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Breeding of bread wheat for leaf rust resistance in Russia

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Abstract. Leaf rust, caused by the fungus *Puccinia triticina* Erikss., is one of the most common diseases of wheat in Russia. The paper reviews *Lr*-genes diversity in Russian commercial wheat varieties. Two hundred and sixty-four winter and one hundred and forty-three spring wheat varieties indexed by the State Register of Breeding Achievements in 2005-2018 were studied. It was found that among new varieties, as many as 5% of winter wheat and 30% of spring wheat possess effective seedling resistance. The wide presence of *Lr19* and *Lr9* genes was detected in the spring wheat. Besides, the high resistance to leaf rust was found in spring wheat varieties with new alien *Lr* genes (originated from *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey and *Aegilops speltoides* Tausch. Over 40% of winter wheat varieties have different levels of field resistance as well. The molecular screening revealed three varieties with effective adult plant resistance gene *Lr37*. Other winter wheat varieties include a range of ineffective genes (*Lr1, Lr3, Lr10, Lr26,* and *Lr34*), alone or in various combinations.

1 Introduction

Wheat is an important crop, and leaf rust, caused by the fungus *Puccinia triticina* Erikss., is one of the most common diseases of wheat in Russia [1]. Main grain production in Russia (about 75% of the grain-growing area) is concentrated in the North Caucasus, Central Black Soil, Central, Volga, Volga-Vyatka, Ural and West Siberia regions. In the period between 1990 and 2000 severe epidemics of leaf rust were reported for 2-3 times causing 30-35% of yield loss in the North Caucasian region. Five to 7 epidemics caused 20-30% of yield loss in the Central and Volga regions. In the Central Black Soil Region, the epidemics occurred up to 4 years in a decade and caused 15-20% of yield loss. Severe disease development was observed every two years and caused 15-20% of yield loss in the Volgo-Vyatka and Ural regions [2]. Since 2010, leaf rust incidents have been decreased significantly in all regions of Russia. The depression of the leaf rust development might be caused by climate change and undesirable conditions for pathogen development. Alternatively, a widespread practice of No-Till in arable farming might have caused the spread of other hemibiotroph-induced diseases such as septoriosis and tan spot. Despite the existing environmental problems and common wheat-growing practices, Russian breeders have made a great effort in the design of the rust-resistant varieties. In addition, immunological and genetic protection has contributed to the reduction of leaf rust severity.

Breeding for resistance to leaf rust has been done for over a half-century in Russia. In 1990-2000 the strategy of deployment of varieties with different bases for resistance involving utilization of major genes, introgression of major genes from wild relatives, alien translocations and slow rusting was adopted in the most of Russian Breeding Centers. This approach denies the domination of a single variety, as occurred in the past period [3].

Since 1995 the All-Russian Institute of Plant Protection (VIZR) has been annually evaluating new varieties for leaf rust resistance. During the same period our laboratory has been conducting seedling resistance studies of common wheat varieties recommended for the cultivation in Russia. We found the increasing number of resistant varieties in 2000 as compared to 1990s. Early studies (before 1995) of 61 winter and 100 spring wheat varieties revealed only 4% of resistant bread wheat varieties. The similar proportion of bread spring (121) and winter (62) varieties in 2005 showed 1.8% of winter and 15% of spring wheat varieties resistant to leaf rust [4].

The State Register of Breeding Achievements permitted to use 264 new varieties of winter wheat and 143 of spring wheat in the period between 2005 and 2018. The paper reviews the studies of Russian commercial wheat varieties for leaf rust resistance and characterises the identification of *Lr*-genes.

2 Materials and methods

Two hundred and sixty-four winter and one hundred and forty-three spring wheat varieties were used in this study.

Leaf rust infection was evaluated for 4 isolates with different virulence/avirulence combinations at the seedling stage. All isolates were avirulent to *Lr24* and *Lr29*, and virulent to Thatcher lines (Tc) with *Lr1, Lr2b, Lr2c, Lr3a, Lr3bg, Lr3ka, Lr10, Lr14a, Lr14b, Lr18,* and *Lr30*. The isolates varied in their virulence to *Lr2a, Lr9, Lr15, Lr16, Lr19, Lr20*, and *Lr26*. Ten-fourteen days old seedlings were used in this study. Infection types were recorded according to Mains & Jackson [5]. Infection type “2” suggested allocation of the seedlings to the resistant group, while infection type “3” meant the susceptible group. The molecular markers were used for identification of 20 genes (*Lr1, Lr3a, Lr9, Lr10, Lr19, Lr20, Lr21, Lr24, Lr25, Lr26, Lr28, Lr29, Lr34, Lr35, Lr37, Lr41, Lr47, Lr51, LrSp,* and *Lr6Agi1*). [6, https://maswheat.ucdavis.edu].

3 Results and Discussion

It was found that among the new varieties, as many as 5% of winter and 30% of spring wheat possess seedling resistance. Besides, over 40% of winter wheat varieties had different levels of field resistance.

Presence of *Lr19* and *Lr9* genes was detected widely in the spring wheat indexed in the State Register and recommended for growing in Russia (Table 1). As many as 7% of the varieties carried *Lr19* and 9% carry *Lr9*. (Table 2). The first variety L503 with *Lr19* gene was included into the State Register in 1993 and variety Tertsiya with gene *Lr9* in 1995. The effectiveness of *Lr19* and *Lr9* was lost in the Volga region in the middle of 1990s and in the Ural and West Siberian regions in 2007, respectively. Our study suggests using a gene combination such as *Lr19* or *Lr9* with *Lr26* to provide high effectiveness to combat virulent isolates of leaf rust. Spring wheat varieties Omskaya 37, Omskaya 38 and Omskaya 41 with genes *Lr19+Lr26* and variety Silach with genes *Lr9+Lr26* were highly resistant to the leaf rust at the seedling and the adult plant stages.

Besides, the high resistance to the leaf rust was found in the spring wheat varieties with new alien *Lr* genes. New resistance genes *Lr6Agi1* and *Lr6Agi2* from *Thinopyrum* *intermedium* (Host) Barkworth & D.R. Dewey were found in varieties Belyanka, Favorit, Lebedushka, Voevoda (*Lr6Agi1*), Tulaikovskaya 5, 10, 100, and Tulaikovskaya zolotistaya (*Lr6Agi2*). The varieties have been recommended for cultivation in Volga regions. The *LrSp* gene is not identical to the known effective *Lr* genes. It was transferred from *Aegilops speltoides* Tausch. and identified in the variety Chelyaba 75. Currently, this variety is recommended for cultivation in the Ural region.

Table 1. Wheat varieties with high or partial effective *Lr* genes

Variety	Year [a]	Regions [b]	Variety	Year	Regions
Varieties with gene *Lr9*			**Varieties with gene *Lr19***		
Tertsya	1995	WS ES U NC	L 503 (+*Lr10*)	1993	LV MV CBS U
Tuleevskaya	2002	WS U	Samsar	1994	MV
Splav	2002	NW	L 505 (+*Lr10*)	1996	LV VV U
Duet (+*Lr10*)	2003	WS U	Volgouralskaya	2001	MV
Chelyaba 2 (+*Lr10*)	2005	U	Dobrunya	2002	LV
Pamyati Ryuba	2006	WS U	Yuliya	2002	MV
Udacha	2006	WS	Ariya	2004	U
Nemchinovskaya 24	2006	C, VV	Ecada 6	2005	MV
Alexandrina	2007	WS	Kinelskaya 61 (+*Lr10*)	2005	MV
Kinel'skaya otrada	2009	MV	Kinelskaya Niva	2007	MV U
Novosibirskaya 44 (+*Lr1,Lr10*)	2009	WS	Lebedushka (+*Lr6Agi1*)	2009	LV
			Omskaya 37 (+*Lr26*)	2009	WS
Sibakovskaya yubileinaya (+*Lr1,Lr10*)	2010	WS	Omskaya 38 (+*Lr26*)	2010	WS
			Tulaikovskaya 108 (+Lr?)	2014	LV U
Chelyaba yubileinaya	2010	WS	Tulaikovskaya 110 (+Lr?)	2015	LV
Mariya 1 (+*Lr10*)	2011	WS	Kinelskaya yubileinaya	2016	MV U
Altayskay 110 (+*Lr10*)	2011	WS	Ulyanovskaya 105	2017	MV U
Apasovka (+*Lr10*)	2012	WS	**Varieties with gene *Lr6Agi2***		
Novosibirskaya 18 (+*Lr10*)	2012	WS ES	Tulaikovskaya 5 (+*Lr10, Lr34*)	2001	MV U
Sibirskaya 17	2013	WS	Tulaikovskaya 10	2003	MV VV U
Nemchinovskaya 17	2013	C	Tulaikovskaya zolotistaya	2006	MV LV U
Sibirskiyi Alyans (+*Lr1*)	2012	WS ES	Tulaikovskaya 100	2007	MV
Zauralochka (+*Lr10*)	2014	WS	**Varieties with gene *Lr6Agi1***		
Kinelskaya 2010	2014	MV U	Belyanka	1999	LV
Chelyaba rannaya (+*Lr10*)	2016	U	Favorit	2007	CBE LV MV U
Stolupinskaya (+*Lr10*)	2017	WS	Voevoda	2008	LV
Varieties with gene *LrSp*			**Varieties with gene *Lr24***		
Челяба 75 (+*Lr1*, *Lr10*)	2012	U	Kanyuk (+1AL/1RS, *Lr20*)	2016	C
			KBC Akvilon	2013	C CBE

[a] year of admission for use;
[b] regions recommended for cultivation of wheat variety.
Abbreviation of regions: NW – North Western, C – Central, CBS – Central Black Soil, LV – Low Volga, MV – Middle Volga, VV – Volga-Vyatka, NC – North Caucasus, U – Ural, WS – West Siberia, ES – East Siberia.

Thus, 20% of spring wheat varieties with seedling resistance carry highly or partially effective major genes and indexed by the State Register. One-third of the varieties carries effective *Lr* genes, however, they are not identical to those registered in the Catalogue.

Winter wheat varieties demonstrated the various responses to leaf rust within wheat-growing region. More than half of the studied varieties originated from North-Caucasian breeding program. They showed a certain level of resistance at the adult plant stage under the field conditions.

Table 2. Distribution of *Lr* genes in Russian bread wheat varieties (%)

Wheat	Number of varieties	Genes *Lr9*	*Lr19*	*Lr24*	*Lr6Agi1*	*Lr6Agi2*	*LrSp*	*Lr1*	*Lr10*	*Lr20*	*Lr26*	*Lr34*	*Lr37*	*1AL.1RS*[a]
*Varieties recommended for cultivation in Russia														
Winter	294	1	0	0	0	0	0	16	16	0	12	39	1	1
Spring	213	8,9	6,6	0,9	1,9	1,9	0,5	14,5	42,7	1,4	7,5	6,6	0	0,5
Varieties recommended for cultivation in European regions (Central, Central Black Earth and North Western)														
Winter	96	3	0	0	0	0	0	12	9	0	5	21	0	1
Spring	42	0	5	5	2	2	0	12	31	9	7	5	0	2
Varieties recommended for cultivation in North Caucasus														
Winter	183	0	0	0	0	0	0	21	18	0	16	46	0,5	1
Spring	9	0	0	0	0	0	0	11	55	0	22	0	0	0
Varieties recommended for cultivation in Volga regions (Low and Middle Volga, Volga-Vyatca)														
Winter	124	0	0	0	0	0	0	7	13	0	5	27	0	0
Spring	78	5	14	0	5	4	0	9	37	0	6	8	0	0
Varieties recommended for cultivation in Ural region														
Spring	74	11	9	0	0	4	1	9	42	0	11	7	0	0
Varieties recommended for cultivation in Western Siberia														
Spring	79	15	2	0	0	0	0	17	47	0	7	9	0	0
Varieties recommended for cultivation in Eastern Siberia and Far East														
Spring	38	3	0	0	0	0	0	21	50	0	3	10	0	0

[a] translocation from *Secale sereale* L.

The molecular screening revealed as many as three varieties (Morozko, Graf, Svarog) with an effective adult plant resistance gene *Lr37*. In Russia other winter wheat varieties carry the wide range of ineffective genes, namely *Lr1, Lr3, Lr10, Lr26* and *Lr34* (Table 2). They have either a single gene or various genes combinations. Probably the resistance of these varieties at the adult plant stage is provided by a combination of minor genes.

And though development of resistant varieties using different combinations of race-specific *Lr* genes is challenged by completely or partial loss of their effectiveness, there is still a worldwide interest to this approach. Creation of varieties with the different combinations of *Lr* genes increases the chances to improve the genetic protection of wheat and limits the overcoming wheat resistance. Monitoring of the rust population has been performed across the country and there are reliable data on the structure on the pathogen population and effectiveness of *Lr* genes. In particular, it has been found that the virulence genes of the leaf rust population differs remarkably in West Siberia when compared to the European regions of Russia, as confirmed by phenotypic and molecular analyses. This phenomenon may be largely explained by the high diversity of wheat varieties grown under different climate conditions linked to the usage of a wide range of donors of resistance.

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