Powdery Mildew Resistance of Czech and Slovak Spring Barley Breeding Lines in Variety Trials

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Abstract: In 2001–2005, resistance to powdery mildew was studied in 227 Czech and Slovak breeding lines of spring barley included in the breeding station trials or official trials. Seventeen known resistances were identified (Al, Ar, At, HH, Kr, La, Ly, Mlo, N81, Ri, Ru, Sp, St, Tu, We, *Mla21*, and *Mlp1*). Unknown resistances were found in 11 breeding lines, in five of which resistance was effective against all used pathotypes of the pathogen. Besides the identified resistances, unknown resistances were detected in another three breeding lines. Sixty-five breeding lines (= 29%) exhibited heterogeneity in the examined trait, i.e. they are composed of components with different resistances to powdery mildew. Comparison of current results with the previous ones shows a considerable increase in the proportion of breeding lines carrying the resistance Mlo (72%), on the account of the resistances located at the *Mla* locus, particularly Ru. The examined set is characterised by a high proportion of breeding lines resistant to all used Czech pathotypes of the given pathogen (78%), however of low diversity in the resistance.

Keywords: *Blumeria graminis* f.sp. *hordei*; *Erysiphe graminis* f.sp. *hordei*; powdery mildew; *Hordeum vulgare* L.; spring barley; breeding lines; resistance

Growing cultivars resistant to diseases is the cheapest, effective and health-safe way to protect any widely grown crop. For a long time, great efforts have been focused on breeding barley (*Hordeum vulgare* L.), particularly spring one, for resistance to the most common disease, powdery mildew (Dreiseitl 2003), which is caused by the fungus *Blumeria graminis* (DC.) Golovin ex Speer f.sp. *hordei* Em. Marchal (= *Bgh*).

Both barley breeders and specialists need to know not only the actual resistance of cultivars and breeding lines in the field (Dreiseitl & Pařízek 2003) but also the genetic background of this resistance that enables to predict the level of and/or changes in such an important trait.

Therefore, the objective of this study was to identify specific resistances to powdery mildew possessed by Czech and Slovak breeding lines of spring barley and based on these results, to judge the effectiveness of the identified resistances, diversity and homogeneity of the set considering the examined trait and to compare the current status of resistance with the earlier findings.

MATERIAL AND METHODS

Barley germplasm. Two hundred and one Czech and twenty-six Slovak (SK) spring barley breeding lines included in the interstation or official trials in 2001–2005 were studied. All the breeding lines were grown from the seed provided by respective breeders.

Pathogen isolates. Sixteen pathotypes of *Bgh* held in the gene bank at the Agricultural Research Institute Kroměříž were used for inoculation of the tested breeding lines in 2001 and 30–32 pathotypes in the following four years. Between the tests in individual years, several pathotypes were always

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. 1P05OC045.

replaced by new ones with greater resolving power. Before inoculation, each pathotype was purified, verified for the correct virulence phenotype on the differential hosts and increased on cultivars Pallas or Monaco.

Inoculation procedure. About 6–8 seeds per breeding line were sown in pots (60 mm upper diameter) in the glasshouse at a continuous temperature of 17 ± 2°C under natural daylight. Pots were placed in mildew-proof glass boxes before seedling leaves emerged. Ten-day-old plants whose first leaves were fully expanded were separately inoculated with a *Bgh* pathotype by brushing and shaking conidia from infected plants over them.

Evaluation of reaction types. Reaction types on the upper part of adaxial sides of the first leaves were scored nine days after inoculation. The nine point 0–4 scale (including intermediate types) was used for scoring reaction types (Torp *et al*. 1978). This scoring scale was supplemented with reaction type 0(4) (i.e. reaction type 0 with a few reaction type 4 colonies) (Jensen *et al*. 1992), which is characteristic of varieties carrying the Mlo resistance.

Verification of resistance spectra. Each breeding line was tested in two replications. If there were significant differences between replications in reaction types, additional tests were carried out.

Identification of resistance genes. Resistance genes in each breeding line were postulated on the basis of the gene-for-gene hypothesis by comparing their resistance spectra, based on their reaction types, with previously determined spectra on barley differentials with known resistance genes (Dreiseitl 2005).

RESULTS

All of the 227 examined breeding lines and detected resistances to powdery mildew are listed in Table 1. A total of 17 known (Al, Ar, At, HH, Kr, La, Ly, Mlo, N81, Ri, Ru, Sp, St, Tu, We, *Mla21*, and *Mlp1*) and another unknown resistances were found. The plants of 65 breeding lines exhibited different RTs, it means they are composed of components (usually of two) with different resistances to powdery mildew. Among these heterogeneous breeding lines, resistance of both components was identified in five of them, resistance of one component in 32 breeding lines and in six breeding lines it was at least found that one of the components carried fully effective, however unidentified resistance. No resistance of any concerned components was identified in 22 heterogeneous breeding lines.

Seventeen resistances to powdery mildew were identified in 152 out of 162 homogeneous breeding lines. The frequencies of 11 known resistances are given in Table 2. The Mlo resistance dominated in the examined set when it was found in 117 homogeneous and in one of two components of another 29 heterogeneous breeding lines. The second most frequent resistance was La detected in 10 homogeneous lines and one heterogeneous breeding line. Other nine resistances (Al, Ar, HH, N81, Ri, Ru, St, Tu, and We) were found in two to eight breeding lines (including heterogeneous ones). Of them, the resistances Ri and Tu were always detected together. An unknown resistance [U(E)] was found in 10 breeding lines, in four of which it was effective against all of the *Bgh* pathotypes employed. Besides the identified resistances, unknown (unidentified) resistances (U+) were found in another three breeding lines. However, these resistances are not presented in Table 2.

In six homogeneous lines and one heterogeneous breeding line, other six resistances were found ("Others" in Table 2), of which the resistance Kr was detected in the breeding line CE-1032, resistance Sp (detected with La also in one of two components of HE-9577) in HE-7513, resistance Ly (together with La and We) in HE-8891, resistance At in HE-9278, the resistance controlled by the gene *Mla21* in KM-2391, and the resistance controlled by the gene *Mlp1* in SG-S 256.

All breeding lines, in which the resistance Mlo was found, possessed another or more resistances. In some of the breeding lines this additional resistance was identified and is given in Table 1. However, neither these additional resistances nor unidentified (and thus unknown) resistances of heterogeneous breeding lines are included in Table 2.

DISCUSSION

In 2001–2005, a total of 227 breeding lines of spring barley were gradually tested, among which 17 known and another unknown resistances to powdery mildew were identified. The breeding lines possessing the resistances Mlo and Tu, resistances controlled by the genes *Mlp1* and *Mla21*, and unknown, fully effective resistances [U(E)], i.e. 126 out of 162 homogeneous breeding lines (= 78%), were resistant to all home pathotypes of the pathogen. In 65 heterogeneous breeding

Table 1. Two hundred and twenty-seven Czech and Slovak breeding lines of spring barley included in variety trials in 2001–2005 and their resistance to powdery mildew

Line	Resistance[1]	Line	Resistance	Line	Resistance
BR-6071[2]	Mlo	HE-8660	Mlo	HE-9540	Mlo
BR-6547	H (Mlo+U)	HE-8665	Mlo	HE-9558	H (Mlo+HH)
BR-6610	H	HE-8666	Mlo	HE-9577	H (Sp, La+La)
BR-6680	Mlo	HE-8667	H	HE-9588	N81
BR-6686	H (Mlo+U)	HE-8681	Mlo	HE-9592	H
BR-6687	H (Mlo+U)	HE-8795	Mlo	HE-9623	H (Mlo+U)
BR-6693	H (Ri, Tu+U)	HE-8803	H	HE-9660	H
BR-6702	H (Mlo+U)	HE-8804	Mlo	HE-9833	Mlo
BR-6703	H (Mlo+U)	HE-8805	H (Mlo+U)	HE-9859A	Mlo
BR-6704	H (Mlo+U)	HE-8809	H (Ru+U)	HE-9883	U (E)
BR-6731	H (Mlo+U)	HE-8891	Ly La We	HE-9890	H
BR-6893[2]	H (Mlo+U)	HE-8904	Mlo	HE-9901	H
BR-6937[2]	U (E)	HE-8925	Mlo	HE-9919	U
BR-7011[2]	Mlo Ar	HE-8931	Mlo	HE-9940	Mlo
CE-961a	Mlo	HE-9258	HH	HE-9964	H
CE-964	Mlo Al	HE-9261	HH La	HE-9968	Mlo
CE-974	U	HE-9278	H (E+U)	HE-9973	Mlo
CE-976[2]	Mlo	HE-9290	H	HE-9996	Mlo
CE-986	Mlo Ru	HE-9361	H (Mlo+U)	HE-10001	H
CE-998	Ru La	HE-9434	Mlo	KM-2089[2]	H (Mlo+St)
CE-1008	U	HE-8937A	H (Mlo+U)	KM-2283	Ru We U
CE-1012	Mlo	HE-8937B	Ar	KM-2311	N81 La
CE-1019	Mlo Ru	HE-8940	H	KM-2322	Mlo
CE-1024	We U	HE-8954	Ar	KM-2326b	H (Mlo+U)
CE-1030	Mlo HH	HE-8955	Mlo	KM-2343	N81 La
CE-1032	Kr	HE-8971	Mlo	KM-2361	N81
CE-1040	Mlo Ru	HE-8977	Mlo	KM-2391	*Mla21*
CE-1043	Mlo We	HE-9010	Mlo	KM-2394	H (N81+U)
CE-1061	Mlo	HE-9015	H	KM-2416	Mlo
CE-1068	Mlo	HE-9060	H (Mlo+U)	KM-2430	St
CE-1094	Mlo Ru	HE-9187	H (E+U)	KM-2431	H
CE-1149	Mlo	HE-9188	At	KM-2436	Mlo
CE-1169	H (E+U)	HE-9191	H (Mlo+U)	KM-2439	Mlo
CE-1173	Mlo	HE-9203	Ru	KM-2452	H (E+U)
CE-1186	H (E+U)	HE-9247	N81	KM-2456	Mlo
HE-7513[2]	Sp	HE-9439	Mlo	KM-2466	Mlo
HE-7869[2]	Mlo	HE-9448	HH	KM-2493	H
HE-8019[2]	Mlo	HE-9473	Mlo	KM-2506	Mlo
HE-8214	H (Ru+U)	HE-9479	Mlo	KM-2508	Al La
HE-8565	Mlo	HE-9486	N81 La	KM-2519	Mlo
HE-8621A	Mlo	HE-9497	Ar	KM-2555	Ru
HE-8621B	Mlo	HE-9506	U	KM-2617	U (E)
HE-8621C	Mlo	HE-9536	Mlo	KM-2628	H

Table 1 to be continued

Line	Resistance[1]	Line	Resistance	Line	Resistance
KM-2629	Mlo	SG-S 281	Mlo	SG-S 314	Mlo
KM-2636	St	SG-S 282	Mlo	SG-S 315	Mlo
KM-2641	Mlo	SG-S 283	St	SG-S 316	H (Mlo+U)
KM-2651A	H	SG-S 284	Mlo	SG-S 317	U (E)
SG-S 252	Mlo	SG-S 285	Mlo	SG-S 318	Mlo
SG-S 253	Ri Tu	SG-S 286	Mlo	SG-S 319	Mlo
SG-S 254	Ri Tu	SG-S 287	Mlo	SK-5104[2]	H (Ri, Tu+U)
SG-S 255	H (Mlo+U)	SG-S 288	Mlo	SK-5138[2]	H (Mlo+HH)
SG-S 256	*Mlp1*	SG-S 289	Mlo	SK-5139	Mlo
SG-S 257	H (Mlo+U)	SG-S 290	H	SK-5239	Mlo
SG-S 258	Mlo	SG-S 291	Mlo	SK-5374	Ar La
SG-S 259	Mlo	SG-S 292	Mlo	SK-5398	Mlo
SG-S 260	Mlo	SG-S 293	Ri Tu	SK-5401	H (Mlo+U)
SG-S 261	Mlo	SG-S 294	Mlo	SK-5404[2]	N81 La
SG-S 262	Mlo	SG-S 295	Mlo	SK-5430	H
SG-S 263	Mlo HH	SG-S 296	H (N81+La)	SK-5451	St
SG-S 264	Mlo HH	SG-S 297	Mlo	SK-5520	Ru U
SG-S 265	H (E+U)	SG-S 298	Mlo	SK-5525	Mlo
SG-S 266	Mlo	SG-S 299	Mlo	SK-5526	H (Ru+U)
SG-S 267	Mlo Sp	SG-S 300	H	SK-5660	H (Mlo+U)
SG-S 268	Mlo	SG-S 301	H	SK-5665	H (Mlo+U)
SG-S 269	H (Mlo+U)	SG-S 302	Ar	SK-5703	Mlo
SG-S 270	Mlo	SG-S 303	Al	SK-5721	Mlo
SG-S 271	Mlo	SG-S 304	H (Mlo+U)	SK-5734	Mlo
SG-S 272	Mlo	SG-S 305	H	SK-5832	Mlo
SG-S 273	Mlo	SG-S 306	H	SK-5835	Mlo
SG-S 274	H (Mlo+U)	SG-S 307	Mlo	SK-5840	Mlo
SG-S 275	Mlo	SG-S 308	Mlo	SK-5873	U
SG-S 276	H (Mlo+U)	SG-S 309	Mlo	SK-5944	Mlo
SG-S 277	H (Mlo+U)	SG-S 310	Mlo	SK-5976	Mlo
SG-S 278	Mlo	SG-S 311	Mlo	SK-6109	Mlo
SG-S 279	Mlo	SG-S 312	Mlo	SK-6134	Mlo
SG-S 280	Mlo	SG-S 313	Mlo		

[1]Boesen *et al.* (1996); H = heterogeneous, breeding line is composed of two or more components with different resistances to powdery mildew; [2]breeding line was examined only after including in official trials

lines, the resistance effective against all pathotypes was found in 37 out of 44 identified components (84%). It should be noticed, however, that these 44 identified components represent only a third of the total number of at least 130 components that form the mentioned 65 heterogeneous breeding lines. The other 12 identified known resistances, as well as the other unknown (U and U+) resistances found in six breeding lines, cannot be considered valuable for the breeding goal, which is the development of spring barley cultivars resistant to powdery mildew (Hovmøller *et al.* 2000; Dreiseitl & Pařízek 2003).

Breeding lines with unknown resistances were classified into the three groups. Group "U" includes the breeding lines that exhibited both susceptible

Table 2. Frequency of resistances to powdery mildew found in 227 Czech and Slovak spring barley breeding lines included in variety trials in 2001–2005

Resistance code[1]	Resistence gene	Breeder[2]						Sum
		BR	CE	HE	KM	SG-S	SK	
Mlo	*mlo*	3 + 8	14 + 0	31 + 7	10 + 3	45 + 8	14 + 4	117 + 29
La	*MlLa*		1 + 0	4 + 0	3 + 0	0 + 1	2 + 0	10 + 1
N81	*Ml(N81)*			3 + 0	3 + 0	0 + 1	1 + 0	7 + 1
Ru	*Mla13*		1 + 0	1 + 2	2 + 0		1 + 1	5 + 3
Ar	*Mla12*			3		1	1	5
St	*Ml(St)*				2 + 1	1 + 1	1 + 0	4 + 2
Ri Tu	*Mla3, Ml(Tu2)*	0 + 1				3 + 0	0 + 1	3 + 2
HH	*Mla8*			3 + 1				3 + 1
We	*Mlg*		1	1	1			3
Al	*Mla1*				1	1		2
U	unknown		2	2			1	6
U+	unknown		1		1		1	3
U (E)	unknown	1 + 0	0 + 2	1 + 2	1 + 1	1 + 1		4 + 6
Others		0 + 1	1 + 0	3 + 1	1 + 0	1 + 0		6 + 1
No. breeding lines		14	21	70	28	68	26	227
Heterogeneous[3]		10	2	23	8	15	7	65

[1]Boesen *et al*. (1996), if the symbol "+" is in a column, frequency of the corresponding resistance found in homogeneous breeding lines is given first followed by the frequency of the given resistance in heterogeneous lines; [2] BR – Monsanto CR, Ltd; CE – Cezea, Co.; HE – Plant Select, Ltd; KM – Agricultural Research Institute Kroměříž, Ltd.; SG-S – Selgen, Co., Stupice; SK – Hordeum, Ltd; for more details see Dreiseitl (2001); [3]heterogeneous (out of No. breeding lines), breeding lines are composed of two or more components possessing different resistances to powdery mildew

and resistant reaction types and no other resistance was found in them after inoculation with the used pathotypes. Group "U+" includes the breeding lines in which known resistances and besides them another resistances were detected. The latter resistances can be again currently unknown resistances or known resistances that could not be identified besides the identified resistances because of a lower number of pathotypes (due to the presence of identified resistances) characterising the corresponding resistance. Group "U(E)" consists of the resistances to which none of the used pathotypes was virulent. All, or at least some of these resistances may have a common genetic background, or on the contrary, each of them can be controlled by other resistance gene. Another group of unknown resistances, which is not given in Tables 1 and 2, includes resistances of components of heterogeneous breeding lines, in which resistances were not identified. In most cases, these are not apparently unknown resistances, but the resistances that could not be identified due to the heterogeneity of the given sample. If the seed of individual components (Dreiseitl & Rashal 2004) were available, there would be no doubt to identify corresponding resistances in most of them.

Based on rough evaluation of diversity of powdery mildew resistance in breeding lines, this parameter within the examined set could be considered sufficient with regard to the number of detected resistances (16 known and other unknown). However, the proportion of fully effective resistances is low (four out of the 17 identified known resistances) and particularly the proportion of these four resistances is extremely irregular; they are present in 122 homogeneous breeding lines, of which only the resistance Mlo is present in 117 out of them. Thus it can be concluded that the propor-

Appendix 1. Comparison of some results from the study of powdery mildew resistance in three sets of spring barley breeding lines tested in variety trials

Period	Total no. of lines	Homogeneous lines (%)	No. of resistances[1]	Resistances at the *Mla* locus		Mlo (%)[1]
				total (%)[1]	Ru (%)[1]	
1991–1995[2]	216	69	12	80	39	14
1996–2000[3]	348	60	15	70	28	48
2001–2005[4]	227	71	17	10	3	72

[1]known resistances in homogeneous breeding lines; [2]Dreiseitl (1996); [3]Dreiseitl (2001); [4]Results of this contribution

tion of breeding lines (considering homogeneous breeding lines only) with fully effective resistance to powdery mildew is high, however diversity of these fully effective resistances is low since they are represented, except some cases, by the resistance Mlo only.

The 65 breeding lines tested (= almost 29%) exhibited heterogeneity in the studied resistance. Most breeders conduct selections for powdery mildew resistance at the stage of both young and adult plants. Considering this aspect, the assessed level of heterogeneity is high. Dreiseitl and Jørgensen (2000) found nine heterogeneous cultivars (= 13%) in the set of 68 Czech and Slovak registered cultivars of spring barley, however in the set of 33 Latvian cultivars Dreiseitl and Rashal (2004) found 18 heterogeneous ones (= 55%), of which five were composed of even more than two components with different powdery mildew resistance.

If we compare the three sets of breeding lines included in similar trials until now (Dreiseitl 1996, 2001, current results) (Appendix 1), we can see that the critical change is the rapidly decreasing proportion of the earlier significant resistances Al, Ar, Ly, MC, Sp, Ri and Ru located at the *Mla* locus (from 80 to the present 10%), particularly of the resistance Ru (from 39 to 3%), and on the contrary, the largely increased proportion of breeding lines with the resistance Mlo from 14% to the present 72%. This led towards a strong decrease in the diversity of powdery mildew resistance in spring barley breeding lines, but at the same time towards an increase in general effectiveness of resistance of these breeding lines because the resistance Mlo is effective against all known *Bgh* pathotypes and its long-term effectiveness can be assumed.

Therefore, general attention paid to the diversity of powdery mildew resistance in barley should be stressed particularly in cultivars of winter barley. Mlo should not be used in winter barley cultivars since the all-year-round adaptation of the pathogen to such a rare resistance could considerably decrease it. In contrast, current endeavour of some barley breeders to combine Mlo with other fully effective resistances is appreciated because it is focused on protection of the gene *mlo* effectiveness.

Acknowledgements: I thank the owners of varieties for their approval with publishing the presented results.

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Received for publication June 21, 2005
Accepted after corrections August 26, 2005

Abstrakt

Dreiseitl A. (2005): **Odolnost k padlí travnímu českých a slovenských šlechtitelských linií ječmene jarního v odrůdových zkouškách.** Czech J. Genet. Plant Breed., **41**: 160–166.

V letech 2001–2005 byla prostudována odolnost k padlí travnímu ve 227 českých a slovenských šlechtitelských liniích ječmene jarního, zařazených v uvedeném období do mezistaničních či do státních odrůdových zkoušek. Bylo identifikováno 17 známých odolností k padlí travnímu (Al, Ar, At, HH, Kr, La, Ly, Mlo, N81, Ri, Ru, Sp, St, Tu, We, *Mla21* a *Mlp1*). V 11 šlechtitelských liniích byly zjištěny neznámé odolnosti, z toho v pěti liniích byly tyto odolnosti účinné vůči všem použitým patotypům daného patogena. Vedle identifikovaných odolností byly zjištěny neznámé odolnosti v dalších třech šlechtitelských liniích. V 65 šlechtitelských liniích (tj. 29 %) byla zjištěna heterogenita sledovaného znaku, tzn. že jsou tvořeny komponentami s rozdílnými odolnostmi k padlí travnímu. Porovnáním stávajících výsledků s předchozími bylo zjištěno významné zvýšení podílu šlechtitelských linií, obsahujících odolnost Mlo (72 %), a to na úkor odolností lokalizovaných v *Mla* lokusu, zvláště Ru. Sledovaný soubor se vyznačuje vysokým podílem šlechtitelských linií odolných ke všem použitým domácím patotypům daného patogena (78 %), ale nízkou diverzitou sledované odolnosti.

Klíčová slova: *Blumeria graminis* f.sp. *hordei*; *Erysiphe graminis* f.sp. *hordei*; padlí travní; *Hordeum vulgare*; ječmen jarní; šlechtitelské linie; odolnost

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