Resistance of Spring Barley Varieties to Powdery Mildew in the Czech Republic in 1971–2000

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Abstract: Resistance to powdery mildew of 127 spring barley varieties was evaluated in 702 official variety trials, using scores from 1 to 9. Trials with sufficient disease severity were only analysed. Varieties possessing the resistance genes *Mla7* (Elgina), *Ml(Kr)* (BR-1519), *Mla13* (Koral) and *mlo* (Forum) were among the most resistant ones. The varieties Diamant, HE-3527, HE-3631, II/61-FUDII and Zefir showed high susceptibility. Fifteen varieties, carrying the genes *Mla1*, *Mla3*, *Mla6*, *Mla*9, *Mla13*, *Ml(Kr)* and *Ml(Sc)*, were in the first years of testing highly resistant, but became susceptible later. The score of the most resistant variety ranged each year from 8.05 to 9.00, only in 1987–1991 it was lower. Since the pathogen population rapidly adapted to most resistance genes in the mid eighties, no resistant variety was found in 1987–1989. From 1986 to 1995 on average only 6.6% of the tested varieties were resistant, but there was no variety with resistance score above 8.50. High resistance was typical for varieties possessing an effective major resistance gene. Since the resistance of such varieties was not durable, we recommend breeding of varieties with at least two fully effective resistance genes, using molecular markers.

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

Powdery mildew, caused by the fungus *Blumeria graminis* f.sp. *hordei* (syn. *Erysiphe graminis* f.sp. *hordei*), is the most common disease of spring barley (*Hordeum vulgare* L.) in the Czech Republic (Dreiseitl & Jurečka 1996). Therefore, powdery mildew resistance is important in breeding, testing and growing of spring barley varieties (Dreiseitl 1993a,b; Dreiseitl & Paříček 1993; Dreiseitl & Svačina 2001). Special attention is given to the study of new resistance sources (Dreiseitl & Bockelman 2000, 2003; Dreiseitl & Dinoor 2003).

The aim of this work was to use long time results of official variety trials for assessing: (1) changes in resistance of selected spring barley varieties to powdery mildew, (2) changes in resistance of tested groups of varieties, (3) other characteristics providing additional information on resistance of varieties during the period studied.

MATERIAL AND METHODS

Data on powdery mildew resistance scores, recorded in official spring barley variety trials obtained by the Central Institute for Supervising and Testing in Agriculture, were analysed.

Years. The data are from official trials conducted from 1971 to 2000 and include 18 years of registration trials (1971–1988) and 12 years of trials with registered varieties (1989–2000).

Locations. The trials in the period studied were conducted at 37 locations in the Czech Republic (for details see Dreiseitl & Jurečka 2003).

Trials. During the period studied, 923 field trials (year × location × variant) were conducted. Trials with no scores ≤ 6 for at least one variety (a total of 221) were considered as trials with insufficient disease severity and were not used. So, results

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of 702 trials with sufficient disease severity were analysed (for details see Dreiseitl & Jurečka 2003). Of them, 307 trials showed high disease severity with average scores of ≤ 6, disregarding data of resistant varieties with scores > 7.50.

Varieties. A total of 144 varieties were tested ("variety" is used both for registered varieties and candidates for registration). Seventeen varieties were not tested in all locations in their first testing year and therefore their scores were excluded. Thus data of 127 varieties were used (Table 1). In 1971–1973, some varieties were tested in two cropping systems with different fertilisation. Results of both systems were used. For easy orientation, commercial variety names are used also in trials before registration. Original variety designations in registration trials and the year of registration of all varieties (except Elgina, Trumpf and Ditta) are given in Dreiseitl and Jørgensen (2000). Varieties with scores > 7.50 in trials with sufficient disease severity were considered resistant in the respective year, the other varieties were designated "non-resistant" (Table 1).

Data. During the period studied in total 16 171 data [Σ (year × no. trials × no. varieties)] were found. 12 444 data (Σ (year × no. trials with sufficient disease severity × no. varieties)) were analysed. To assess some characteristics 5561 data [Σ (year × no. trials with high disease severity × no. varieties)] were used.

Scores. A 1–9 scale was used for scoring resistance; 1 = the highest susceptibility of the variety (extreme infection of entire plants), 9 = the variety fully resistant (plants are without visible symptoms of infection). Scores ≤ 3 indicate high susceptibility, i.e. heavy infection of the variety. Scores > 8.50 indicate high resistance in trials with high disease severity.

Scoring procedure. In 1971–1988, resistance of each variety was scored once per season. In 1989–2000, resistance was scored in two to four replicates and the average was used.

RESULTS

Classification of varieties. The category "resistant" comprised 149 assessments (an average resistance a variety in a year) and the category "non-resistant" 388 assessments (Table 1). Thirty-four varieties were resistant during the whole period of testing, 67 varieties were non-resistant, and 26 varieties changed these categories during the testing. In the latter group, 10 originally non-resistant varieties advanced during the period of testing to resistant, and on the contrary, 12 originally resistant varieties "fell" in non-resistant. Three originally non-resistant varieties reached the category "resistant" and later, they fell again in the category "non-resistant". The variety Opal shifted the two categories in this period more times. Out of 101 varieties in the first two categories, 39 were tested for a year only.

Frequency of varieties with high resistance. To determine a number of data on high resistance (> 8.50) in individual varieties, results of 307 trials with high disease severity (5561 data) were used. 647 data (11.6%) on high resistance were obtained for 62 varieties (Table 2). Of them, in eight varieties (Atribut, BR-1519, Elgina, Forum, KM-1192, Koral, Krona and Krystal) a number of data on high resistance exceeded 20 for the whole period of testing of each of these varieties. The highest number (67) of data on high resistance was found for the variety Forum. In 12 varieties (in the first seven ones from the previous group and in Heris, Karat, KM-1038, Madeira and Nordus), an average annual number of these data exceeded 5 for the years of their testing and it was even 13 in KM-1192. Distribution of data on high resistance of the selected varieties in individual years is presented in Table 3.

Frequency of varieties with high susceptibility. A number of data on high susceptibility (≤ 3) of tested varieties was determined in 702 trials (Table 2). For 57 varieties, 525 such data were found (4.22% of total number). Of them, in seven varieties (Diamant, HE-3527, II/61-FUDII, Bonus, Favorit, Hana and Zefir) a number of the data on high susceptibility exceeded 20 for the whole period of their testing. The highest number (53) of data on high susceptibility was found for the variety Diamant. In four varieties (in the first three ones from the previous group and in HE-3631) an average annual number of data on high susceptibility exceeded 5 in years of their testing (it was even 15 in HE-3527). The variety HE-3631 was tested in 1988 only when 18 data on high susceptibility were found. Distribution of data on high susceptibility of the selected varieties in individual years is presented in Table 4.

Varieties exhibiting high resistance as well as high susceptibility. Both data characterising high resistance and data indicating high susceptibility were found for 15 varieties (Ametyst, Bonus, KM-184, KM-S-119, Koral, Krystal, Mars, Novum, Opal,

Table 1. A chronological list of 127 spring barley varieties tested in the Official Trials of the Czech Republic in 1971–2000 and whose data on infection/resistance were used (in 1971–1973, some varieties were tested in two different types of trials)

Variety	Year[1]	Variety	Year	Variety	Year	Variety	Year
Ametyst	71, 71, 72, 72, 73, 73, 74, 75, 76, 77	ST-211	76, 77	Jarek	90, 94, 95, 96	Pax	99
		CE-PHS	77	KM-57	**84**	Viktor	91, 92, 93, 94, 95, 96, 97
		Fatran	77, 78, 79, 80	Perun	**84, 85**, 86, 87, 88		
Denar	71, 72	Opal	**77**, **78**, 79, **80**, 81, **82**, 83, 84, 85			Amulet	95, 96, 97, 98, 99, 00
Diamant	71, 71, 72, 72, 73, 73, 74, 75			SK-2074	84		
				TR-1055	**84**	Kompakt	95, 96, 97, 98, 99, 00
Dukat	71, 72	UH-2/69	77, 78	BR-2174	**85**		
Dvoran	71, 71, 72, 72	Karat	**78**, **79**, **80**	KM-A-10	85, 86, 87	Lumar	95, 96, 97, 98
	73, 73, 74	ST-6984	78, **79**, **80**, **81**	Novum	**85**, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99	Primus	95, 96, 97, 98, 99, 00
Elgina	**71**, **72**, **73**, **74**	Zefir	**78**, 79, 80, 81, 82, 83, 84, 85, 86				
Favorit	71, 71, 72, 72, 73, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83					Atribut	**96**, **97**, **98**, **99**
						Ditta	**96**, **97**, **98**, **99**
		Krystal	**78**, **79**, **80**, **81**, **82**, **83**, **84**, **85**, 86, 87, 88, 89, 90, 94	Profit	85, 86, 87, 88, 89, 90, 91, 94, 95		00
						Famin	96, 97, 98
H-80	71					Krona	**96**, **97**, **98**, **99**
Hana	71, 71, 72, 72, 73, 73, 74, 75, 76			SK-1952	**85**	Olbram	96, **97**, **98**, **99**, **00**
		BR-638	79	CE-396	**86**, 87, 88		
		HE-985	79	KM-143	86, 87, 88	Pejas	96, 97, 98, 99, 00
II/61 FUDII	71, 71, 72, 72	KM-S-119	**79**, **80**, 81	Malvaz	86, 87, 88, 89, 90, 94, 95		
IX/61 DFU	71	KM-S-170	**79**, **80**, 81			Signal	96, 97
Jantar	71, 72	Rubin	79, **80**, **81**, **82**, 83, 84, 85, 86, 87, 88, 89, 91, 92, 93, 94, 95, 96	TR-1148	**86**	Scarlett	**97**, 99, **00**
KM-232	71			Galan	87, 88	Tolar	97, 98, 99, 00
Merkur	71			HE-3527	87, 88	Heris	**98**, **99**, **00**
Sladar	71, 72			KM-C-545	87, 88	Madonna	98, 99, 00
Topas	71, 72			BR-3011	88	Nordus	**98**, **99**, **00**
Valticky	71, 72	BR-1519	**80**, **81**, **82**, **83**	DB-132	88	Prosa	**98**, **99**, **00**
HE-481/128	72, 72, 73, 73	Kredit	**80**, **81**, **82**, **83**	HE-3631	88	Madeira	**99**, **00**
HE-498	72, 72, 73, 73	Mars	**80**, 81, **82**, 83, 84, 85, 86, 87, 88	Jubilant	88, 89, 90, 91, 92, 94, 95, 96, 97	Maridol	99, 00
KM-1192	**73**, **73**, **74**					Orthega	99, 00
Atlas	74, 75, 76, 77, 78					Annabell	00
		Bonus	81, **82**, **83**, **84**, 85, 86, 87, 88	Terno	88, 89, 90, 91, 92, 94, 95, 96	Diplom	00
DB-13/64	74, 75					Ebson	**00**
Rapid	74, 75, 76, 77, 78, 79, 80	HVS-1461	**81**	Akcent	89, **90**, 91, 92, 93, **94**, 95, 96, 97, 98, 99, 00	Jersey	**00**
		KM-1038	**81**, **82**			Malz	00
BR-9	75	KM-J-326	**81**			Philadelphia	**00**
CE-JH/73	75	DB-121	**82**	Ladik	89, 90, 91, 92, 93, 94, 95, 96, 97	Prestige	**00**
Diabas	75, 76, 77, 78, 79, 80	ST-15299	**82**, 83, **84**			Sabel	**00**
		Zenit	**82**, **83**, **84**, **85**, 86, 87, 88	Sladko	89, 90, 91, 92, 93, 94, 95, 96, 97	Saloon	**00**
Koral	75, **76**, **77**, **78**, **79**, **80**, **81**, **82**, **83**, **84**, **85**, 86	Jaspis	83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 94, 95			1020128[2]	00
						1020152	00
				Svit	89, 90, 91, **92**, 93, 94, 95	1020171	**00**
Safir	75, 76, 77, 78					1020173	**00**
	79, **80**	KM-184	**83**, **84**, 85, 86	Forum	**90**, **91**, **92**, **93**, **94**, **95**, **96**, **97**, **98**, **99**, **00**	1020177	00
Spartan	**75**, **76**, **77**, **78**, **79**, **80**, 81, 82, 83	Orbit	83, 84, **85**, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96			1020194	00
						1020195	**00**
				Stabil	90, 91, 92, 93, 94, 95, 96, 97	1020196	**00**
Trumpf	**75**, **76**, **77**, **78**, 79					1020198	**00**
		Salome	**83**, **84**	Pax	91, 92, 93, 94, 95, 96, 97, 98		
DB-15/68	76, 77, 78	Jarek	**84**, **85**, 86, 89				

[1]In bold years a resistance of the respective varieties exceeded 7.50 (according to the 1–9 scale, 9 = variety fully resistant, plants are without visible symptoms of infection); [2]Codes of tested, not registered varieties

Table 2. An alphabetical list of 127 spring barley varieties, numbers of data on their high resistance and high susceptibility to powdery mildew obtained in 307 trials characteristic of high severity of the disease (Official Trials of the Czech Republic, 1971–2000)

Variety	A	B	C	Variety	A	B	C	Variety	A	B	C
Akcent	12	2		IX/61 DFU	1			Primus	6		1
Ametyst	7[1]	3	1	Jantar	2		3	Profit	9		15
Amulet	6		6	Jarek	8	6		Prosa	3	12	
Annabell	1	1		Jaspis	12		14	Rapid	7		7
Atlas	5			Jersey	1	5		Rubin	18	3	14
Atribut	4	30		Jubilant	9		3	Sabel	1	2	
Bonus	8	12	22	Karat	3	18		Safir	6	2	
BR-9	1		1	KM-57	1	4		Salome	2	5	
BR-638	1		5	KM-232	1			Saloon	1	2	
BR-1519	4	21		KM-143	3		4	Scarlett	3	6	1
BR-2174	1	1		KM-184	4	7	4	Signal	2		4
BR-3011	1	1		KM-1038	2	13		SK-1952	1	2	
CE-JH/73	1		3	KM-1192	3	39		SK-2074	1		
CE-PHS	1			KM-A-10	3			Sladar	2		8
CE-396	3	2		KM-C-545	2			Sladko	9		2
DB-13/64	2		5	KM-J-326	1	5		Spartan	9	15	12
DB-15/68	3	1		KM-S-119	3	6	5	ST-211	2		1
DB-121	1	3		KM-S-170	3	10		ST-6984	4	5	
DB-132	1			Kompakt	6		3	ST-15299	3	4	
Denar	2			Koral	12	63	1	Stabil	8		2
Diabas	6		7	Kredit	4	16		Svit	7		2
Diamant	5[1]		53	Krona	4	31		Terno	8		4
Diplom	1			Krystal	14	35	9	Tolar	4		
Ditta	5	5		Ladik	8		1	Topas	2		1
Dukat	2		1	Lumar	4		11	TR-1055	1	4	
Dvoran	4[1]		16	Madeira	2	12		TR-1148	1		
Ebson	1	4		Madonna	3	1		Trumpf	5	19	
Elgina	4	30		Malvaz	7		9	UH-2/69	2		
Famin	3		2	Malz	1			Valticky	2		7
Fatran	4			Maridol	2			Viktor	7		6
Favorit	13[1]		25	Mars	9	3	5	Zefir	9		39
Forum	11	67		Merkur	1		1	Zenit	7	15	5
Galan	2		2	Nordus	3	18		1020128[2]	1		
H-80	1			Novum	15	5	11	1020152	1		
Hana	9		21	Olbram	5	20		1020171	1	2	
HE-481/128	2[2]		3	Opal	9	2	6	1020173	1	1	
HE-498	2[2]		17	Orbit	14	1	13	1020177	1		
HE-985	1			Orthega	2	2		1020194	1		
HE-3527	2		31	Pax	9		13	1020195	1	3	
HE-3631	1		18	Pejas	5			1020196	1	4	
Heris	3	18		Perun	5	5	9	1020198	1	3	
HVS-1461	1	4		Philadelphia	1	4		Σ		647	525
II/61 FUDII	2[3]		29	Prestige	1	2					

A – number of years of the variety in trials; B – number of data of high resistance (> 8.50) (according to the 1–9 scale, 9 = variety fully resistant, plants are without visible symptoms of infection); C – number of data of high susceptibility (scores ≤ 3); [1]varieties tested in two different types of trials in 1971–1973; [2]varieties tested in two different types of trials in 1972 and 1973; [3]variety tested in two different types of trials in 1971 and 1972

Orbit, Perun, Rubin, Scarlett, Spartan and Zenit) during the period of their testing (Table 2).

Grouping of varieties according to their resistance (a proportion of varieties exhibiting low resistance). Grouping of the tested spring barley varieties depending on their resistance in 702 trials is given in Table 5. There was no variety with low resistance (≤ 5.5) for four years (1976, 1978, 1982 and 1992). By contrast, the proportions of varieties exhibiting low resistance were 38, 45 and 47% in 1972, 1993 and 1995, respectively, and even 52% in 1988. The highest proportion of varieties with low resistance was recorded in 1971–1975 (24.6%), whereas the lowest proportion of such varieties (6.3%) was found in the following period 1976–1980.

Grouping of varieties according to their resistance (a proportion of varieties exhibiting moderate resistance). The proportion of varieties with moderate resistance of 5.51–7.50 exceeded 75% in eight years, and even 80% in 1971, 1987 and 1990–1992.

Grouping of varieties according to their resistance (a proportion of resistant varieties). The proportion of resistant varieties at the average of resistance exceeding 7.50 steadily increased from the beginning of the period studied (1971) up to the maximum in 1982 when this category comprised 12 of 15 tested varieties (80%). It was in the middle of 1980–1984 when the highest proportion (58%) of tested varieties (27 varieties) were included among resistant ones. This proportion was on average higher than 56% during the period of eight years (1978–1985). However, no resistant variety was found in the trials in 1987–1989. In 1987–1991, only 3.6% of varieties (Forum and Akcent) and in 1986–1995 only 6.6% of varieties were resistant. In the final period of 1996–2000, 38% of tested varieties (21 varieties) were included among resistant ones; in the last year 2000, the proportion of resistant varieties exceeded 50% for the first time since 1984. The highest proportion of varieties with high resistance (> 8.50) was found in 1982 (67%) and a high proportion (33% and more) in 1984, 1999 and 2000. The varieties exhibiting high resistance were not found in the trials in 1972 and in the continual 11-year period of 1985–1995.

The most resistant varieties (trials with sufficient disease severity). The resistance of the variety that was most resistant in the trials with sufficient disease severity varied in the range from 8.05 to 9.00 in individual years (Table 6). Only in 1987–1991, the resistance of the most resistant variety was lower than 8.00 (7.07–7.91).

The most susceptible varieties (trials with sufficient disease severity). The resistance of the most susceptible variety in the trials with sufficient disease severity ranged from 4.27 to 5.63 (Table 6). The lower resistance (2.96 and 3.90) was found in 1988 and 1972 only. On the contrary, the variety scored with 6.00 was found in 1982.

Differences in resistance of the most resistant and the most susceptible variety (trials with sufficient disease severity). The highest difference between resistance of the most resistant and the most susceptible variety in the trials with sufficient disease severity (Table 6) was found in 1972 (4.51) and 1999 (4.49); the lowest difference was assessed in 1989 (2.20) and 1992 (2.55). The lowest average difference of 2.99 was found in 1987–1994.

The most resistant varieties (trials with high disease severity). The resistance of the most resistant variety in individual years in trials with high disease severity mostly varied between 8.23 and 9.00 (Table 6). It ranged from 7.10 to 7.78 only in 1990, 1991 and 1994 and it was even less than 7.00 (6.16–6.86) in a three-year period of 1987–1989.

The most susceptible varieties (trials with high disease severity). The resistance of the variety that was most susceptible in individual years in trials with high disease severity most often ranged from 3.00 to 4.87 (Table 6). The variety with resistance lower than 3.00 was found in 1988 (2.48), 1986 (2.50) and 1984 (2.80) only, the variety with the highest average (5.00) in 1982. The lowest average of the most susceptible variety was recorded in 1984–1988 (2.82).

Differences in resistance of the most resistant and the most susceptible variety (trials with high disease severity). The highest difference between resistance of the most resistant and the most susceptible variety in the trials with high disease severity (Table 6) was found in 1984 (6.11), 1979 and 1986 (5.75 in both years). The difference lower than 3.34 (1987) was recorded only in 1989 (2.21). A high average difference was found in 1983–1986 (5.59) and a low average difference in 1987–1994 (3.62).

A proportion of data on high resistance of varieties. 647 data characterising high resistance of varieties (scores > 8.50) were found. It is 11.63% of a total number 5561 data obtained in 307 trials with high disease severity (Table 6). The highest proportion of data on high resistance of varie-

Table 3. Distribution of number of data on high resistance of spring barley varieties to powdery mildew in the years of testing these varieties (Official Trials of the Czech Republic)

Variety[a]	*Ml*-genes	Y	*n*	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Elgina	*a7*, g^1	4	30	9	12	8	1																										
Ametyst	*a6*, $a14^2$	7^6	3	1	2	0	0	0	0	0																							
KM-1192	$(Kr)^2$	3^7	39			28	11																										
Trumpf	*a7*, (*Ab*), $aTr3^1$	5	19					16	3	0	0	0																					
Safir	$a13^2$	6	2					0	0	0	0	0	2																				
Spartan	*a9*, $k1^2$	9	15					9	3	1	2	0	0	0	0	0																	
Koral	*a13*, g^2	12	63					10	4	3	6	6	5	11	3	10	4	1	0														
DB-15/68	unidentified	3	1						1	0	0																						
Opal	*a6*, La^2	9	2							0	0	0	1	0	1	0	0	0															
Karat	$a13^2$	3	18								5	8	5																				
ST-6984	*a6*, at^3	4	5								1	0	3	1																			
Krystal	*a13*, g^2	14	35								2	2	6	10	3	6	5	1	0	0	0	0	0	–	–	–	0						
KM-S-119	$a9^4$	3	6									5	1	0																			
KM-S-170	$a9^4$	3	10									5	5	0																			
Rubin	$a1^2$	18	3									0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
BR-1519	$(Kr)^3$	4	21										5	9	3	4																	
Kredit	$(Kr)^2$	4	16										5	7	2	2																	
Mars	*a3*, g^2	9	3										1	0	2	0	0	0	0	0	0												
KM-1038	$a13^4$	2	13											10	3																		
ST-15299	unidentified	3	4												3	0	1																
Zenit	$a13^2$	7	15												2	9	4	0	0	0													
Bonus	$a13^2$	8	12												3	6	3	0	0	0	0												

Variety[a]	*Ml*-genes	Y	*n*	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Salome	*mlo, a7*[1]	2	5													2	3																
KM-184	*(Kr)*[3]	4	7													5	2	0	0														
Orbit	*a6, at, La*[2]	14	1													0	0	1	0	0	0	0	0	0	0	0	0	0	0				
Perun	*a13*[2]	5	5														5	0	0	0	0												
Jarek	*(Kr), La*[2]	8	6														4	2	0	–	–	0	0	–	–	–	0	0	0				
Novum	*a13, g*[2]	15	5															5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
CE-396	*mlo*[3]	3	2																2	0	0												
Akcent	*a7, La*[2]	12	2																			0	0	0	0	1	0	0	0	0	1	0	0
Forum	*mlo*[2]	11	67																				0	1	2	6	3	11	9	13	7	10	5
Atribut	*mlo*[2]	4	30																										7	11	5	7	
Krona	*mlo*[5]	4	31																										7	11	5	8	
Olbram	*mlo*[2]	5	20																										0	9	6	2	3
Ditta	u[5]	5	5																										0	2	2	1	0
Scarlett	*(Sc)*, g[5]	3	6																											6	–	0	0
Heris	*mlo*[2]	3	18																												5	9	4
Madonna	*mlo* + *a12*[5]	3	1																												1	0	0
Nordus	*mlo*[5]	3	18																												5	8	5
Prosa	u[5]	3	12																												3	8	1
Madeira	*mlo, a12*[5]	2	12																													9	3
Orthega	*a12, La, g*[5]	2	2																													2	0

[a]without 20 varieties included in the trials for one year only; Y – number of years of testing the variety in the trials; *n* – number of data on high resistance of the variety (> 8.50) (according to the 1–9 scale, 9 = variety fully resistant, plants are without visible symptoms of infection) in the trials with high severity of powdery mildew; 71 to 00-years 1971 to 2000; [1]Brown and Jørgensen (1991); [2]Dreiseitl and Jørgensen (2000); [3]Dreiseitl (1997); [4]Brückner (unpublished); [5] Dreiseitl (unpublished); [6]variety was tested in two different types of trials in 1971–1973; [7]variety was tested in two different types of trials in 1973; – testing of the variety was interrupted

Table 4. Distribution of data on high susceptibility of spring barley varieties by powdery mildew in the years of testing these varieties (Official Trials of the Czech Republic)

Variety[a]	*Ml*-genes	Y	*n*	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Dukat	g^1	2	1	0	1																												
II/61 FUDII	g^4	2[b]	29	5	24																												
Jantar	g^1	2	3	0	3																												
Sladar	$a8^{1,4}$	2	8	2	6																												
Topas	g^1	2	1	0	1																												
Valticky	$a8^{1,4}$	2	7	2	5																												
Dvoran	$a8^{1,4}$	4[c]	16	2	8	5	1																										
Diamant	$a8^{1,4}$	5[c]	53	9	17	7	9	11																									
Hana	$a8^{1,4}$	6	21	0	10	3	3	5	0																								
Ametyst	$a6$, $a14^{1,4}$	7[c]	1	0	0	0	0	0	0	1																							
Favorit	g^1	13[c]	25	1	5	6	0	3	0	2	0	2	0	3	0	3																	
HE-481/128	unidentified	2[d]	3		1	2																											
HE-498	unidentified	2[d]	17		12	5																											
DB-13/64	unidentified	2	5				1	4																									
Rapid	$a6$, g^1	7	7				2	1	0	2	0	2	0																			
Diabas	$a7^1$	6	7					2	0	0	0	4	1																			
Spartan	$a9$, $k1^1$	9	12					0	0	0	0	0	0	3	0	9																
Koral	$a13$, g^1	12	1					0	0	0	0	0	0	0	0	0	0	0	1													
ST-211	unidentified	2	1						0	1																							
Opal	$a6$, La^1	9	6							0	0	0	0	0	0	2	2	2														
Zefir	$a12$, g^1	9	39								0	1	0	9	0	7	3	9	10													
Krystal	$a13$, g^1	14	9								0	0	0	0	0	0	0	0	1	0	2	3	2	–	–	–	1						
KM-S-119	$a9^3$	3	5									0	0	5																		
Rubin	$a1^1$	18	14									0	0	0	0	0	0	0	2	1	1	1	0	0	0	2	1	5	1				
Mars	$a3$, g^1	9	5										0	1	0	0	0	1	1	1	1											
Bonus	$a13^1$	8	22											1	0	0	0	1	4	7	9											
Zenit	$a13^1$	7	5												0	0	0	1	1	2	1											

Variety[a]	*Ml*-genes	Y	*n*	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
KM-184	*(Kr)*[2]	4	4													0	0	2	2														
Jaspis	*a6, at, La*[1]	12	14													0	0	1	3	2	0	1	0	1	0	–	1	5					
Orbit	*a6, at, La*[1]	14	13													0	0	0	2	1	2	1	0	1	0	2	1	3	0				
Perun	*a13*[1]	5	9														0	1	1	2	5												
Profit	*a6, La*[1]	9	15															4	5	4	1	1	0	0	–		0	0					
Novum	*a13, g*[1]	15	11															0	0	0	1	3	0	3	0	1	0	1	0	2	0	0	
KM-143	*(Kr)*[2]	3	4																2	0	2												
Malvaz	*(Kr)*[1]	7	9																0	2	1	0	1	–	–	–	1	4					
Galan	*a13*[1]	2	2																	1	1												
HE-3527	*a7*[2]	2	31																	11	20												
Terno	*a9, La*[1]	8	4																		2	1	0	0	0	–	0	1	0				
Jubilant	*a12, La*[1]	9	3																		1	0	0	0	0	–-	0	1	0	1			
Svit	*a13, at*[1]	7	2																			0	0	0	0	0	1	1					
Ladik	*a12*[1]	8	1																			0	0	0	0	1	0	0	0				
Sladko	*a13, La*[1]	9	2																			0	0	0	0	0	1	1	0	0			
Stabil	*a6, a13, La*[1]	8	2																				0	0	0	0	0	1	0	1			
Viktor	*a13, La, g*[1]	7	6																					0	0	2	0	2	0	2			
Pax	*a13, La*[1]	9	13																					0	0	0	0	0	0	5	2	6	
Amulet	*a13, La*[1]	6	6																									0	0	2	1	3	
Kompakt	*a13, La*[1]	6	3																									1	0	1	1	0	0
Lumar	*a1, k1, g*[1]	4	11																									5	2	3	1		
Primus	*a6, a13, at, La*[1]	6	1																									0	0	1	0	0	0
Signal	u[4]	2	4																										2	2			
Famin	*a7, La*[1]	3	2																										1	1	0		
Scarlett	*(Sc)*[4]	3	1																											1	–	0	0

[a]without six varieties included in the trials for one year only; [b]variety tested in two different types of trials in 1971 and 1972; [c]varieties tested in two different types of trials in 1971–1973; [d]variety tested in two different types of trials in 1972 and 1973; – testing of the variety was interrupted; Y – number of years of testing the variety in the trials; *n* – number of data on high susceptibility of the variety (scores ≤ 3) (according to the 1–9 scale, 9 = variety fully resistant, plants are without visible symptoms of infection); 71 to 00-years 1971 to 2000; [1]Dreiseitl and Jørgensen (2000); [2]Dreiseitl (1997); [3]Brückner (unpublished); [4]Dreiseitl (unpublished)

Table 5. Numbers of spring barley varieties according to their resistance to powdery mildew in selected trials with sufficient disease severity (Official Trials of the Czech Republic)

Year	Number of varieties according to their resistance to powdery mildew[1]										Σ number of varieties
	Susceptible			Moderately resistant				Resistant			
	≤ 4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	
1971		1	1	4	3	6	1			1	17
1972	1	3	3	3	3	1			1		15
1973			1	2	3		1			2	9
1974		1	1	2	2	2		1		1	10
1975	1		3	3	3	1		1	1	1	14
1976				1	1	5	1	1	1	2	12
1977			2	3	2	1	3	2	1	1	15
1978				2	3	1	3	3	2	2	16
1979			2	1	1	4	3	2	3	2	18
1980			1	2		2		5	4	4	18
1981	1		3	1		2	1	1	6	2	17
1982				1	1	1		1	1	10	15
1983		2	1	1		1	4	1	5	2	17
1984		1	1			1	3	1	3	8	18
1985	1			2		1	5	4	5		18
1986	1		1	1	3	8	3	1	1		19
1987		1	2	2	5	5	2				17
1988	3	2	6	5	1	3	1				21
1989		2	1	2	3	4	2				14
1990			1	2	1	4	6	2			16
1991		1			6	5	2	1			15
1992				2	5	3	2	1	1		14
1993		2	3	1	3	1			1		11
1994			2	5	5	4		1	1		18
1995	2	1	5	7	4	1			1		21
1996		1	2	2	11	3	1	1	1	2	24
1997			3	9	3			2	3	1	21
1998		1	2	2	4	1	1	1	4	3	19
1999	1	1	1	5		3	1	1	1	7	21
2000		1	5	3	3	2	3	2	3	13	35

[1]scale 1–9 (9 = variety fully resistant, plants are without visible symptoms of infection)

ties was found in 1982 (31 data = 68.9%) and in 1980–1984 (210 data = 26.6%). In 1986–1994, the proportion of these data was 1.1% (16), of which in 1987–1991 even 0.2% only.

A proportion of data on high susceptibility of varieties. 525 data characterising high susceptibility (≤ 3) were obtained. It is 4.22% of a total number 12 444 data recorded in 702 trials with sufficient disease severity (Table 6). No data characterising high susceptibility of varieties were found in the years 1976, 1978, 1982, 1992 and 2000. The highest proportion of data on high susceptibility was found in 1972 (13.9%) and 1988 (12.0%). In four years (1973, 1975, 1986 and 1987), the proportion

Table 6. Data on trials characterising resistance of spring barley varieties to powdery mildew (Official Trials of the Czech Republic)

Year	Number of trials		Number of varieties				Number of data		Resistance of variety				Difference in resistance		Number of assessments	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1971	23	10	17 (6)[1]	1	14 (4)[1]	2 (2)[1]	529	230	8.70	4.94	8.90	3.90	3.76	5.00	10	22
1972	29	19	15 (8)[1]	1	7 (2)[1]	7 (6)[1]	667	437	8.41	3.90	8.58	3.05	4.51	5.53	14	93
1973	24	14	9 (8)[1]	2 (1)[1]	6 (6)[1]	1 (1)[1]	408	238	9.00	5.23	9.00	4.07	3.77	4.93	36	28
1974	31	14	10	2	6	2	310	140	8.90	4.55	8.79	3.50	4.35	5.29	12	16
1975	36	21	14	3	7	4	504	294	8.67	4.50	8.86	3.62	4.17	5.24	35	30
1976	24	5	12	4	8	0	288	60	8.75	5.58	8.80	4.80	3.17	4.00	11	0
1977	11	3	15	4	9	2	165	45	8.82	5.45	9.00	3.67	3.37	5.33	4	6
1978	24	6	16	7	9	0	384	96	8.75	5.63	9.00	4.33	3.12	4.67	16	0
1979	24	8	18	7	9	2	432	144	8.88	5.04	9.00	3.25	3.84	5.75	26	14
1980	14	8	18	13	4	1	252	144	8.79	5.07	8.63	4.25	3.72	4.38	39	1
1981	34	17	17	9	4	4	578	289	8.68	4.32	8.71	3.24	4.36	5.47	57	22
1982	10	3	15	12	3	0	150	45	9.00	6.00	9.00	5.00	3.00	4.00	31	0
1983	34	13	17	8	6	3	578	221	8.74	4.68	8.62	3.38	4.06	5.24	44	21
1984	13	5	18	12	4	2	234	90	8.91	4.91	8.91	2.80	4.00	6.11	39	5
1985	33	8	18	9	8	1	594	144	8.48	4.45	8.25	3.00	4.03	5.25	13	23
1986	30	8	19	2	15	2	570	152	8.07	4.27	8.25	2.50	3.80	5.75	2	35
1987	33	16	17	0	14	3	561	272	7.27	4.61	6.67	3.33	2.66	3.34	0	34
1988	27	21	21	0	10	11	567	441	7.19	2.96	6.86	2.48	4.23	4.38	1	68
1989	29	10	14	0	11	3	406	140	7.07	4.87	6.16	3.95	2.20	2.21	0	11
1990	20	3	16	2	13	1	320	48	7.86	5.06	7.10	3.67	2.80	3.43	0	3
1991	15	5	15	1	13	1	225	75	7.91	4.81	7.50	3.36	3.10	4.14	1	5
1992	13	3	14	2	12	0	182	42	8.16	5.61	8.67	4.87	2.55	3.80	2	0
1993	16	10	11	1	5	5	176	110	8.19	4.64	8.28	4.07	3.55	4.21	7	8
1994	21	10	18	2	14	2	378	180	8.05	5.21	7.78	4.33	2.84	3.45	3	7
1995	28	18	21	1	12	8	586	378	8.45	4.33	8.43	3.79	4.12	4.64	11	31
1996	22	9	24	4	17	3	528	216	8.59	4.98	8.98	4.51	3.61	4.47	23	6
1997	26	15	21	6	12	3	546	315	8.67	5.05	8.69	4.02	3.62	4.67	52	22
1998	23	10	19	8	8	3	437	190	8.58	4.88	8.23	3.86	3.70	4.37	40	5
1999	24	10	21	9	9	3	504	210	8.85	4.36	8.94	3.74	4.49	5.20	64	9
2000	11	5	35	18	11	6	385	175	8.97	4.95	9.00	4.14	4.02	4.86	54	0
	702	307	(127)	(34)	–	–	12 444	5561	8.45	4.83	8.39	3.82	3.62	4.57	647	525

A – sufficient disease severity; B – high disease severity (selection of the trials A); C – tested varieties in total; D – resistant varieties (an average of resistance in the trials A > 7.50) (according to the 1–9 scale, 9 = variety fully resistant, plants are without visible symptoms of infection); E – moderately resistant varieties (an average of resistance in the trials A from 5.51 to 7.50); F – varieties with low resistance (an average of resistance in the trials A up to 5.50); G = A × C; H = B × C; I – most resistant (trials A); J – most susceptible (trials A); K – most resistant (trials B); L – most susceptible (trials B); M = I – J; N = K – L; O – number of data on high resistance (> 8.50); P – number of data on high susceptibility (≤ 3); [1]number of varieties tested in two trials

of these data exceeded 6.0%. The proportion of data on high susceptibility from all obtained data was 7.8% in 1971–1975 (the sum = 189). It is the highest proportion of these data obtained for the whole period studied. The lowest proportion of data on high susceptibility was found in the following years 1976–1980 (1.4% = 21 data), and a low proportion of these data also in 1990–1994 and in 1996–2000, which was 1.8% for both periods.

DISCUSSION

Resistance of the variety to the disease is conditioned by specific resistance genes (major genes) and genetic background (minor genes) of the given variety. Efficiency of specific resistance genes depends on the frequency of matching virulence in the pathogen population. Genetic background of the variety results in a certain level of quantitative resistance. Final resistance of varieties in the field is influenced by the environment, and particularly an actual inoculation potential of the pathogen. If the inoculation potential is low, all varieties look like resistant. Therefore, results of trials with insufficient severity of infection were not considered in this work. To obtain some characteristics, only data from trials with high severity of the disease were used.

Resistance of some varieties steadily decreased during their testing. Such a phenomenon is common for resistances based on specific genes. Resistance most often decreases due to direct selection of pathotypes that are able to overcome the effect of a resistance gene in the pathogen population (Dreiseitl 2000a). It results in increasing the frequency of a matching virulence. This was undoubtedly the case in Spartan, Krystal, Zenit, Jarek and others varieties. However, another adaptation mechanisms constituting the pathogen population also took part in breaking the resistance of tested varieties (Dreiseitl 2000b, 2002, 2003a,b).

In the period of testing, some varieties became even more resistant. It can be induced at least by three causes. Firstly, each variety has a certain level of resistance. It is determined by a number of evaluators at different locations. If resistance of a certain variety is not full, numerical scoring of such resistance can vary around the limit between both categories due to subjective evaluation. The other reason can be different inoculation potential of the pathogen at different locations in individual years. The third reason is initial non-homogeneity of some varieties the resistance. Non-homogeneous varieties are composed of lines with different resistance or contain admixtures of other varieties showing lower resistance. The consecutive homogenisation can influence resistance of the variety. That is true for the varieties Rubin and Olbram (Dreiseitl & Jørgensen 2000), but undoubtedly for some others too.

At the beginning of the period studied, the variety Elgina possessing the gene *Mla7* (Brown & Jørgensen 1991) showed high resistance. The most resistant varieties were Koral, Krystal, Karat and KM-1038 possessing the gene *Mla13* (Dreiseitl & Jørgensen 2000; Brückner unpublished). The gene *Mla13* conditioned high resistance of varieties until 1985. The varieties BR-1519 and KM-1192 carrying the gene *Ml(Kr)* (Dreiseitl 1997; Dreiseitl & Jørgensen 2000) exhibited high resistance until the same year. At the end of the period studied, high resistance was found particularly in the varieties Atribut, Forum, Krona, Heris, Madeira and Nordus possessing the gene *mlo* (Dreiseitl & Jørgensen 2000; Dreiseitl unpublished).

Varieties Diamant and Hana possessing the gene *Mla8*, Favorit, Zefir and II/61-FUDII possessing the gene *Mlg* (accompanied with *Mla12* in Zefir) (Dreiseitl & Jørgensen 2000), and HE-3631 with unknown resistance (Dreiseitl 1997) ranked among varieties with the lowest resistance. Among them there was also HE-3527 tested in 1987 and 1988. It possesses the same gene *Mla7* as the variety Elgina, the most resistant variety in 1971–1973. Similarly, the varieties possessing the gene *Mla13* (Bonus, Krystal, Novum, Perun, Zenit and others) were characteristic of high resistance until 1984, however they exhibited high susceptibility after 1985.

Originally resistant varieties with the gene *Mla9* (Spartan and KM-S-119) had high susceptibility after 1980. The gene *Mla9* is also present in KM-S-170. After the gene *Mla9* had been overcome, its resistance considerably decreased, however the decrease was not as dramatic as in KM-S-119 and powdery mildew on KM-S-170 did not reach values of high susceptibility. It documents distinctness in both sister varieties "KM-S" in their genetic background. A higher level of quantitative resistance can be also assumed in the varieties Akcent, Ladik and Tolar since their somewhat higher resistance in the field cannot be explained by the presence of known specific resistance genes. However, the efficiency of quantitative resistance is, particularly in the case of powdery mildew on barley, very limited.

The highest number of varieties (27) and the highest proportion of resistant varieties (58%) as well as

the highest proportion of data on high resistance (26.6%) were recorded in 1980–1984 at culminating these characteristics in 1982. However, selection and reproduction of virulent pathotypes induced infection of originally resistant varieties at such an extent that no variety with high resistance (> 8.50) was found after 1985 during 11 years, and in 1987–1989 even no resistant variety (> 7.50) was found either. A number of resistant varieties due to the adapted pathogen population (Dreiseitl 2003b) was reduced for a long time and neither at the end of 1996–2000 nor in 2000, parameters of resistance of groups of tested varieties in individual years were obtained in comparison with those in 1980–1984, and particularly in 1982.

Resistance of varieties depended particularly on efficiency of specific resistance genes. The resistance conferred by major genes was usually broken down very soon. The erosion of these specific resistances could be slowed down owing to high resistance and resistance diversity in grown varieties in 1980–1984 (Dreiseitl 1993b).

The difference in a resistance level depends on both resistance of the most resistant variety and the most susceptible variety in the respective year. The resistance of the most resistant variety was hardly lower than 8.00, and it is influenced by the inoculation potential of the pathogen only little (the average of resistance of the most resistant variety was 8.45 in the trials with sufficient pathogen severity and 8.39 in the trials with high pathogen severity). On the contrary, infection of susceptible variety completely depends on the actual inoculation potential of the pathogen. If the pathogen is absent, a level of "resistance" (phenotype) is 9.00 even for the most susceptible variety. In the trials with sufficient pathogen severity, the average of resistance of the most susceptible variety was 4.83 for the whole period studied; in the trials with high pathogen severity, the average was 3.82 and in the year with the highest disease severity (1988) it was even 2.48 (Dreiseitl & Jurečka – in preparation), when the most susceptible variety (HE-3527) was scored 1, the lowest possible score, in three trials.

The highest proportion of data on high susceptibility of varieties was assessed in 1971–1975, i. e. in the same period when the highest proportion of varieties exhibiting low resistance was recorded. The lowest proportion of data on high susceptibility was found in 1976–1980 and it again corresponded with the period of the lowest proportion of varieties exhibiting high susceptibility. So, very strong infection data document presence of varieties characteristic of high susceptibility. Data about high resistance in trials with high disease severity (with high inoculation potential of the pathogen) conversely argue about high resistance of varieties.

The results suggest that high resistance was characteristic for the varieties possessing major resistance gene (unless the efficiency of these genes is overcome by an adaptable pathogen population) and the varieties carrying the gene *mlo*. A number of new resistances are known now to which no matching virulences have been detected in the European population (Dreiseitl & Bockelman 2003; Dreiseitl & Dinoor 2003). Many major resistance genes are located mostly in the *Mla* locus (Jahoor & Fischbeck 1987, 1993), but also in other parts of barley genome (Schönfeld *et al*. 1996). Thus, marker assisted selection enables to develop barley varieties with combinations of fully efficient major resistance genes that have not been overcome until now. The durability of resistance of such varieties can be prolonged by using of higher diversity of resistance donors and should be encouraged by their assumed growing jointly with the varieties possessing the gene *mlo*.

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Abstrakt

Dreiseitl A., Paříček P. (2003): **Odolnost odrůd ječmene jarního k padlí travnímu v České republice v letech 1971–2000**. Czech J. Genet. Plant Breed., **39**: 31–44.

Byly analyzovány výsledky hodnocení odolnosti 127 odrůd ječmene jarního v 702 odrůdových pokusech Ústředního kontrolního a zkušebního ústavu zemědělského s dostatečným výskytem padlí travního. Odrůdy obsahující geny *Mla7* (Elgina), *Ml(Kr)* (BR-1519), *Mla13* (Koral) a *mlo* (Forum a další) patřily v průběhu jejich zařazení do zkoušek k nejodolnějším. Odrůdy Diamant, HE-3527, HE-3631, II/61-FUDII a Zefir se vyznačovaly velmi nízkou odolností. Patnáct odrůd nesoucích geny *Mla1*, *Mla3*, *Mla6*, *Mla9*, *Mla13*, *Ml(Kr)* a *Ml(Sc)* se vyznačovalo nejdříve nejvyšší a později velmi nízkou odolností. Odolnost nejodolnější odrůdy se každoročně pohybovala v rozpětí 8,05–9,00, pouze v pětiletém období 1987–1991 byla nižší. Odolnost nejméně odolné odrůdy se s výjimkou tří ročníků pohybovala v rozpětí 4,27–5,63. V důsledku zrychlené adaptace patogenní populace v polovině osmdesátých let nebyla v letech 1987–1989 zjištěna žádná odolná odrůda, v průměru let 1986–1995 příslušelo jen 6.6 % odrůd k odolným a v nepřetržitém období jedenácti let 1985–1995 nebyla zjištěna žádná odrůda s nejvyšším stupněm odolnosti (nad 8,50). Vysokou odolností se vyznačovaly odrůdy, obsahující geny velkého účinku. Odolnost takovýchto odrůd však byla zpravidla jen krátkodobá. Proto je doporučeno šlechtit odrůdy alespoň se dvěma plně účinnými geny odolnosti kombinovanými pomocí molekulárních markerů.

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

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