is not cultivated, but could be utilized for wheat production and export (Zhuchenko 2004). The yield potential of Ukraine could also be enhanced for exports.

TABLE 1 HERE

The enormous territory of Russia and Ukraine has a wide diversity of soil and climatic environments reflected in the diversity of wheat varieties cultivated in the region. In general the wheat growing area of Russia and Ukraine can be subdivided into three major overlapping regions (Fig. 1). Region 1 covers southern Ukraine and Russia. This is primarily a winter wheat growing region with relatively mild winters and variable precipitation. Spring wheat is planted on a commercial scale only in some years to replace winter wheat that did not survive the winter, as in Ukraine, for example, in 2003. This region stretches from the northern Caucasus and north shore of the Black Sea to 55-57^{o}N, or beyond the latitude of Moscow. Moving northwards, the amount of annual rainfall increases from 300-350 mm per year to 500-600 mm. The second region stretches from northern Ukraine and central European Russia to the Ural Mountains. Low temperatures in winter limit cultivation of winter wheat in this region and spring wheat occupies a significant share of the crop area. Precipitation is variable and decreases eastwards from 600 mm in the Moscow region to 300-350 mm beyond the Volga River. The third wheat production region is Siberia, which due to its cold climate, grows almost entirely spring wheat. Western Siberia is the major production region, with a frost free period of 110-120 days and precipitation varying from 300-350 mm in the south to 450-500 mm at the northern border with the forest belt. This region comprises one uniform spring wheat production area of 15-17 m ha including northern Kazakhstan. Wheat breeding and rust research in Kazakhstan is not reviewed here, but was previously covered in separate publication (Morgounov et al. 2007). There are several smaller sub-regions of wheat cultivation like the Far East and northwestern part of European Russia, but their contributions to overall wheat production are minor. The objective of the current paper is to provide a review of wheat breeding for rust resistance and relevant rust research in Russia and Ukraine relating to the regions described above and with a focus on the current status.

FIGURE 1 HERE

Institutional framework for wheat breeding and rust research in Russia and Ukraine

The agricultural research system of Russia and Ukraine with public centralized institutions was inherited from the Soviet Union. Although some countries of the former USSR went through radical re-organizations of their research systems, the situation in Russia and Ukraine is largely unchanged (Morgounov and Zuidema 2001). Wheat breeding and research in Ukraine are primarily conducted by the research institutions of the National Academy of Agrarian Sciences. Five research centers and 52 research institutes and stations are part of the Academy with the total arable land exceeding 0.5 m ha (http://www.uaan.gov.ua/). The key wheat breeding programs are located throughout the country at Odessa in the south (Plant Breeding and Genetics Institute), Kiev region in the center (Mironovka Wheat Institute) and Kharkov in the northeast (Ukrainian Institute of Plant Industry). The Institute of Plant Physiology and Genetics (located in Kiev) belonging to the National Academy of Sciences is also involved in wheat breeding as well as several other institutes and universities. A few private wheat breeding companies are mostly involved in testing and promotion of foreign germplasm from major agricultural companies abroad. Pathology research related to rust is conducted in the same institutions as wheat breeding.
The Russian Academy of Agricultural Sciences is much larger comprising 51 research centers and 196 research institutes with a total arable area of 1.7 m ha (http://www.agroacadem.ru) . There are several All-Russian research centers and institutes with a national mandate and these primarily address more narrow topics across the whole country. In the case of wheat the All-Russian Research Institute of Phytopathology located near Moscow and the All-Russian Research Institute of Crop Protection located near St. Petersburg with respective branches and stations cover more basic aspects of pathogen research. Wheat breeding is conducted by regional research institutes which serve specific areas of the country with new technologies including wheat varieties. Applied rust pathology research is also conducted by the same institutes. There are more than 30 wheat breeding programs in the country. The role of universities is limited though some of them do have active and successful breeding programs. As in Ukraine, private companies serve the needs of foreign seed companies. Wheat breeding and rust research in both Russia and Ukraine underwent economic crises after the disintegration of the USSR in the 1990s. However, the core breeding and research programs were maintained and some even strengthened. The 2000s witnessed a revival of the wheat industry and wheat research to meet greater demands from the farming community for new varieties. Agricultural research funding is also recovering through public sources, research grants and royalties, as well as direct contracts with the producers.

Winter wheat breeding for rust resistance in Ukraine

Among the three wheat rusts, the least damaging in Ukraine are yellow rust (caused by *Puccinia striiformis*) and stem rust (*P. graminis*). Yellow rust occurs occasionally on highly susceptible varieties, but yield losses do not exceed 5-10%. Over the last 20 years yellow rust infections reaching commercially significant scales were observed in 1991, 2001, 2005 and 2007. The *P. striiformis* population is dominated by races (European nomenclature) 0E0, 6E0 and 6E16 which lack virulence to *Yr3c*, *Yr5*, *Yr9*, *Yr10*, *Yr15* and *Yr17* (Babyants et al. 2009) (Table 2). Stem rust is not common and has not damaged the crop in the last 10 years. In the past (1930-1970) it was observed on late maturing winter wheats (especially winter durums) in western and central Ukraine (Babayants et al. 2004a) with yield losses of 15-20%. Effective *Sr* genes are listed in Table 2. Leaf rust (*P. triticina*) is the most common rust across the country and reaches epidemic dimensions on susceptible varieties every two to three years in five (Babayants et al. 2004b). Over the last 10 years leaf rust epidemics occurred in 2000, 2001, 2004 and 2006 with average yield losses of 10-30%. A similar frequency of epidemics took place in the previous 50 years. More than 50 races have been identified in Ukraine with races 77 and 144 being dominant (Traskovetskaya 2009). Effective *Lr* genes are listed in Table 2.

TABLE 2 HERE

A detailed description of the history of wheat breeding in Ukraine was presented by Litvinenko et al. (2001). In breeding for rust resistance three main stages are clearly defined:

1) Breeding based on selection from local varieties and landraces and the development of the first varieties originating from crosses. Most of the varieties bred and utilized during that time were susceptible to prevailing diseases including leaf rust and other rusts. This period lasted until the 1960s.

2) The development and release of landmark varieties Bezostaya 1, Aurora, Kavkaz and Mironovskaya 808 in the early 1960s began a new era of rust resistance breeding. Aurora and Kavkaz possess the 1B.1R translocation with a combination of resistance genes. Bezostaya 1 possesses the slow rusting *Lr34* gene. Mironovskaya 808, although susceptible to leaf rust, had broad adaptation and a capacity to provide high yields in the presence of the pathogen. These varieties not only contributed to production but served as common parents for numerous other varieties, thus, transferring their resistances/responses to the next generation of germplasm. Early CIMMYT germplasm resistant to leaf rust was also utilized in crosses and contributed to new rust resistant germplasm.

3) The current period of resistance breeding is characterized by accumulation of rust resistance from different sources and incorporation of resistance from wild relatives. The Plant Breeding and Genetics Institute in Odessa introgressed resistances to leaf rust and stem rust from *Aegilops cylindrica*, *Triticum erebuni* and Amphidiploid 4 (*T. dicoccoides* x *Ae. tauschii*), and stem rust from *Aegilops variabilis* (Babayants et al. 2010). New winter wheat varieties such as Knyaginya, Olga, Lastivka Odeska and Vihovanka Odeska possess some of these genes and display high degrees of resistance to one or more rust pathogens. Rust resistance breeding at Mironovka Wheat Institute was initially based on crosses and backcrosses with triticale which resulted in variety Mironovskaya 10 (Novohatka 1976). More recent efforts are based on incorporation of resistance from foreign, primarily European, germplasm. A list of modern Ukrainian winter wheat varieties from Odessa, their reactions to rusts and nature of resistances are provided in Table 3.

Winter wheat breeding for rust resistance in the European part of Russia

The southern part of European Russia or North Caucasus region is the breadbasket of the country due to its favorable soils, climatic conditions and dynamic farming community. The average yields in the

Krasnodar and Rostov regions covering 2-3 m ha normally exceed 4-5 t/ha or double the national average. However, this favorable environment is also very suitable for wheat diseases, including the rusts, and especially leaf rust. The early 20th century witnessed devastating leaf rust epidemics leading to widespread hunger in the region. In the period 1939-1953 leaf rust epidemics occurred in 1939, 1949, 1941, 1946, 1948, 1952 and 1953. No wonder when P. Lukyanenko, breeder of Bezostaya 1, started his breeding work in Krasnodar in the early 1930s resistance to leaf rust was a primary objective. His first rust resistance breeding efforts were based on crosses of local winter wheats with resistant spring wheat varieties from USA such as Marquis and Kitchener (Lukyanenko 1973). His paper on methodology of breeding winter wheat for rust resistance, published in 1941, classified the types of resistance into seedling and adult plant, listed the sources of resistance, and described the screening methodology. Eventually, his efforts resulted in development of variety Bezostaya 1 which was a landmark both in production and as a future breeding parent.

The entire history of wheat breeding in the north Caucasus of Russia represents a continuous race between the breeders and the evolving leaf rust pathogen. The first widespread leaf rust resistant variety developed by Lukyanenko was Novoukrainka 83 which lost its resistance in 1948 due to the appearance of race 77. In the 1950s this variety was replaced by Bezostaya 4, Skorospelka 3b (*Lr3a*) and Bezostaya 1 with field resistance to leaf rust (Voronkova 1980). In the early 1970s new higher yielding varieties Avrora and Kavkaz with specific resistance against races 58 and 77 (1B.1R translocation with *Lr26*) were released to replace Bezostaya 1. However, a leaf rust epidemic in 1973 devastated 80% of the area covered by these varieties, demonstrating that major genes alone were not able to protect the varieties. The following genes protected wheat from leaf rust when the resistance of Avrora and Kavkaz was broken: *Lr9*, *Lr19*, *Lr23*, *Lr24* and *Lr25* (Alekseeva 1986). Genes *Lr10*, *Lr14a*, *Lr14b* and *Lr18* also contributed to resistance. In the early 1980s race 77 became dominant and a new generation of winter wheat varieties was grown in the region (e.g. Olimpya, Krasnodarskaya 57, Prikubanskaya, Partizanka, Obriy). Intensification of production in the late 1980s resulted in the release of semi-dwarf varieties Spartanka and Yuna (*Lr23* + *Lr26*) – the latter alone occupying almost 38% of the total wheat area (Romanenko et al. 2005). The leaf rust pathogen responded by evolving new virulent races. In the early 1990s race 25 became dominant. Variety Yuna became susceptible within five years after release. The changes in virulence in the pathogen population in the north Caucasus region are shown in Table 4.

In the 1990s the strategy of deployment of varieties with different bases for resistance (both major genes and adult plant resistance genes) was adopted. This approach denies domination of a single variety as occurred in the past and demanded that any variety could not exceed a maximum 15-20% of the wheat area. In 2001, for example, there were 14 winter wheat varieties with the area covered by any single variety varying from 1 to 14%. This strategy might be the main reason for gradual reduction of leaf rust occurrence in the region (Fig. 2). At the same time the number of pathogen races identified in the region increased (Table 4). The last outbreak of leaf rust took place in 2004, affecting varieties Krasnodarskaya 39, Polovchanka and Knyazhna which jointly did not exceed 20% of the total area. Varieties developed at Krasnodar Agricultural Research Institute are classified into 4 groups based on their reaction to leaf rust: viz. Group 1: practically immune with necrotic flecks (varieties Yara, Veda); Group 2: slow rusting genotypes with low AUDPC both under natural and artificially inoculated conditions (Rannaya 12, Krasnodarskaya 6, Umanka, Zimorodok, Afina, Starshina, Kuma, Doka, Valentin); Group 3: varieties reaching infection levels of 60% under inoculated nursery conditions, but still possessing a degree of resistance (Delta, Kroshka, Deya, Yubilejnaya 100); Group 4: varieties susceptible to rust (Bezostaya 1, Krasota, Polovchanka). Yellow rust and stem rust are not common in the region, but all materials are routinely evaluated during the breeding process.

The second largest wheat producing region in southern Russia is Rostov province which has its own research institute and a highly successful winter wheat breeding program. The environment of this region requires varieties with higher winter hardiness and drought tolerance than in the Krasnodar area. However, leaf rust resistance remains an important breeding objective. The modern germplasm from the Rostov region is based on Bezostaya 1 and its derivatives. Varieties Donskaya Bezostaya, Donskaya Polukarliovaya, and more recently Don 85, Ermak, Stanichnaya, Zarnitsa and Dar Zernograda, are slow rusting (Kovtun et al. 2001). The winter wheat producers of the central part of European Russia are served by a breeding program located near Moscow. The main challenge there is the combination of semi-dwarf stature with winter hardiness as the temperatures decline as wheat production areas move north. Leaf rust resistance remains a high priority and yellow rust is observed in some years. Breeding is based on interrupted back- and top crosses utilizing Mironovskaya 808 type germplasm to maintain high degrees of winter hardiness with different sources of *Rht* genes and rust resistance (Sanduhadze et al. 2001). The resulting varieties (Inna, Moskovskaya 39) possess field resistance to leaf rust and are broadly adapted essentially extending the northern and eastern limits of winter wheat cultivation due to their superior winter hardiness.

TABLES 3 AND 4 HERE
FIGURE 2 HERE

Spring wheat breeding for rust resistance in European part of Russia

This important wheat production region stretches as a belt from west of Moscow to the Ural Mountains below 50-55^{o}N. It is a traditional spring wheat production area since winter wheat is frequently killed during severe winters. However, climatic changes over the last 5-10 years have made winter wheat more reliable, and in some locations it competes with spring wheat in area and profitability. The amount of precipitation is variable and a large part of the region (especially the middle and lower Volga region) is subjected to moisture stress during the season. Except in severely dry years, leaf rust is common throughout the region. A study of 42 spring wheat varieties released in the USSR during 1967-69 indicated that none was resistant (Nettevich 2008). Systematic monitoring of races started in the 1970s. Between 1971 and 2004 epidemics occurred in 1973, 1974, 1976, 1978, 1989, 1994, 2000, 2001 and 2004, or one year in three (Markelova 2009). The virulence of the rust population in the Volga region is similar to that in the north Caucasus winter wheat region suggesting that inoculum from the south moves to the north with the wind, and earlier maturing crops in the south serve as a source of spores for more northern and eastern areas of spring wheat production. Table 5 presents data for yield losses during the epidemic years as well as associated changes in the virulence pattern in the Volga region. The data clearly demonstrate the continuous co-evolution of wheat and rust. Once breeding programs started to use gene *Lr23* new races possessing corresponding virulence were detected. The same happened with varieties protected by *Lr19*. Long term research by Markelova (2009) in Saratov concludes that currently only gene *Lr9* continues to maintain a high degree of resistance in the region. At the same time evaluation of *Lr* Thatcher isogenic lines in Bezenchuk (Samara Agricultural Research Institute) demonstrated that acceptable resistance was conferred by *Lr9*, *Lr24*, *Lr25*, *Lr28*, *Lr29*, *Lr36*, *Lr38* and *LrTR*.

The two main research institutions involved in spring wheat breeding and rust research in the region are the Agricultural Research Institute of the South East in Saratov and Samara Agricultural Research Institute in Bezenchuk located 300 km apart on the Volga River. Unlike the winter wheat breeding programs in southern Russia relying primarily on slow-rusting, the strategy of rust resistance breeding in the Volga region is based on continuous screening for possible sources of resistance and incorporation of resistance genes from wild relatives and related wheat species. The first leaf rust resistant spring wheat varieties developed only in the 1980s, utilized *Lr23* and *Lr19* which soon lost their effectiveness. Syukov et al. (2006) introduced a highly effective resistance gene, *LrAg*, from *Elytrigia intermedia*. Varieties Tulaikovskaya 5, Tulaikovskaya 10, Tulaikovskaya 100 and Lutescens 101 possess this gene which is different from *Lr24, Lr25, Lr28, Lr29, Lr36, Lr38* and *LrTR*. Genes combinations, even including some defeated genes such as *Lr19*+*Lr26* and *Lr19*+*Lr23*, are also considered part of a viable strategy at Samara Institute. The Agricultural Research Institute in Saratov has been developing drought tolerant superior grain quality varieties well adapted to the dry Volga region. Most of them lack resistance to leaf rust as it is asumed that the pathogen affects wheat less during drought. The specific effort in rust resistance research at Saratov has concentrated on screening a huge number of germplasm accessions (50,000) over the last 20 years to select resistant germplasm. A number of foreign wheats, including CIMMYT germplasm, were selected and utilized in crosses. Wide crosses have also been utilized as well as a combination of alien translocations with known *Lr* genes (*Lr19* + *Lr26*) (Sibikeev et al. 2009). Leaf rust reactions of spring wheat varieties currently released in the Volga and Ural regions are provided in Table 6. Among 81 varieties tested, 21 (25%) were resistant mostly due to introgressed major genes.

Spring wheat breeding for rust resistance in Siberia

A recent historical analysis of the wheat rust situation in northern Kazakhstan and western Siberia and respective breeding efforts were described by Morgounov et al. (2007). Wheat production areas in the Siberian part of Russia are divided into three major areas: Western Siberia, Eastern Siberia and the Far East. The importance of wheat as a crop decreases eastwards and by far the most important region is Western Siberia. Early 20th century reports on wheat and diseases do not emphasize rust, but pay more attention to loose smut and common bunt. The massive commercial wheat production in western Siberia started in the 1960s after implementation of the program of virgin land exploration. The wheat area increased several fold and leaf rust started to damage the crop. Until the 1980s epidemics were on average one to three years in ten (Chulkina et al. 1998). There was, and still is, a common belief among breeders and wheat producers that leaf rust comes late during the maturing stages and does not damage the crop. However, numerous data suggest significant yield losses of up to 20-30% during epidemics (Koyshibaev 2002). In the 1990s leaf rust affected spring wheat in western Siberia in seven years out of ten, with 1993 and 1995 being epidemic years. In the 2000s leaf rust occurred every year, with 2001, 2005, 2007 and 2008 being epidemic years. The important issue is that it occurs during more favorable wet years when higher average yields mask losses from the disease.

There are different opinions in regard to the sources of infection for leaf rust in Western Siberia. Turapin (1991) summarizing the rust research in Kazakhstan during the Soviet Union era suggested that cultivated and wild grasses (such as *Aegilops*, *Agropyrum* and others) may play an important role in maintaining infection during winter. Mostovoy and Berezhnova (1985) compared the pathotypes of leaf rust collected in the atmosphere of northern Kazakhstan with those collected in European Russia and found many common ones suggesting there was movement of spores from the western part of Russia to Siberia and northern Kazakhstan. Koyshibayev (2002) suggested an important role of rust infected winter wheat as a 'green bridge' to preserve infections during winter. Odintsova and Shelemova (1987) compared the virulence pattern of *P. triticina* across different regions of the country and concluded that the pathogen population in Siberia is relatively closely related to the population in the European part of the country, but differs from the population in Central Asia (Kazakhstan and Uzbekistan) and the Far East. This conclusion supports the possible movement of spores from west to east with the prevailing winds. The data from the Siberian Agricultural Research Institute in Omsk for 2003-2005 obtained on Thatcher near-isogenic lines demonstrated that genes *Lr9, Lr28* and *Lr36* provided complete resistance. The genes *Lr19, Lr24, Lr25* and *Lr37* conferred resistant or moderately resistant responses depending on the year. Some genes (e.g. *Lr12, Lr29, Lr30*) seemed to have slow rusting effects with moderately susceptible reaction types, but with rust severities not exceeding 50%.

TABLES 5 AND 6 HERE

The reactions of 55 spring wheat varieties released in the USSR from 1975 to 1991 were studied in Mexico (Singh et al. 1995). Almost half of the cultivars had high or moderate degrees of adult plant resistance. Leaf tip necrosis associated with *Lr34* was observed in 20 varieties. The most common known leaf rust resistance genes were *Lr10* (14 varieties), *Lr3* (7 varieties) and *Lr13* (5 varieties). However, none of these genes is effective in Russia. Despite substantial efforts in breeding new spring wheat varieties with undoubted progress in yield potential, grain quality and other traits, little improvement was made in leaf rust resistance (Morgounov et al. 2010). One important reason for this was utilization of a limited number of leaf rust susceptible parents (e.g. Saratovskaya 29) in the crossing programs to maintain and enhance adaptation and yield. The sources of leaf rust resistance most frequently used in the region can be classified into three groups: viz. Those used in winter wheats, local spring wheats, and foreign spring wheats with variable genetic basis of resistance. The development of more input-responsive semi-dwarf winter wheat varieties in Russia in the 1970s and 1980s resulted in increased yields and enhanced resistance to diseases. Some of the most successful winter wheat varieties were utilized in crosses to improve spring wheat. One example is variety Bezostaya 1 used as a parent in a number of spring wheat varieties grown in Northern Kazakhstan and Siberia (e.g. Tulunskaya 12, Sibakovskaya 3, Omskaya 9, Kazakhstanskaya Rannespelaya) (Morgounov 2001). Since Bezostaya 1 possesses *Lr34* and possibly some other genes it has contributed to leaf rust resistance in Russia. On the other hand, utilization of winter wheat for spring wheat breeding raised a concern that the same genes and gene combinations would be protecting the crop across a huge continuous area, increasing vulnerability to the disease.

Starting from the mid-1990s CIMMYT initiated broad germplasm exchange and cooperative breeding efforts with the region to enhance leaf rust resistance while maintaining the general adaptation and grain quality. Testing of CIMMYT germplasm showed that resistance effective in Mexico was also effective in northern Kazakhstan and Siberia. The resulting shuttle breeding of germplasm was intensively tested in the region and proved competitive for achieving rust resistance and general adaptation. Incorporation of gene *LrTR* from an Australian breeding line (designated i-286064 by the Vavilov Institute) made a tremendous impact on production when it was initially used in varieties such as Tertsia, Sonata, Duet and Sibakovskaya Yubileynaya. Gene *LrTR* located on chromosome 6B (Tsilke 1984) provided good protection for more than 10 years with varieties possessing the gene covering up to 25% of wheat area in the region in 2005. However, virulent pathotypes were detected on varieties possessing *LrTR* in 2007 . The initial source material for *LrTR* was possibly brought by I.A. Watson or R. McIntosh during their visits to to the USSR in the 1970s and given the time and the fact that the gene was located on chromosome 6B, it is very likely to be *Lr9* (McIntosh pers comm). The leaf rust reactions of spring wheat varieties released and cultivated in the region are provided in Table 7. Several varieties released after 2003 continue to have acceptable levels of resistance.

TABLE 7 HERE

Utilization of wheat genetic resources in rust resistance breeding

Vavilov (1965) in his fundamental work titled "The laws of natural immunity of plants to infectious diseases" emphasized the importance of genetic resources for rust resistance. His studies covering a wide range of environments in the USSR demonstrated high levels of rust resistance in species *T. boeoticum*, *T. monococcum* and *T. timopheevii*. The Vavilov Institute was always at the forefront of wheat pathology and wheat rust research emphasizing not only the host, but also the pathogen. Research by I. Odinstova and her colleagues in 1980s provided theoretical and practical bases for resistance breeding including consideration of different strategies for gene deployment. Evaluation and utilization of genetic resources for rust resistance involved both cultivated wheat considered globally, and wild and related species. Two recent catalogs (Mitrofanova 2004, 2007) list rust resistant germplasm of winter and spring wheats, respectively.

Conclusions

Genetic protection of wheat in Russia and Ukraine against leaf rust has employed different strategies involving utilization of major genes, introgression of major genes from wild relatives, alien translocations and slow rusting. The use of major gene protection proved as in other countries that sooner or later the pathogen evolves to overcome the resistance. Thus future efforts must focus on ways to find new resistance alternatives. Although being used by a number of breeding programs in

Russia, slow rusting has yet to be adopted as a main strategy for wheat protection, and its use in conjunction with major genes is yet to be better understood. Monitoring of the rust population has occurred across the country and there are reliable data on the structure of the pathogen population. This, coupled with close cooperation between pathologists and breeders, is an important pre-requisite for successful rust resistance breeding. Yellow rust and stem rust seem to be of only minor regional importance at present.

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Table 1 Wheat areas harvested and average yields in the Russian Federation and Ukraine, 2000-2008 (http://faostat.fao.org)

Year	Russian Federation		Ukraine	
	Area harvested, m ha	Yield, t/ha	Area harvested, m ha	Yield, t/ha
2000	21.34	1.61	5.16	1.97
2001	22.83	2.06	6.88	3.10
2002	24.48	2.07	6.74	3.04
2003	20.06	1.70	2,46	1.47
2004	22.92	1.98	5.53	3.17
2005	24.68	1.93	6.57	2.84
2006	23.05	1.95	5.51	2.53
2007	23.50	2.10	5.95	2.34
2008	26.07	2.45	7.05	3.67

Table 2 Wheat rust resistance genes effective against the pathogen populations in Ukraine

Genes effective at both the seedling and adult plant stages	Genes effective at the adult stage only
Leaf rust	
Lr9, Lr19, LrAc[1], *LrTe*[2], *LrAd4*[3]	*Lr24, Lr25, Lr37, Lr42*
Yellow rust	
Yr3c, Yr5, Yr9, Yr10, Yr15, Yr17	*Yr2, Yr3a, Yr3b, Yr4a, Yr4b*
Stem rust	
Sr14, Sr31, SrTe[2], *SrAv*[4], *SrAd4*[3], *SrAc*[1]	*Sr24, Sr25, Sr26, Sr27, Sr36*

[1]*LrAc*, *SrAc* – genes originating from *Aegilops cylindrica*

[2]*LrTe, SrTe* – genes originating from *Triticum erebuni*

[3]*LrAd4, SrAd4* – genes originating from Amphiploid 4 (*Triticum dicoccoides* x *Triticum tauschii*)

[4]*SrAv* – gene originating from *Aegilops variabilis*

Table 3 Reactions of modern winter wheat varieties from the Plant Breeding and Genetics Institute, Odessa, Ukraine, to rusts, 2007-2009

Variety	Pedigree	Leaf rust		Yellow rust		Stem rust	
		Reaction	Type of resistance/genes	Reaction	Type of resistance/genes	Reaction	Type of resistance/genes
Otaman	Zoryanka/Viktoria//Obriy/Albatros// Nikonia	R	Major genes, *LrZ*	R	Major genes, *YrZ*	MS	-
Nebokray	Strumok/Yubileynaya 75	R	Major genes, *LrTt*	MR-MS	-	R	Major genes, *Sr5, Sr36*
Vychovanka Odeska	Obriy/Tr.erebuni//Od162/2*Ukrainka	R	Major genes, *LrTe*	R	Major genes, *YrUkr*	R	Major genes, *SrT*e
Knyaginya Olga	Obriy/Tr.erebuni//Od162/2*Ukrainka	R	Major genes, *LrTe*	R	Major genes, *YrUkr*	R	Major genes, *SrTe*
Lastivka Odeska	Don.polukarl/Ae.variabilis//Ukrainka/ Nikonia	MR-MS	Non specific resistance	R	Major genes, *YrUkr*	R	Major genes, *SrA*v
Erythrospermum 139/09	Od.polukarl/Ae.cylindrica// Od.polucarl./ Kyriya	R	Major genes, *LrAc*	R	Major genes, *YrK*	R	Major genes, *SrA*c
Erythrospermum 249/09	Obriy/Tr.erebuni//Od16/2*Ukrainka// Selyanka	R	Major gene, *LrTe*	R	Major genes, *YrUkr*	R	Major genes, *SrT*e

Table 4 Changes in the virulence of the leaf rust pathogen population in North Caucasus region of Russia, 1980-2000 (Volkova et al. 2002)

Years	*P. triticina* races	Frequency of virulences against *Lr* genes		
		High	Low	Absent
1980 – 1984	5, 7, 15, 21, 25, 54, 58, 62, 77, 105, 122, 130, 144, 149, 192	*1, 2a, 2b, 2c, 3, 11, 14b, 17, 20, 30*	*10, 14a, 16*	*9, 19, 23, 24, 25*
1991 – 1994	2, 15, 16, 21, 25, 52, 62, 77, 92, 122, 123, 130, 144, 192	*3a, 11, 12, 13, 14b, 17, 30*	*18, 21, 28, 34 (+13)*	*9, 19, 24, Tr*
1998 – 1999	2, 5, 6, 15, 16, 21, 25, 28, 44, 51, 52, 57, 61, 62, 77, 92, 105, 122, 140, 141, 144, 149, 163, 169, 170, 179, 192, 222	*3a, 11, 12, 13, 14b, 17, 22a, 22в, 30, 37*	*18, 20, 21, 24, 26, 32*	*9, 19, 38, Tr*
2000	2, 5, 6, 15, 16, 17, 21, 25, 28, 33, 44, 51, 52, 58, 62, 77, 92, 93, 105, 122, 124, 129, 140, 141, 144, 149, 152, 161, 169, 170, 175, 179, 192, 214, СК1, СК2, СК3, НР8, НР9	*2c, 3a, 10, 11, 12, 13, 14a, 14b, 15, 16, 17, 22a, 22в, 27+31, 28, 29, 30, 37*	*18, 21, 24, 32, 33*	*9, 19, 38, Tr*

Table 5 Yield losses during epidemics years and associated changes in the virulence pattern of *P. triticina* in the Volga region, Bezenchuk, 1964-2005 (Vjyushkov et al. 2008)

Epidemic years	Grain yield, t/ha		Correlation coefficient between yield and Leaf rust infection rate[1]	Changes in the pathogen-host interaction
	Susceptible variety	Resistant variety		
1964	1.10 Saratovskaya 29	2.10 Eritrospermum 132-76		Race 77 spread and appearance of pathotypes virulent to *Lr3* (Mironovskaya 808, Bezostaya 1). Vareity Bezenchukskaya 98 loss of resistance to some pathotypes.
1974	2.10 Bezenchukskaya 98	3.20 Zhigulevskaya (*Lr3*+*LrB*)		Maximum spread of race 77/1.2 with virulence to *Lr26*. Loss of resistance by varieties Avrora and Kavkaz.
1983	2.06 Saratovskaya 46	2.93 Olimp (*Lr23*)	-0,854**	Spread of race 77/c with virulence to *Lr10* and *Lr14a*. Loss of resistance by varieties Saratovskaya 46 and Kutulukskaya.
1990	2.83 Saratovskaya 42	4.40 Samsar (*Lr19*)	-0,836**	Virulence to *Lr23* and increase in the frequency of virulence to *Lr26*. Loss of resistance by variety Zhigulevskaya.
1993	1.53 Saratovskaya 29	3.54 Olimp (*Lr23*)	-0,460*	Increase of pathotypes with virulence to *Lr23*. Varieties with *Lr23* maintain good field resistance.
1994	2.11 Saratovskaya 42	3.13 Tulaikoskaya 5 (*LrAg*)	-0,681*	Areas under varieties with *Lr19* (L 503, Samsar) expanded. Virulence to *Lr19* detected. Frequency of virulence to *Lr23* reached 80%.
2000	0.96 Saratovskaya 42	2.06 Tulaikoskaya 10 (LrAg)	-0,674*	The infection of varieties possessing gene *Lr23* increases. Frequency of virulence to *Lr19* exceeds 33%. Loss of resistance by variety Prohorovka with pyramided genes *Lr26*+.
2005	0.88 Prohorovka	1.85 Tulaikoskaya 100 (LrAg)	-0,730**	Maximum spread of virulences to *Lr23* and *Lr19*. Variety Prohorovka shows high susceptibility.

[1]Based on Yield Trial data consisting of 20-30 genotypes with variable responses to leaf rust

Table 6 Leaf rust reactions of spring wheat varieties released in Volga and Ural Mountain regions of Russia, Bezenchuk, 2008. Response = infection type (0-4 scale)/area affected

Variety	Year of release	Pedigree	Lr genes	Leaf rust response	
				At release	2008
Albidum 188	1996	Rodina/FS-3//Ershovskaya 32/3/Albidum 43/4/Saratovskaya 55		4/80	4/100
Albidum 28	1987	Kransnokutka 4/Albidum 2759		4/80	4/100
Albidum 29	1994	Saratovskaya 46// Albidum 43/Kransnokutka 3		4/80	4/100
Albidum 31	2001	Line 23/Saratovskaya 55// Albidum 28		4/80	4/100
Albidum 32	2008	With participation of Saratovskaya 46		4/40	4/60
Amir	2001	Rodina/2*Priokskaya		4/90	4/90
Bashkisrskaya 24	1994	Saratovskaya 46/Leukurum 87		4/90	4/90
Bashkisrskaya 26	2004	Zhnitsa/Kazakhstanskaya 10		4/90	4/90
Belyanka	1999	L-23/Saratovskaya 55//AS-13/Pysar 29/3/ AC38BC	*LrBel*	0	0
Boevchanka	2009	L.70-94/L.196-94-6		3-4/40	3-4/40
Varyag	1997	Saratovskaya 46/NP 876		4/80	4/100
Voevoda	2008	L-504/Kransnokutka 10//L-504/Belyanka	*LrBel*	0	0
Volgouralskaya	2001	Albidum 653*2/Lutescens 29	*Lr19*	4/30	4/70
Voronezhaskaya 12	1998	Bezostaya 1 spring/Kamyshinskaya 3//Kharkovskaya 93		4/90	4/90
Dobrynya	2002	Albidum 28/L-401//Saratovskaya 55/3/L-503	*Lr19*	4/40	4/100
Duet	2003	Erythrospermum 59//Tselinnaya 20/ANK-102	*LrTR* +	0	0
Zhigulevskaya	1984	Bezostaya 1/Bezenchukskaya 98		3/20	4/80
Zhnitsa	1983	Strela/mixture of varieties		4/60	4/90
Zemlyachka	1999	Isheevskaya//Bezostaya 1/Saratovskaya 29/3/ Red River 68		4/80	4/90
Zlata	2009	Ivolga/Prohorovka		4/70	4/70

Iren	1998	Irgina/Krasnoufimskaya 90		4/80	4/80
Isheevskaya	1992	Tr.durum/Tr.aestivum// Albidum 21/3/ Zhigulevskaya		4/60	4/90
Kazanskaya yubileynaya	2004	Omskaya 20/ Lut.204-80-1//Lut.3-86-6		4/80	4/90
Kazakhstanskaya 10	1990	Priboy/Strela		4/70	4/90
Kamyshinskaya 3	1972	Albidum K-19100/Sarrubra		4/80	4/100
Kinelskaya 59	1995	Saratovskaya 35//Lee/Mironovskaya 808	*Lr23/lr23*	4/30	4/90
Kinelskaya 60	1998	Kinelskaya 40/ Nadadores		2-4/5	4/20
Kinelskaya 61	2005	ISWRN-225 / Kutulukskaya // Zavolzhskaya		4/80	4/100
Kinelskaya niva	2007	Tulaykovskaya 1/L-503	*Lr19+ Lr23*	4/25	4/40
Kinelskaya otrada	2009	Tulaykovskaya 1/ K-56395	*Lr23+*	0	0
L 503	1993	Saratovskaya 52/Pysar 29//Saratovskaya 29*6/ Rescue/3/Saratovskaya 46	*Lr19*	0	4/90
L 505	1996	Saratovskaya 55*6/Sonora 64//L-503	*Lr19*	4/20	4/90
Lebedushka	2009	Belyanka/L-1089	*LrBel*	0	0
Lyuba	1988	Minskaya/Leningradka//Bezostaya 1/3/ Moskovskaya 35		4/60	4/80
Lyubava 5	2009	PV-18/Saratovskaya 29//World Seeds 1812/ Saratovskaya 29	*Lr23+ ?*	0	0
Margarita	2008	Krestyanka/Isheevskaya//Simbirka/L.355-83	APR	4/40	4/40
MIS	2003	Trippel/Priokskaya		4/80	4/80
Moskovskaya 35	1975	Minskaya/Bezostaya 1		4/40	4/90
Niva 2	1997	Solo/Kavkaz//Irtyshanka 10		3/10	4/80
Novosibirskaya 15	2003	Bezenchukskaya 98/Irtyshanka 10//Tulunskaya 10/3/ Novosibirskaya 92		4/80	4/80
Novosibirskaya 89	1993	Moskovskaya 21/Saratovskaya 29		4/90	4/90
Omskaya 18	1991	Omskaya 11/Gaines		4/60	4/90
Omskaya 33	2002	L 137-87-39/Omskaya 28		4/90	4/90
Omskaya 35	2004	Omskaya 29/Omskaya 30		4/80	4/80

Omskaya 36	2007			4/80	4/80
Orenburgskaya 13	1993	Pembina/ Albidum 18-73		4/70	4/100
Pamyati Azieva	2000	Saratovskaya 29/3/Irtyshanka 10//Grekum 114/ Kavkaz		4/60	4/90
Pamyati Ryuba	2006	Tertsiya/Erythrospermum 19542	*LrTR*	0	0
Piramida	2000	Kuibyshevskaya 1/Ershovskaya 32	*Lr23+ Lr13*	4/40	4/70
Prohorovka	1996	Omskaya 9/3* Ershovskaya 32 (?)	*Lr26+ ?*	2/1	4/100
Samsar	1994	Saratovskaya 52/Pysar 29//Saratovskaya 29*6/ Rescue/3/Saratovskaya 46	*Lr19*	0	4/70
Saratovskaya 29	1957	Albidum 24/Lutescens 55-11		?	4/90
Saratovskaya 42	1973	Albidum C-1616/Saratovskaya 38		4/80	4/100
Saratovskaya 55	1986	Saratovskaya 29/Saratovskaya 51		4/80	4/100
Saratovskaya 64	2000	Erythrospermum C-1976/Saratovskaya 60		4/80	4/90
Saratovskaya 66	2000	Saratovskaya 46/ Albidum C-1872		4/80	4/100
Saratovskaya 68	2003	Tselinnaya 20/Saratovskaya 60		4/80	4/80
Saratovskaya 70	2002	Albidum C-2015/Leukospermum C-1983		4/80	4/100
Saratovskaya 73	2008	L-2014/Tr.timopheevii		4/40	4/40
Simbirka	1986	Minskaya/Bezostaya 1//Saratovskaya 36		4/80	4/90
Simbirtsit	2007	Krestyanka/Isheevskaya//L-503	APR	4/25	4/25
Tertsiya	1995	ANK-1/ANK-2//ANK-3/3/ANK-7A	*LrTR*	0	0
Timer	2007	Meshinskaya/ Lyuba		4/100	4/100
Tulaykovskaya 10	2003	Albidum 653/Tulaykovskaya 5	*LrAg*	0	0
Tulaykovskaya 100	2007	Albidum 653/Tulaykovskaya 5	*LrAg*	0	0
Tulaykovskaya 5	2001	Erythrospermum 865/Agis 1	*LrAg*	0	0
Tulaykovskaya Zolotistaya	2006	Albidum 653/Tulaykovskaya 5	*LrAg*	0	0
Tulaykovskaya Stepnaya	1998	Hope/Timstein*6// Saratovskaya 29/3/ Saratovskaya 55	*Lr23*	4/40	4/90

Tuleevskaya	2002		?	0	0
Uchitel	2001	Orenburgskaya 1/Tselinogradka//Moskovskaya 35/ Leukurum 51/3/Orenburgskaya 7		4/90	4/100
Favorit	2007	L-2033/Belyanka	*LrBel*	0	0
Fora	1996	Tezanos Pintos Precoz/Carazinho// Siete Cerros 66/3/2*Kinelskaya 30		4/90	4/90
Chelyaba 2	2005	Tezpishar/2*Irtyshanka 10//Tselinnaya 20/ANK-102	*LrTR*	0	0
Ekada 6	2005	Krestyanka/Samsar	*Lr19*	4/60	4/90
Ekada 66	2009	Volzhanka/Hja 21677//Tulaykovskaya Yubileinaya	APR	3-4/15	3-4/15
Ekada 70	2007	Volzhanka/Hja 21677//Tulaykovskaya Yubileinaya	APR	4/25	4/25
Erythrospermum 59	1994	Chaika/Irtyshanka 10		4/40	4/80
Ester	2004	Eta/Line 52-4		4/40	4/40
Yugo-vostochnaya 2	1999	PPG-596/Uralochka/4/Ershovskaya 32/ Rodina//Saratovskaya 46/3/Saratovskaya 55		2/1	4/60
YUV 4	2002	PPG-596/Uralochka/4/Ershovskaya 32/ Rodina //Saratovskaya 46/3/Saratovskaya 55		4/40	4/80
Yuliya	2002	Lutescens 770/Lutescens 29	*Lr19*	4/40	4/100

Table 7 Leaf rust reactions of spring wheats released in western Siberia, Omsk region, 2008

Variety	Year of release	Pedigree	Possible genes	Infection, %	Reaction type
		Early maturing			
Pamyati Azieva	2000	Saratovskaya 29/ Lut.99-80-1		85	S
Altayskaya 92	1995	Novosibirskaya 67/ Lut.4029		68	S
Omskaya 32	2001	Almaz/Omskaya 16// Omskaya 18/3/Chris		84	S
Chernyava 13	2001	ANK-17/2*OmGAU-6		73	S
Strada Sibiri	2002	Rang/Hybrid 21// Irtyshanka 10/3/ TR-55p-6628/ Lut.1633-617		58	S
Tuleevskaya	2003			4	R
Novosibirskaya 15	2004	Bezenchukskaya 98/Irtyshanka 10//Tulunskaya 10/3/ Novosibirskaya 92		10	R
Kazanskaya Yubileynaya	2007	Omskaya 20/ Lut.204-80-1//Lut.3-86-6		50	MS
Omskaya 36	2007			40	MR
Katyusha	2008			78	S
Boevchanka	2009	Lut. 70-94/ Lut. 196 -94-6		10	R
		Medium-maturing			
Omskaya 29	1999	Lut.204-80-1/Lut.99-80-1		90	S
Sibakovskaya 3	1980	Bezostaya 1/Saratovskaya 29		86	S
Tertsiya	1996	ANK-1/ANK-2//ANK-3/3/ANK-7A	*LrTR*	4	R
Niva 2	1998	Solo/Kavkaz// Irtyshanka 10		76	S
Rosinka 2	1999	Mutant 797 (Tselinnaya 21)		66	S
Slavyanka Sibiri	2002	Mutant 777 (Lutescens 65)		53	S
Sonata	2005	Tselinnaya 20/Tertsiya	*LrTR*	20	MR
Omskaya 33	2002	Lut.137-87-39/Omskaya 28		10	R
Duet	2004	Erythrospermum 59//Tselinnaya 20/ANK-102	*LrTR*	3	R

Svetlanka	2004	Omskaya 23/Tselinnaya 26		49	MS
		Late-maturing			
Omskaya 35	2005	Omskaya 29/Omskaya 30		60	S
Omskaya 18	1991	Omskaya 11/Gaines		88	S
Omskaya 24	1996	Sibiryachka 8/ Milturum 1578// Krasnodarskaya 39		96	S
Omskaya 28	1997	Omskaya 12/Semidwarf (Canada)+ free polination		73	S
Erythrospermum 59	1994	Chaika/Irtyshanka 10		57	S
Omskaya 37	2009	Lut. 61-89-100 / Lut.350-89-9		4	R
Sibakovskaya Yubileynaya	2010	Lut. 121*2/ANK-102	*LrTR*	8	R

Fig. 1 Wheat production areas in Russia and Ukraine: Region 1 – winter wheat area of Ukraine and European Russia; Region 2 – spring wheat area of European Russia; Region 3 – spring wheat area of Siberia

Fig. 2 Occurrence of leaf rust and the level of infection in Krasnodar region of Russia, 1971-2006