Virulence in the *Puccinia triticina* population in the Czech Republic and resistance genes in registered cultivars 1966–2019

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Abstract We present a summary of *Puccinia triticina* virulence surveys in former Czechoslovakia and Czech Republic from the 1960s to 2019. Cultivars Malakoff, Carina, Brevit, Webster, Loros, Mediterranean, Hussar, Democrat and, later Salzmünder Bartweizen, were used as differentials until 2002. Thereafter tests were carried out on Thatcher near-isogenic lines (NILs) possessing resistance genes *Lr1*, *Lr2a*, *Lr2b*, *Lr2c*, *Lr3a*, *Lr9*, *Lr10*, *Lr11*, *Lr13*, *Lr15*, *Lr17a*, *Lr19*, *Lr21*, *Lr23*, *Lr24*, *Lr26* and *Lr28*. In tests with differential cultivars, races 14, 77, 61, 53 and 2 progressively prevailed, first avirulent to cultivar Salzmünder Bartweizen and later virulent. In tests with NILs the average virulence frequency to most *Lr* lines was above 50%. Virulences below 50% included *Lr2a*, *Lr2b*, *Lr2c*, *Lr24* and *Lr28*, and below 1% *Lr9* and *Lr19*. During the 1960s and 1970s *Lr3a* and *Lr26* were commonly used resistance genes. In the first decades of the 21st century genes *Lr37* and *Lr10* prevailed. We used molecular markers to postulate the presence of *Lr1*, *Lr3a*, *Lr10*, *Lr24*, *Lr26*, *Lr28*, *Lr34* and *Lr37* in winter wheat cultivars registered in the Czech Republic.

Keywords Pathogenicity surveys · Multi-pathotype tests · *Triticum aestivum* · *Lr* genes · Resistance gene postulation

Introduction

Leaf rust caused by *Puccinia triticina* Eriks. (*Pt*) is an important pathogen of wheat (*Triticum aestivum* L.) in the Czech Republic where it causes considerable yield losses. Breeding for rust resistance and growing resistant cultivars is the most economic means to protect against rust. Breeding for resistance is greatly assisted by knowledge of virulence in the pathogen population and knowledge of suitable sources of resistance.

Knowledge of virulence in the Czech Republic is also important for studies of rust epidemics. Virulence surveys of the *Pt* population have been undertaken since the 1960s (Šebesta and Bartoš 1968, 1969) and results were published periodically. The most recent report was Hanzalová et al. (2020). The present contribution is a summary of *Puccinia triticina* virulence and resistance genes in winter wheat cultivars in former Czechoslovakia/Czech Republic during 1966–2019.
Materials and methods

Samples of wheat leaf rust were obtained every year, mostly from variety trials located across the country and organized by the Central Institute for Supervising and Testing in Agriculture, Czech Republic. The pathogen was propagated on a susceptible cultivar and single pustules were isolated and tested first on the standard differential cultivars Malakoff, Carina, Bre-vit, Webster, Loros, Mediterranean, Hussar, Democrat (Johnston and Browder 1966) and an additional differential Salzmünder Bartweizen (Lr26). Since 2002 Thatcher near-isogenic lines (NILs) with genes Lr1, Lr2a, Lr2b, Lr2c, Lr3a, Lr9, Lr10, Lr11, Lr13, Lr15, Lr17a, Lr19, Lr21, Lr23, Lr24, Lr26 and Lr28 were used. In the same year laboratory isolates of races 77, 61, 14 and 12 were also tested on differential NILs in order to establish continuity between the old and new sets. Seedlings were inoculated by rubbing leaves with a urediniospore water suspension and then sprayed with water and placed in glass cylinders for 24–48 h to maintain humidity. Thereafter plants were kept in the greenhouse at 18–22 °C. Infection types based on Stakman et al. (1962) were scored after 10–14 days. Leaf rust resistance genes (Lr) in wheat cultivars registered in the Czech Republic were postulated from multi-pathotype test results and later predicted by molecular markers for Lr1, Lr10, Lr19, Lr24, Lr26, Lr28, Lr34 and Lr37 (Hanzalová et al. 2020) (Table 1).

Genomic DNA was isolated from the youngest leaves of 20–30 plants per cultivar. Leaf tissue was frozen in liquid nitrogen, ground to a powder and used for DNA extraction by a commercial kit (Qiagen, Germany). Protocols for individual polymerase chain reactions (PCR) are listed in the Table 1. PCR was performed in a thermal Labcycler (SensoQuest GmbH, Germany). Amplification products were separated by electrophoresis on 1.6% agarose gels stained with ethidium bromide, and visualized under UV light. GeneRuler™ 100 bp DNA Ladder (Fermentas, Lithuania) was used as a molecular weight marker. Thatcher NILs containing the corresponding Lr genes were included as positive controls.

‘Race/physiologic race’ was used to designate isolates pre-2002 whereas ‘pathotype’ was used to describe isolates post 2002.

Results and discussion

Virulence in the pathogen population and physiologic races/pathotypes

Years 1966–2001

Races 14 and 77 dominated in the second half of the 1960s (Table 2). These races were quite different in number of genes for virulence. Race 14 was virulent on only two of nine differentials, race 77 was virulent on all of them (Table 3). In the 1970s the prevailing race was race 77; gradually it gained additional virulence to cv. Salzmünder Bartweizen possessing Lr26 (historically designated with suffix SaBa). Virulence to the cultivar Salzmünder Bartweizen later appeared also in race 14 and other races. Race 77 SaBa prevailed in the second half of the 1970s before being replaced by races 61 and 61 SaBa. Race 61 SaBa gradually increased and was the most important race until the beginning of the 21st century. Race 61 was virulent on four standard differentials (Table 3). The virulence frequency of other races did not exceed 15%, except for race 53 SaBa in the years 1987–1990 at 23.4%. Increased virulence to Lr26 and Lr3a followed the spread of cultivars possessing Lr26 and/or Lr3a.

Race 77 was important also in other European countries; for example, Nover et al. (1964) identified race 77 in leaf rust samples collected in Germany, Bulgaria, Finland, The Netherlands and Norway, as well as the former Czechoslovakia. Race 61 also gained importance in Poland (Dwurazna M., personal communication to Bartoš, 1978), Italy (Pasquini et al. 1979), Germany (Unger O., personal communication to Bartoš, 1978).

Years 2002–2019

Virulence frequency At the time of adoption of NILs to assess pathogen (Table 4) average frequencies of virulence on NILs carrying Lr2a, Lr2b, Lr2c, Lr24 and Lr28 were below 50% with those carrying Lr9 and Lr19. Virulence to the other Lr NILs approached 100%.

Virulence to Lr9 appeared in years 2009, 2010 and 2011 and later in years 2016 and 2017. Virulence to Lr19 was rare, and recorded only in years 2005, 2008 and 2015. Low frequencies of virulence were recorded
for Lr24 in the period 2004–2011, and later rarely exceeded 10%. Virulence to Lr28 fluctuated; in most years it was below 20%. However, incidences 30% and more were recorded in years 2008, 2009, 2013, 2015, 2016 and 2017. Virulences to Lr24 and Lr28 were recorded in Germany as early as 1999 (Gultyaeva 2000). Virulence to Lr24 was found earlier in Romania and Bulgaria along with virulences to Lr24 and Lr28 in Bulgaria (Mesterházy et al. 2000).

Table 1 PCR conditions and primers

| Gene | Chromosome location | PCR product (bp) | References | Amplification conditions |
|------|---------------------|------------------|------------|-------------------------|
| Lr1  | 5DL                 | 760              | Qiu et al. (2007) | 94 °C for 5 min; 35 cycles of 94 °C for 60 s, 65 °C for 60 s, 72 °C for 60 s; 72 °C for 10 min |
| Lr10 | 1AS                 | 310              | Gultyaeva et al. (2009) | 95 °C for 3 min; 35 cycles of 94 °C for 45 s, 57 °C for 45 s, 72 °C for 30 s; 72 °C for 3 min |
| Lr19 | 7DL                 | 512              | Gupta et al. (2006b) | 95 °C for 2 min; 35 cycles of 94 °C for 60 s, 60 °C for 60 s, 72 °C for 60 s; 72 °C for 7 min |
| Lr24 | 3DL                 | 607              | Gupta et al. (2006a) | 95 °C for 2 min; 36 cycles of 94 °C for 60 s, 60 °C for 60 s, 72 °C for 60 s; 72 °C for 7 min |
| Lr28 | 4AL                 | 570              | Cherukuri et al. (2005) | |
| Lr26 | 1BS                 | 412              | De Froidmont (1998) | 94 °C for 3 min; 35 cycles of 95° for 45 s, 62 °C for 45 s, 72 °C for 45 s; 72 °C for 10 min |
| Lr37 | 2AS                 | 259              | Helguera et al. (2003) | |
| Lr34 | 7DS                 | 150              | Lagudah et al. (2006) | 5 cycles of 94 °C for 1 min, 55 °C for 1 min, 72 °C for 2 min; 30 cycles of 94 °C for 30 s, 55 °C for 30 s, 72 °C for 50 s; 1 cycle of 94 °C for 30 s, 55 °C for 30 s, 72 °C for 5 min |

Table 2 Most important races during years 1966–2002

| Years     | Races (frequencies %) |
|-----------|-----------------------|
| 1966–1969 | 77 (34.5), 14 (34.5)  |
| 1970–1973 | 77 (41.6), 14 (23.2), 1 (6.5) |
| 1974–1976 | 77 SaBa (87.2), 77 (5.4), 14 (2.7) |
| 1977–1980 | 77 SaBa (50.2), 61 (22.0), 14 (8.0) |
| 1981–1983 | 61 SaBa (41.3), 61 (39.4), 14 (9.0) |
| 1984–1986 | 61 SaBa (42.9), 61 (16.7), 14 (7.9) |
| 1987–1990 | 61 SaBa (42.8), 53 SaBa (23.4), 2 SaBa (12.4) |
| 1991–1993 | 61 SaBa (51.0), 2 SaBa (13.8), 61 (9.6) |
| 1994–1996 | 61 SaBa (7.2), 2 SaBa (6.0), 62 SaBa (10.0) |
| 1997–1999 | 61 SaBa (49.0), 2 SaBa (14.0), 12 SaBa (4.0) |
| 2000–2002 | 61 SaBa (29.0), 12 SaBa (12.0), 2 (11.0) |

There was a low average virulence frequency for Lr1 during 2002 - 2007, followed by a rapid increase from the year 2008, even reached 100% and 98% in years 2013 and 2018, respectively. An increased virulence frequency for Lr1 was reported earlier by Gultyaeva et al. (2000) in central Russia.

Pathotypes

The most frequent pathotypes (combinations of individual virulences) are summarized in Table 5. Pathotypes 4 and 5 differed only in avirulence/virulence to Lr15. They were characteristic for the first and the beginning of the second decade of tests, together with pathotypes 8 and 9, that differed in avirulence/virulence to Lr28. Pathotype 11 was the most common one in the second decade of the tests. Most of the pathotypes prevailing in the period 2002–2019 were virulent to Lr3a and Lr26. Table 3 enables a comparison between the data obtained on standard differential cultivars and on NILs.
Leaf rust resistance genes in registered cultivars 1966–2002

Earlier data on leaf rust resistance genes were based on phenotypic analysis (multi-pathotype tests) in combination with F2 segregation data from crosses. Data on Lr genes in some wheat cultivars grown in the 1960s in former Czechoslovakia and abroad were published by Bartoš et al. (1969). Cultivars possessing Lr3a from the former Soviet Union were introduced after the World War II (Table 6). Initially, cultivar Mironovskaya 808 prevailed, followed by other cultivars carrying Lr3a, including Bezostaya 1, Yubileynaya 50, and Ilyitchovka. Another important gene was Lr26 present in the 1BL.1RS translocation, which was originally developed in Germany. This gene became almost universally distributed in varieties developed from the 1960s. The translocation first appeared in the former Czechoslovakia with cultivars Aurora and Kavkaz from the former Soviet Union and soon was also widely used in Czech and Slovak cultivars such as Solaris, Amika, and Iris.

2002–2019

Application of molecular markers at the beginning of the 21st century led to postulation of several other genes (Table 6) such as gene Lr37 for adult plant resistance (APR), and Lr10. Genes Lr26 and Lr3a continued to be present. Gene Lr28 played an important role only for a limited period; it was present in cv. Frisky, Gordian, Tobak, SY Passport, and WPB Calgary. Lr37 and Lr10 were also common in other European countries. Serfling et al. (2011) reported similar results from molecular marker assays of 115 German cultivars; Lr37 was recorded in 42% and Lr10 in 30% of them. Multi-pathotype tests on 275 cultivars grown in France identified Lr37 in 45%, and Lr10 in 34% of tested cultivars (Goyeau and Lannou 2011). Lr37 together with stem rust resistance gene Sr38 and yellow rust resistance gene Yr17a was derived from Aegilops ventricosa. In the first decade of the 21st century cultivars possessing Lr37 tested in State Trials by the Czech Republic Central Institute for Supervising and Testing in Agriculture included Corsaire (Lr3a); Clever, Globus, Ilias, and Rapsodia (Lr10 & Lr26), Caphorn and Biscay (Lr10 & Lr13); and Orlando (Lr26). All were rated highly resistant leaf rust scores of 7.5–8 on a 0 (susceptible) – to 9 (highly resistant) scale. The APR conferred by Lr37 decreased from about 2010. Gene Lr24 derived from

| Table 3 | Comparison of selected leaf rust races (1966–2001) with pathotypes (2002–2019) |
|---------|-----------------------------------------------------------------------------|
|         | Pre 2000 | Post 2000* |
| **Differential cultivar** | **NIL** | 77 | 61 | 14 | 12 | 4 | 5 | 8 | 9 | 11 |
| Malakoff | Lr1 | V | A | A | A | A | A | V | V | V |
| Webster | Lr2a | V | A | A | A | A | A | A | A | A |
| Carina | Lr2b | V | A | A | A | A | A | A | A | A |
| Brevit, Loros | Lr2c | V | V | V | V | V | V | V | V | V |
| Mediterranean, Democrat | Lr3a | V | V | A | V | V | V | V | V | V |
| Lr9 | A | A | A | A | A | A | A | A | A | A |
| Lr10 | V | V | A | V | – | – | – | – | – | – |
| Hussar | Lr11 | V | V | V | V | V | V | V | V | V |
| Lr15 | V | A | A | A | A | V | V | V | V | V |
| Lr17a | V | V | V | V | V | V | V | V | V | V |
| Lr19 | A | A | A | A | A | A | A | A | A | A |
| Lr21 | V | V | V | V | V | V | V | V | V | V |
| Lr23 | V | V | V | V | V | V | V | V | V | V |
| Lr24 | A | A | A | A | A | A | A | A | A | A |
| SaBa | Lr26 | A | A | A | A | V | V | V | V | V |
| Lr28 | A | A | A | A | A | A | A | A | A | A |

*Pathotypes according to Table 5
Thinopyrum ponticum was identified in several less widespread cultivars (e.g. RGT Cesario, Futurum, Sheriff).

| Table 4 | Frequency of virulent isolates (%) on NILs possessing Lr genes |
|---------|---------------------------------------------------------------|
| Lr gene | 2002  | 2003  | 2004  | 2005  | 2006  | 2007  | 2008  | 2009  | 2010  | 2011  |
| Lr1     | 3     | 10    | 12    | 14    | 12    | 21    | 82    | 96    | 92    | 67    |
| Lr2a    | 8     | 7     | 21    | 18    | 15    | 25    | 44    | 35    | 5     | 9     |
| Lr2b    | 14    | 33    | 23    | 28    | 25    | 35    | 22    | 39    | 5     | 7     |
| Lr2c    | 92    | 83    | 61    | 66    | 70    | 72    | 24    | 41    | 13    | 12    |
| Lr3a    | 94    | 88    | 90    | 94    | 94    | 92    | 78    | 76    | 89    | 64    |
| Lr9     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 2     | 3     | 2     |
| Lr10    | 81    | 77    | 92    | 92    | 95    | 88    | 87    | –     | –     | –     |
| Lr11    | 83    | 93    | 90    | 91    | –     | 96    | 90    | 93    | 95    | 93    |
| Lr13    | –     | –     | –     | –     | –     | –     | –     | 100   | 95    | 100   |
| Lr15    | 20    | 35    | 72    | 75    | 70    | 96    | 92    | 85    | 97    | 91    |
| Lr17a   | 97    | 95    | 89    | 67    | 66    | 84    | 78    | 100   | 97    | 78    |
| Lr19    | 0     | 0     | 0     | 1     | 0     | 0     | 2     | 0     | 0     | 0     |
| Lr21    | 81    | 88    | 95    | 86    | 91    | 87    | 94    | 100   | 95    | 88    |
| Lr23    | 92    | 95    | 85    | 95    | 86    | 76    | 56    | 87    | 98    | 84    |
| Lr24    | 22    | 17    | 3     | 0     | 0     | 0     | 0     | 6     | 4     | 8     |
| Lr26    | 67    | 50    | 69    | 74    | 72    | 45    | 56    | 67    | 78    | 60    |
| Lr28    | 14    | 5     | 9     | 12    | 12    | 19    | 30    | 33    | 13    | 7     |
| Total number of isolates | 35  | 60    | 53    | 65    | 72    | 46    | 50    | 46    | 64    | 54    |

| Lr gene | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | Average % 2002–2019 |
|---------|------|------|------|------|------|------|------|------|----------------------|
| Lr1     | 72   | 100  | 94   | 76   | 53   | 82   | 98   | 95   | 60                   |
| Lr2a    | 9    | 0    | 14   | 20   | 0    | 20   | 2    | 2    | 14                   |
| Lr2b    | 7    | 0    | 17   | 29   | 32   | 18   | 0    | 3    | 19                   |
| Lr2c    | 11   | 0    | 14   | 31   | 32   | 22   | 0    | 5    | 36                   |
| Lr3a    | 69   | 100  | 90   | 37   | 97   | 51   | 96   | 95   | 83                   |
| Lr9     | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0.4                  |
| Lr10    | –    | 100  | 97   | 96   | 88   | 84   | 100  | 100  | 91a                  |
| Lr11    | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 96                   |
| Lr13    | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 99b                  |
| Lr15    | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 100  | 83                   |
| Lr17a   | 91   | 100  | 100  | 88   | 100  | 82   | 100  | 100  | 90                   |
| Lr19    | 0    | 0    | 0    | 2    | 0    | 0    | 0    | 0    | 0.3                  |
| Lr21    | 94   | 96   | 97   | 100  | 100  | 100  | 98   | 94   | 94                   |
| Lr23    | 91   | 96   | 100  | 96   | 91   | 80   | 96   | 100  | 89                   |
| Lr24    | 11   | 22   | 19   | 10   | 15   | 11   | 6    | 14   | 10                   |
| Lr26    | 70   | 100  | 75   | 71   | 79   | 89   | 92   | 97   | 73                   |
| Lr28    | 6    | 39   | 11   | 32   | 35   | 31   | 23   | 15   | 19                   |
| Total number of isolates | 55  | 23   | 36   | 49   | 34   | 45   | 51   | 61   | 545                  |

| aExcept years 2009–2012 |
| bExcept years 2002–2008 |
Gene \textit{Lr28} originating from \textit{Triticum speltoides} was present in cultivar Tobak that was widely grown in the Czech Republic following its release in 2013. The breakdown of resistance conferred by \textit{Lr28} affected its response: in 2011–2014 Tobak was scored resistant (7) in the State Trials, in 2015 the average score of 2.7 from 11 field trials showed a rapid loss of effectiveness.

\textit{Gene Lr10}, the second most common gene in the prevailing cultivars is not widely effective on its own but may have a role in gene combinations in some regions (McIntosh \textit{et al.} 1995). Genes \textit{Lr13} and \textit{Lr34} condition resistance at the adult plant stage with \textit{Lr13} becoming effective at an earlier growth stage then \textit{Lr34} (McIntosh \textit{et al.} 1995).

Genes \textit{Lr34} (cv. Astella, Samanta, Svitava), \textit{Lr1} (cv. Atuan, Butterfly, Rivero) and \textit{Lr19} (Slovak cv. Bona Dea) were identified by molecular markers in addition to \textit{Lr10}, \textit{Lr13}, \textit{Lr24}, \textit{Lr26}, \textit{Lr28}, and \textit{Lr37}. Pathan and Park (2006) postulated \textit{Lr13} in eight cultivars as well as \textit{Lr3ka}, \textit{Lr14a}, and \textit{Lr17b} in single cultivars registered in the Czech Republic in addition to \textit{Lr3a} and \textit{Lr26} recorded also by us. A high frequency of \textit{Lr13} in European cultivars was noted by Winzeler \textit{et al.} (2000) and Serfling \textit{et al.} (2011). Gene \textit{Lr13} is likewise probably quite frequent in cultivars grown in the Czech Republic. However, a molecular marker for \textit{Lr13} was not used in the present work.

Virulence changes in the \textit{Pt} population in the former Czechoslovakia/Czech Republic can be only partially attributed to selection by resistance genes in the local cultivars. Changes in the prevailing races/pathotypes were quite rapid and the virulences unnecessary to match the resistance genes were present in all races/pathotypes. The same or similar races/pathotypes in many European countries suggests widespread interchange of airborne inoculum. Winds carrying urediniospores from eastern and southeastern Europe likely contribute to rapid race changes. Sporadically occurring races are presumed to be of local origin from overwintering rust mycelium producing urediniospores in spring.

Molecular studies on isolates of \textit{P. triticina} from several countries across Europe and Turkey confirmed the presence of several different race groups across the area (Kolmer \textit{et al.} 2013) and proved widespread migration. The use of similar resistance genes in different countries also lead to the likely isolation of similar races. Host gene markers revealed the presence of more genes than had been identified previously, but the role of some of them, such as \textit{Lr10}, in influencing

**Table 5 Predominant leaf rust pathotypes in the years 2002–2019**

| No. | Virulence for genes | Years of incidence |
|-----|---------------------|--------------------|
| 1   | \textit{Lr2c}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23} | 2002, 2005 |
| 2   | \textit{Lr2b}, \textit{Lr2c}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2003, 2005, 2007 |
| 3   | \textit{Lr2a}, \textit{Lr2b}, \textit{Lr2c}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2004 |
| 4   | \textit{Lr2c}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2003, 2004, 2007 |
| 5   | \textit{Lr2c}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2003, 2004, 2007 |
| 6   | \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2004, 2007 |
| 7   | \textit{Lr1}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr26} | 2008 |
| 8   | \textit{Lr1}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2006, 2008, 2009, 2010, 2011 |
| 9   | \textit{Lr1}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26}, \textit{Lr28} | 2006, 2008, 2009, 2010, 2011 |
| 10  | \textit{Lr1}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23} | 2008, 2010, 2011 |
| 11  | \textit{Lr1}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019 |
| 12  | \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23} | 2012 |
| 13  | \textit{Lr1}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26}, \textit{Lr28} | 2013, 2018, 2019 |
| 14  | \textit{Lr1}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26} | 2014, 2015, 2017 |
| 15  | \textit{Lr2b}, \textit{Lr2c}, \textit{Lr3a}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr21}, \textit{Lr23}, \textit{Lr26}, \textit{Lr28} | 2016 |

Differentials: TC NILs; \textit{Lr1}, \textit{Lr2a} \textit{Lr2b}, \textit{Lr2c}, \textit{Lr3a}, \textit{Lr9}, \textit{Lr11}, \textit{Lr15}, \textit{Lr17a}, \textit{Lr19}, \textit{Lr21}, \textit{Lr23}, \textit{Lr24}, \textit{Lr26}, \textit{Lr28}
race frequencies was unclear. An important advantage of molecular markers is the fast determination of the presence of genes for adult plant resistance in laboratory tests rather than time-consuming adult plant tests. However, virulence analyses by seedling tests on differentials still remain important for resistance breeding and, at present, can be only partially replaced by molecular methods.

**Table 6**  Prevailing wheat cultivars and *Lr* genes in years 1966–2019

| 1966–1980 | 1981–1994 | 1995–2001 | 2002–2010 | 2011–2019 |
|-----------|-----------|-----------|-----------|-----------|
| Cultivar  | *Lr* genes | Cultivar  | *Lr* genes | Cultivar  | *Lr* genes | Cultivar  | *Lr* genes | Cultivar  | *Lr* genes |
| Kasťická | – | Vala | – | Brea | *Lr*3a | Sulamit | Bohemia |
| osinatá  | Fanal | – | Regina | – | Hana | *Lr*3a | Batis | *Lr*3b |
| Qualitas | – | Zdár | – | Samanta | *Lr*3c, *Lr*13c | Ebi | – | Potenzial | *Lr*10, *Lr*37 |
| Jubilar | – | Košutka | – | Bruta | *Lr*3a, *Lr*14c | Alana | *Lr*10 | Magister |
| Pavlovická | – | Amiška | *Lr*3a, *Lr*26 | Boka | *Lr*3b, *Lr*34 | Ludwig | Elly | *Lr*37 |
| 198 | Mironovskaya | *Lr*3a | Iris | *Lr*26 | Mona | *Lr*3c, *Lr*13c, *Lr*26c | Ilias | *Lr*37 | Mulan | *Lr*10, *Lr*37 |
| 808 | Bezostaya 1 | *Lr*3a | Ilona | – | Vlada | *Lr*3b, *Lr*3a, *Lr*13b | Rheia | *Lr*37 | Julie | *Lr*37 |
| Slavia | – | Viginta | *Lr*3a | Siria | *Lr*10b, *Lr*13b, *Lr*26b | Rapsodia | *Lr*10, *Lr*26, *Lr*37 | Genius | *Lr*10, *Lr*37 |
| Zora | – | Hana | *Lr*3a | Alka | *Lr*10 | Eitela | *Lr*26 | Vanessa | *Lr*26, *Lr*37 |
| | Yubileynaya | *Lr*3a | Danubia | *Lr*26 | | Mulan | *Lr*10, *Lr*37 | Patras | *Lr*10 |
| 50 | Ilyitchovka | *Lr*3a | Selektka | *Lr*26 | | Bohemia | Evina | *Lr*37 |
| | Grana | *Lr*3a | Sparta | *Lr*3b, *Lr*13b, *Lr*26 | | Cubus | *Lr*10, *Lr*26 | Turandot |
| | | | | | | | | | |
| Aurora | *Lr*3a, *Lr*26 | | | | | | | | |
| | Kavkaz | *Lr*26 | | | | | | | |
| | Solaris | *Lr*26 | | | | | | | |

Genes postulated by molecular markers are in bold

*Prevalence was estimated according to the area under seed increase (Central Institute for Supervising and Testing in Agriculture, 1966–2019)*

*Tested by Pathan and Park (2006)*

*Tested by Park et al. (2001)*

– Not tested

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Code availability Not applicable.

Data availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. Seeds are not publicly available until released as commercial genotypes.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval Not applicable.

Consent to participate Not applicable.

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