Severity of Powdery Mildew on Spring Barley in the Czech Republic in 1971–2000

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Abstract

Dreiseitl A., Jurečka D. (2003): **Severity of powdery mildew on spring barley in the Czech Republic in 1971–2000**. Plant Protect. Sci., **39**: 39–51.

Results of scoring the resistance to powdery mildew of 127 spring barley varieties that were gradually included in 923 official variety trials were analysed. The resistance of a variety was defined by the level of infection by the disease. Therefore, the data can be used to assess the disease severity. Several characteristics indicative of disease severity were considered, including the disease severity coefficient (= average infection of non-resistant varieties in trials with a high disease severity/the proportion of such trials). The value of the coefficient is inversely proportional to disease severity. According to the coefficient the highest powdery mildew severity occurred in 1988, 1972 and 1995, and during the period 1971–1975. This is confirmed by results of some other characteristics, while that of further characteristics point to 1985–1989 as the period with the highest disease severity. The lowest disease severity was found in 1982 and 1977 and for the period 1976–1980. High disease severity was found every year in 9–75% (on average in 33%) of the trials. The characteristics of disease severity as well as the effects of widely grown and susceptible varieties of winter barley on the increase in inoculum potential and, as a consequence, on faster adaptation of the pathogen to resistance of spring barley, especially that conditioned by gene *Mla13*, are discussed.

Keywords: *Hordeum vulgare*; *Blumeria graminis* f.sp. *hordei*; powdery mildew; disease severity

Powdery mildew, caused by the fungus *Blumeria graminis* (DC.) Golovin ex Speer f.sp. *hordei* Em. Marchal (synamorph *Erysiphe graminis* DC. f.sp. *hordei* Em. Marchal), is the most common disease of both spring and winter barley (*Hordeum vulgare* L.) in the Czech Republic (Dreiseitl & Jurečka 1996, 1997). *Blumeria graminis* f.sp. *hordei* is an obligate pathogen of barley that is able to survive on green organs only, particularly on leaves. Under Central European conditions, the pathogen survives mostly in a vegetative form, i.e. mycelium that produces conidia. At the end of the growing season, the fungus produces abundant chasmothecia in which traits, including virulence, may recombine. Every year there are two periods critical for the survival of this pathogen. Winter is characterised by slow growth of the pathogen and fewer living organs of the host, while in summer at the maturity stage green organs of these crops are almost absent (volunteer plants of both winter and spring barley are present later).

Spring barley varieties with one or more genes for resistance have been developed to limit the damage by powdery mildew (Dreiseitl & Jørgensen 2000). It could be supposed that as a consequence the severity of powdery mildew on spring barley has decreased. The objective of this paper was to judge: (1) characteristics documenting the disease severity during the period studied, (2) a possible trend of powdery mildew severity on spring barley, and (3) effects of changes of the plant production structure on disease severity.

Partly supported by the Grant Agency of the Czech Republic, Project No. 522/00/1062.

MATERIAL AND METHOD

The reaction of a variety was defined by the level of infection by the disease on it. Therefore, the data can be used to assess the disease severity. This is inversely proportional to the resistance of a variety. Therefore, in some cases the data are presented as variety infection/resistance.

Years. Results of official variety trials conducted by the Central Institute for Supervising and Testing in Agriculture over a period of 30 years (1971–2000) were analysed. Of these, 18 years (1971–1988) were registration trials and 12 years (1989–2000) trials of registered varieties.

Locations and variants. The trials were conducted at 37 locations across the Czech Republic. At some locations, two (or three as an exception) variants differing in the preceding crop were established. In such cases, a letter indicating the preceding crop was added to the year of trials (Table 1).

Trials. During the period studied, 923 field trials (year × location × variant) were conducted. Trials exhibiting a mean of variety resistance of ≤ 6 (after eliminating the data on resistant varieties with a

Table 1. Locations of 702 variety trials of spring barley with sufficient powdery mildew severity (Official Trials of the Czech Republic)

Location	Years[1]
Branišovice	**95**, **96**, **97**, 98, 99
Čáslav	**72c**, **72o**, 73c, 73o, 74o, 75j, 76p, 78p, **81p**, **83p**, 85p, 86p, 87p, **88p**, 89, 90, **93**, 94, **95**, **96**, **97**, **98**, **99**, **00**
Čejč	94, **95**, 96, **97**, **98**, 99
Domanínek	71b, **72o**, 78p, **80p**, 85p, 87p, **88p**, **89**, 90, 91, 92, 93, 97, 98, 99
Horažďovice	**74b**, **74o**, **75b**, **75p**, **76b**, 76p, 78b, 78p, **79b**, **79p**, 80p, **81b**, **81p**, **83b**, 85b, 85p, 86b, 86p, **87b**, **87p**, **89**, 90, **92**, **93**, **95**, **96**, **97**, **98**, **99**
Hradec n. S.	71b, **72b**, **73b**, 74b, 75b, 75ž, 76p, 79p, 80p, 81p, 83p, **85p**, 86p, **87p**, **89**, **90**, **91**, **92**, 93, **94**, **95**, 96, **97**, 98, 99, **00**
Hrubčice	**95**, **97**, **98**, 99
Chrastava	**78b**, **79b**, **81b**, 82b, **83b**, **84b**, **85b**, 86b, 87b, 88b, 89, **90**, **91**, 92, **93**, **95**, 96, 97, **98**, **99**, **00**
Chrlice	**71c**, **71o**, **72c**, **72o**, **73o**, 74c, 74o, **75c**, **75p**, 76j, **77c**, **77p**, 78p, 79c, 79p, **80c**, **80p**, **81c**, **81p**, 82c, 82p, 83c, **83p**, **84c**, **86c**, **86p**, **87c**, **87p**, **88c**, **88p**, 89, 90, 92, **93**, **94**, **95**, **96**, **97**, **98**, **99**, 00
Jaroměřice	71o, 72o, 73b, 74b, 74o, **75b**, 76b, **78b**, **78j**, 79b, 79j, **80b**, **80j**, **81b**, 81j, **82b**, **82j**, 83b, 83j, **85b**, 85p, 86b, 86p, 87b, 87p, 88b, **88p**, 89b, 89o, 90, **93**, **94**, **95**, **96**, **97**, **98**, **99**, 00
K. Údolí	73b, **71b**, 72o, **74b**, **74o**, 75b, **75j**, 76b, 76j, 78b, 78p, **79b**, **79j**, **81b**, **81j**, **83b**, **83j**, 84b, 85b, 85p, 86b, 86j, **88b**, **88j**, 89o, 90b, **91**, 92, 94, 97, 98, **99**
Kroměříž	95, 96, 97, 98, 99
Kujavy	**71o**, **72o**, **74b**, **74o**, **75b**, **75j**, **76j**, 79o, 81p, 83p, 85p, 87p, **88p**, 89, 90, 93, 94, 95, 96, 97, 98,
Lednice	77p, **78p**, 79p, **80p**, **81p**, 82k, **83j**, 84k, **85k**, 86k, 87k, 89, 91, 92, 94k, 94o, 95, **96**, 97, 98, **00**
Libějovice	**71b**, 72b, 73b, **74b**, 75b, 75j, 78b, 81b, **83b**, 83p, 85b, 87b, **88b**, 89, 91, 92, **93**, **94**, **95**, 96, 97, 99
Lípa	72b, 74b, 75b, 76b, 79b, 80b, 81b, **83b**, 85b, 87b, **88b**, 89, **90**, 95, 96, **97**, **98**, 99, 00
Machnín	71b, 71o, 72b, 72o, **73b**, 74b, **76j**
Měšice	**72o**, **73o**, **74b**, 74o, **75b**, 75j, **81p**, 83p, 84p, 85p, 86p, 87p, **88p**, 89, 95
Nechanice	71c, **73c**, 74c, 75c, 78c, 81c, 81p, 83c, 85c, 86p, 87c, 87p, 89, 90, 91, 95, 97
Oblekovice	**71c**, **71o**, **72c**, **72o**, 73o, **74o**, **75c**, **75p**, **78p**, **80j**, 81p, 83p, **84p**, **85p**, **86p**, **87p**, **88p**, **89**, **91**, **93**, **94**, 96, **97**, 98, 99

mean of resistance > 7.5) were considered as trials with high disease severity. Trials in which at least one variety was scored ≤ 6, but did not reach the parameter of the previous category, are considered as trials with low disease severity. Both categories were considered as trials with sufficient disease severity (Table 1). Trials in which none of the varieties was scored ≤ 6 were considered to have insufficient disease severity and were excluded from further evaluation (their numbers according to locations are given in Table 2).

Varieties. A total of 144 spring barley varieties (the term "variety" is used for both registered varieties and candidates for registration) were tested. Commercial names are given for registered varieties even in years of their registration testing. In the first year of testing, some varieties were included only in part of the trials. Data of such varieties (17 in total) were omitted, so that data on 127 varieties were used. In 1971–1973 some varieties were tested under two cropping systems with a different level of fertilisation; results of both systems were used. Varieties with a resistance of > 7.5 at locations with sufficient disease severity in a specific year were considered resistant; those with a lower resistance were designated "non-resistant". A list of varieties is given in Dreiseitl and Pařízek (2003).

Table 1 to be continued

Location	Years[1]
Opava	**72c**, 73c, 75c
P. Jakartice	79c, 79p, 81c, **81p**, 82c, **82p**, 83c, 83p, 85p, 86c, **86p**, 87p, 88c, **88p**, 89c, 89o, 90, 91, **92**, **93**, **94**, **95**, **96**, **97**, 98, **99**, **00**
Podivín	71k, **72k**, **73k**, **74k**, **75k**, 76v
Přerov n. L.	78p, 81p, 83p, 85p
Rožnov p. R.	71b, 72b, **73b**, 74k, 76k, 77l, 79b, **81l**, 84p, 85p, 86p
Rýmařov	71b, **72b**, **72o**, **73b**, 73o, **74b**, 74o, **75b**, 75j, 76b, 79b, **81b**, 85b, **87b**, **88b**, **89**, 90, **91**, 92, **93**, **94**, 95, 96, **97**, 98
Sedlec	**71o**, **72c**, **72o**, **73c**, **73o**, **74c**, **74o**, **75c**, **75p**, 76c, **76p**, 77c, 78c, **78j**, 79c, 79p, 81, 81c, 83c, **83j**, 84c, 84p, 85c, 85p, **86c**, **86p**, **87c**, **87p**, **88c**, **88p**, **89c**, **89o**, 95, 97, 00
Stachy	72b, **73b**, 75b, 76b, 77b, **80b**, **81b**, 82b, 83b, 84b, 85b, 86b, **87b**, **88b**, **89**, 90, 91, 92, 93, 94, 95, 96
Staňkov	**71o**, **72o**, 73b, 74b, 74o, **75b**, **75j**, 76b, 76p, 77b, 77p, 78p, 79b, 79p, 80p, 81k, 81p, 83b, **83k**, 83p, 85b, 85k, 85p, 86p, **87b**, **87p**, **88b**, **88p**, **89**, 91, 92, 93, **94**, **95**, 96, **97**, 99, 00
Stupice	94, **95**, **97**, **98**, **99**
Trutnov	71b, **73b**, **74b**, 75b, 76b, **76j**, 77b, **77j**, 78b, 78p, **79b**, **79p**, **83b**, **83p**, **84b**, **84p**, **85p**, **86b**, **86p**, 87b, 87p, **88b**, **88p**, 89, 90, 91, **93**, **94**, **95**, **96**, **97**, **98**, **99**
U. Ostroh	**71o**, 73o, 74o, **75k**, **75p**, 78k, 78p, 80p, **81k**, 83p, 84p, **85p**, 86p, 87p, 88p, 91, **95**, **96**, 97, 98, 99, 00
Uhřetice	**94**, **95**, 98, **99**
Věrovany	71c, 71o, **72c**, **72o**, **73c**, **73o**, 74c, 74o, 75c, 75p, 76p, 77c, 78c, 78j, 81c, 81p, 83c, 83p, 85c, 85p, 86c, 86p, 87c, **87p**, 88c, 88p, **89c**, 89o, 90c, 90o, **95**, 96, 98, 99
Vysoká	71b, 72b, **75b**, **75p**, 76b, 76o, **81b**, 83b, **85b**, 86b, 86p, **87b**, **87p**, 89b, 89o, 90b, 90o, 91, 92, 93, 94, 95
Žabčice	94, 99
Žatec	72o, **79j**, 80j, 81j, 82p, 83j, 85p, 86j, **87j**, 89, 90, 94, **95**, 96, 97, 99

[1] Last two digits of the years 1971–2000; the letter indicates a preceding crop if it is necessary to distinguish from another trial (c – sugarbeet, j – barley, k – corn, l – legume, o– cereal, p – wheat, ž – rye); 307 trials with high powdery mildew severity are in **bold**; they differ from 395 trials with low disease severity

Data. During the period studied, 16 171 data (Σ (year × location × variant × variety)) were evaluated.

Scoring scale. A 1–9 scale was used to score the infection/resistance of barley varieties to powdery mildew in the field: 1 = high susceptibility (extreme infection of entire plants), 9 = complete resistance (plants free of any visible symptoms). In this work, infection of ≤ 3 on a variety are considered as high infection (very low resistance).

Scoring procedure. From 1971 to 1988 the infection/resistance of each variety was characterised by one value. From 1989 to 2000 the score of the infection/resistance was based on the mean of two to four replications.

Disease severity. To determine the powdery mildew severity at locations the following three characteristics were analysed: the proportion of trials with insufficient disease severity; the proportion of trials with high disease severity; and the proportion of data on very high infection related to the total number of trials at a location (Table 2). The disease severity in individual years was determined in a similar way using 13 characteristics (see results) including the disease severity coefficient.

Disease severity coefficient. The disease severity coefficient comprises infection intensity of non-resistant varieties in trials with high disease severity, and the proportion of such trials of the

Table 2. Distribution of numbers of variety trials and numbers of data on very high powdery mildew infection of spring barley characterising disease severity at 37 locations (Official Trials of the Czech Republic, 1971–2000)

Location	A	B	C	D	E	Location	A	B	C	D	E
Branišovice	6	1	2	3	12	Oblekovice	29	4	6	19	83
Čáslav	31	7	12	12	14	Opava	4	1	2	1	1
Čejč	6		3	3		Pusté Jakartice	36	9	15	12	17
Domanínek	27	12	11	4	15	Podivín	6		2	4	10
Horažďovice	30	1	9	20	8	Přerov n. L.	6	2	4		
Hradec n. S.	31	5	14	12	9	Rožnov p. R.	14	3	9	2	
Hrubčice	7	3	1	3	2	Rýmařov	30	5	12	13	10
Chrastava	21		8	13	27	Sedlec	49	14	15	20	62
Chrlice	47	6	13	28	61	Stachy	25	3	6	16	21
Jaroměřice	45	7	21	17	13	Staňkov	44	6	25	13	22
Krásné Údolí	56	12	30	14	6	Stupice	6	1	1	4	3
Kroměříž	5		5			Trutnov	39	6	11	22	57
Kujavy	29	8	13	8	8	Uherský Ostroh	33	11	15	7	11
Lednice	24	3	14	7	3	Uhřetice	6	2	1	3	3
Libějovice	31	9	15	7	7	Věrovany	52	18	27	7	23
Lípa	23	4	14	5	3	Vysoká	32	10	16	6	7
Machnín	9	2	5	2		Žabčice	5	3	2		
Měšice	25	10	9	6	6	Žatec	31	15	13	3	1
Nechanice	35	18	16	1		Σ	923	221	395	307	525

A – total number of trials; B – number of trials with insufficient disease severity; C – number of trials with low disease severity; D – number of trials with high disease severity; E – number of data on very high infection ≤ 3 (according to the 1–9 scale, 9 = fully resistant, plants are free of visible symptoms of infection) total number of trials. It was calculated as follows: average infection of non-resistant varieties in trials with high disease severity/the proportion of trials with high disease severity. A value of the coefficient is inversely proportional to disease severity (Table 3).

For further methodological details see Dreiseitl and Pařízek (2003).

RESULTS

Data on powdery mildew infection in 923 variety trials of the Central Institute of Supervising and Testing in Agriculture, in which 127 spring barley varieties were gradually included from 1971 to 2000, were analysed. The 16 171 data were used to calculate the frequencies of classes of infection/resistance to be presented in tables, and for proportions given in the text.

Disease severity at locations

The proportion of trials with insufficient disease severity. The proportion of trials with insufficient severity of the disease exceeded 50% of all trials conducted at Nechanice. At seven other locations (Domanínek, Hrubčice, Měšice, Přerov nad Labem, Věrovany, Žabčice and Žatec), this proportion was higher than 33% (however, only a small number of trials were conducted at the locations Hrubčice, Přerov nad Labem and Žabčice). A low proportion of such trials (lower than 15%) was found at Horažďovice, Chrlice, Lednice, Oblekovice, Stachy and Staňkov. None of the trials had insufficient disease severity at Chrastava and three locations with a low number of conducted trials (Čejč, Kroměříž and Podivín) (Table 2).

The proportion of trials with high disease severity. At seven locations (Horažďovice, Chrastava, Chrlice, Oblekovice, Podivín, Stachy and Trutnov) over 50% of the trials had a high disease severity. At Nechanice, Rožnov pod Radhoštěm, Věrovany and Žatec a low proportion of trials (less than 15%) showed a high disease severity. None of the trials at Kroměříž, Přerov nad Labem and Žabčice showed a high disease severity (a low number of trials were conducted at these locations) (Table 2).

The proportion of data on very high infection related to the total number of trials. The proportion of data on very high infection of varieties at Oblekovice was almost three times higher than the total number of trials conducted at this location. At six locations (Branišovice, Chrastava, Chrlice, Podivín, Sedlec and Trutnov), the proportion of data of very high infection of the total number of conducted trials was higher than one. However, there were small numbers of trials at the locations Branišovice and Podivín. No data on very high infection of a variety was found in 35 trials at the location Nechanice. No data on very high infection of a variety was also found at six other locations (Čejč, Kroměříž, Machnín, Přerov nad Labem, Žabčice and Rožnov pod Radhoštěm). However, the first five locations had only a small number of trials. At Lednice, Lípa and Žatec the proportion of data on very high infection in relation to the total number of trials conducted at the locations was lower than 15% (Table 2).

Proportion of trials

Insufficient disease severity. Of the 923 trials conducted, the results from 221 (24%) had to be excluded due to insufficient disease severity (3725 data) (Table 3). The highest proportion of these trials was recorded in 1982 (71%), 1977 (66%), 1984 (63%) and 1980 (59%). In contrast, no trial was excluded in the first year of the study (1971) and the proportion of excluded trials was less than 10% in eight other years. Of 5-years periods, the highest proportion of trials with insufficient disease severity was found in 1976–1980 (45%), the lowest in 1985–1989 (4%).

Sufficient disease severity. Of the 923 trials conducted, 702 trials (76%) showed sufficient (low or high) severity of the disease studied. The proportion of these trials was 29% (1982) to 100% (1971). The trials with sufficient disease severity yielded 12 444 data on the infection/resistance of varieties to powdery mildew (Table 3).

Low disease severity. Of 702 trials with sufficient disease severity, 395 (43% of the total number of trials) showed a low disease severity (Table 3). In individual years, the proportion of such trials was 17% (1980) up to 71% (1985). Trials with low disease severity comprised 6883 data on varietal infection/resistance.

High disease severity. Of 702 trials with sufficient disease severity, 307 trials (33% of the total number of the trials) showed a high disease severity (Table 3). These trials (after eliminating 1288 data on resistant varieties, i.e. varieties with the mean resistance > 7.50) supplied 4273 data on the infection/resistance of varieties to powdery mildew. High disease severity was found each

Table 3. Data characterising powdery mildew severity on spring barley (Official Trials of the Czech Republic)

Year	*n*	Number				Disease severity in trials					
		varieties		data		insufficient[1]		low[2]		high[3]	
		A	B	C	D	*n*	%	*n*	%	*n*	%
1971	23	17 (6)[4]	16 (6)[4]	529	220	0	0	13	57	10	43
1972	32	15 (8)[4]	14 (8)[4]	667	418	3	10	10	31	19	59
1973	28	9 (8)[4]	7 (7)[4]	408	196	4	14	10	36	14	50
1974	36	10	8	310	112	5	14	17	47	14	39
1975	42	14	11	504	231	6	14	15	36	21	50
1976	39	12	8	288	40	15	38	19	49	5	13
1977	32	15	11	165	33	21	66	8	25	3	9
1978	34	16	9	384	54	10	29	18	53	6	18
1979	35	18	11	432	88	11	31	16	46	8	23
1980	34	18	5	252	40	20	59	6	17	8	24
1981	35	17	8	578	136	1	3	17	48	17	49
1982	34	15	3	150	9	24	71	7	20	3	9
1983	35	17	9	578	117	1	3	21	60	13	37
1984	35	18	6	234	30	22	63	8	23	5	14
1985	35	18	9	594	72	2	6	25	71	8	23
1986	32	19	17	570	136	2	6	22	69	8	25
1987	34	17	17	561	272	1	3	17	50	16	47
1988	28	21	21	567	441	1	4	6	21	21	75
1989	31	14	14	406	140	2	6	19	61	10	32
1990	26	16	14	320	42	6	23	17	65	3	12
1991	24	15	14	225	70	9	37	10	42	5	21
1992	21	14	12	182	36	8	38	10	48	3	14
1993	24	11	10	176	100	8	33	6	25	10	42
1994	27	18	16	378	160	6	22	11	41	10	37
1995	32	21	20	586	360	4	13	10	31	18	56
1996	31	24	20	528	180	9	29	13	42	9	29
1997	31	21	15	546	225	5	16	11	36	15	48
1998	32	19	11	437	110	9	28	13	41	10	31
1999	25	21	12	504	120	1	4	14	56	10	40
2000	16	35	17	385	85	5	31	6	38	5	31
	923	(127)	(93)	12 444	4 273	221	23.9	395	42.8	307	33.3

Table 3 to be continued

Year	Mean of variety infection				Difference in infection		Very high infection		Disease severity coefficient
	E	F	G	H	I	J	K	L	
1971	6.29	6.18	8.70	5.33	0.96	3.23	22	6	12.40
1972	5.54	5.41	8.41	4.77	0.77	3.64	93	15	8.08
1973	6.44	5.92	8.89	5.13	1.31	3.76	28	5	10.26
1974	6.42	5.92	8.42	4.81	1.61	3.61	16	8	12.33
1975	6.32	5.79	8.27	5.06	1.26	3.21	30	12	10.12
1976	7.17	6.57	8.36	5.78	1.39	2.58	0	0	44.46
1977	6.82	6.30	8.25	4.88	1.94	3.37	6	2	54.22
1978	7.24	6.54	8.14	5.63	1.61	2.51	0	0	31.28
1979	7.23	6.50	8.37	5.23	2.00	3.14	14	5	22.74
1980	7.65	6.09	8.25	5.38	2.27	2.87	1	1	22.42
1981	7.15	5.83	8.31	5.05	2.10	3.26	22	10	10.31
1982	8.22	6.27	8.71	5.33	2.89	3.38	0	0	59.22
1983	7.23	6.29	8.29	5.29	1.94	3.00	21	12	14.30
1984	7.78	6.19	8.58	4.60	3.18	3.97	5	3	32.86
1985	7.32	6.57	8.07	5.88	1.44	2.19	23	10	25.57
1986	6.62	6.46	8.00	4.94	1.68	3.06	35	11	19.76
1987	6.22	6.22	(7.27)[5]	5.32	0.90	(1.05)[5]	34	14	11.32
1988	5.45	5.45	(7.19)[5]	5.09	0.36	(1.74)[5]	68	20	6.79
1989	6.26	6.26	(7.07)[5]	5.38	0.88	(0.81)[5]	11	6	16.81
1990	6.86	6.74	7.70	5.63	1.23	2.07	3	2	46.92
1991	6.57	6.48	7.91	5.44	1.13	2.47	5	3	25.90
1992	6.71	6.50	7.93	5.65	1.06	2.28	0	0	40.36
1993	5.90	5.67	8.19	5.08	0.82	3.11	8	3	12.10
1994	6.29	6.10	7.80	5.30	0.99	2.50	7	2	14.32
1995	5.76	5.62	8.45	5.04	0.72	3.41	31	10	9.00
1996	6.54	6.19	8.31	5.47	1.07	2.84	6	2	18.86
1997	6.50	5.78	8.30	4.97	1.53	3.33	22	5	10.35
1998	6.99	5.98	8.37	5.11	1.88	3.26	5	3	16.48
1999	7.07	6.00	8.51	5.14	1.93	3.37	9	8	12.85
2000	7.34	6.03	8.57	5.20	2.14	3.37	0	0	16.77
	6.73	6.07	8.30	5.23	1.50	3.07	525	178	21.64

n – number of trials; [1]trials in which no variety reached infection by powdery mildew scored with ≤ 6 (according to the 1–9 scale, 9 = fully resistant, plants are free of visible symptoms of infection); [2]trials with low disease severity (at least one variety was infected ≤ 6.00, but does not reach infection of the trials[3]); [3]trials with high disease severity (the mean of infection of the tested varieties, after eliminating resistant varieties, is ≤ 6.00); [4]number of varieties that were included in two types of trials; [5]no variety reached the parameter of the resistant variety (resistance > 7.50), therefore a value of the least infected variety is given

A – total number of tested varieties; B – number of non-resistant varieties (resistance ≤ 7.50); C – number of trials[2+3] × number of tested varieties (A); D – number of trials[3] × number of non–resistant varieties (B); E – mean of infection of all varieties in the trials[2+3]; F – mean of infection of non-resistant varieties in the trials[2+3]; G – mean of infection of resistant varieties in the trials[2+3]; H – the mean of infection of non-resistant varieties in the trials[3]; I = E – H; J = G – H; K – number of data on very high infection of varieties (≤ 3); L – number of trials in which very high infection of the variety(ies) was found; disease severity coefficient = the mean of infection of non-resistant varieties in the trials with high disease severity[(3)](H)/proportion of such trials[(3)], the coefficient is inversely proportional to disease severity year, and the proportion of trials with it ranged from 9 to 75% in individual years. The lowest proportions were recorded in 1977 and 1982, and the highest in 1988. Over half of the trials fell into this category also in 1972 (59%) and 1995 (56%). The several-year period with the highest proportion of trials with high disease severity was 1971–1975 (48%), the lowest 1976–1980 (17%).

Mean of infection

All varieties in trials with sufficient disease severity. This characteristic varied widely from 5.45 (1988) to 8.22 (1982) (Table 3). A high mean of infection (= a low mean of resistance) below a limit of 6.00 was also recorded in 1972 (5.54), 1995 (5.76) and 1993 (5.90). By contrast, a low mean of infection (= a high mean of resistance) above 7.50 was recorded in 1980 (7.65) and 1984 (7.78). A low mean of infection (7.38) was recorded over the decade 1976–1985, whereas in the following decade 1986–1995 considerably higher infection of varieties was found (mean of resistance 6.26).

Non-resistant varieties in trials with sufficient disease severity. These means ranged closer, from the lowest in 1972 (5.41) and 1988 (5.45) to the highest in 1990 (6.74) (Table 3).

Resistant varieties in trials with sufficient disease severity. These means were in a close range, from 7.70 in 1990 to 8.87 in 1973. During 1987–1989 no resistant variety was tested; Table 3 thus shows data on the most resistant variety in these three years.

Non-resistant varieties in trials with high disease severity. This characteristic ranged from 4.60 (1984) to 5.88 (1985) (Table 3). A high mean of infection (= a low mean of resistance) was also recorded in 1972 (4.77) and in four other years when it was below 5.00. A low mean of infection (= a high mean of resistance) was recorded in 1978 and 1989 (5.63 in both years) and in 1992 (5.65). In the remaining 20 years this mean ranged from 5.04 to 5.47.

Difference between the means of infection

All varieties in trials with sufficient disease severity. High differences in the mean of infection/resistance between varieties in the trials with sufficient disease severity (they comprise all the varieties tested) and varieties in the trials with high disease severity (they comprise non-resistant varieties only) were found in 1984 (3.18) and in 1982 (2.89). This difference was higher than 2.00 in three other years. By contrast, the lowest difference was assessed in 1988 (0.36), 1995 (0.72) and 1972 (0.77). Differences that did not exceed 1.00 were also found in five other years (Table 3). In periods of several years, this difference averaged 2.48 during 1980–1984, whereas during the decade 1987–1996 it was only 0.92.

Resistant and non-resistant varieties in trials with sufficient disease severity. The difference varied from 2.07 in 1990 and 2.28 in 1992 to 3.76 in 1973 and 3.97 in 1984. No resistant variety was included in the trials in 1987–1989, therefore values of the most resistant variety were used in these three years. The differences between these means were only 0.81 in 1989 and 1.05 in 1987. Low differences between these means were found during 1987–1992.

Proportion, in trials with sufficient disease severity, of data on very high infection of varieties

In 178 of 702 trials with sufficient disease severity, 525 data on very high infection of varieties (≤ 3) were assessed. They are 4.2% of the total number of 12 444 data (Table 3). No data characterising very high infection were found during the five years 1976, 1978, 1982, 1992 and 2000. The highest proportion of data on very high infection of varieties was assessed in 1972 (13.9%) and 1988 (12.0%). In four other years (1973, 1975, 1986 and 1987) this proportion exceeded 6.0%. Of 5-years periods, the highest proportion of data on very high infection (7.8%) was during 1971–1975, the lowest in the subsequent years 1976–1980 (1.4%). A low proportion of such data was also found in 1990–1994 and 1996–2000; 1.8% in both periods.

Proportion, of the total number of trials, of trials with a occurrence of very high infection

No data on very high infection of varieties were found during the five years 1976, 1978, 1982, 1992 and 2000. The years with the highest proportions of trials with very high infection were 1988 (71%) and 1972 (47%). In the next three years (1983, 1986 and 1987) the proportion of trials with very high infection was 33% (Table 3). The lowest proportion for a 5-year period was in 1976–1980 (5%), the highest in 1985–1989 (38%).

Disease severity coefficient

The lowest values of this coefficient (= the highest disease severity) were found in 1988 (6.79), 1972 (8.08) and 1995 (9.00) (Table 3). A low value of this coefficient (< 12.50) was also found in eight other years. The highest disease severity coefficients (= the lowest disease severity) were found in 1982 (59.22) and 1977 (54.22). A high value of this coefficient (> 30.00) was also assessed in five other years. Based on this coefficient, the severity of the disease in the remaining 12 years can be considered medium. The lowest 5-year mean was assessed in 1971–1975 (10.64), the highest in the subsequent years 1976–1980 (34.94).

DISCUSSION

Powdery mildew severity is conditioned by the resistance of host varieties and actual inoculum potential of the pathogen. Since both factors influence one another in the analysed type of trials, it is difficult to determine the effect of each factor. Therefore, the results were grouped into several characteristics and analysed from various points of view. For individual characteristics, several-year periods were chosen to underline the determined differences.

Out of the 37 locations where the variety trials were conducted, the location Nechanice was highly unsuitable for evaluating the resistance of spring barley varieties to powdery mildew because of the generally low disease severity. The same reason makes Domanínek, Přerov nad Labem, Rožnov pod Radhoštěm, Věrovany, Žabčice and Žatec rather unsuitable. By contrast, high disease severity was frequent at Branišovice, Horažďovice, Chrastava, Chrlice, Oblekovice, Podivín, Sedlec, Stachy and Trutnov which could thus be considered as very suitable for evaluating the resistance of barley varieties to powdery mildew.

The proportion of trials with insufficient disease severity depended on the proportion of resistant varieties in the trials (Dreiseitl & Pařízek 2003). A high proportion of trials was excluded from analyses because of insufficient powdery mildew severity in 1976–1984 (except 1981 and 1983); a high proportion of resistant varieties was recorded in 1980–1984. In contrast, a low proportion of trials was excluded due to insufficient disease severity during 1985–1989, i.e. in the period with the lowest proportion of resistant varieties (1987–1989). However, the indicated relation is not definite because, for example, the proportion of resistant varieties was also high in 1981 and 1983, but the proportion of excluded trials was very low, apparently due to a combination of factors, such as existence of a sufficient number of non-resistant varieties and high inoculum potential of the pathogen.

The proportion of trials with high disease severity correlated with the proportion of non-resistant varieties. The highest proportion of trials with high disease severity was found in 1971–1975, i.e. in the same period that also had the highest proportion of non-resistant varieties. The lowest proportion of trials with high disease severity was recorded during 1976–1980, i.e. in the same period with the lowest proportion of non-resistant varieties (Dreiseitl & Pařízek 2003).

The proportion of data on very high infection of varieties of a total number of data is in direct relation to both the proportion of non-resistant varieties (Dreiseitl & Pařízek 2003) and to the proportion of trials with high disease severity. The highest proportion of data on very high infection of varieties as well as the highest proportion of trials with high disease severity were recorded in 1971–1975. The lowest proportion of data on very high infection of varieties of a total number of data as well as the lowest proportion of trials with high disease severity were found in 1976–1980.

The mean of variety infection in the trials with sufficient disease severity was approximately related to the proportion of resistant varieties. However, the relation is more apparent between differences in the mean of infection in the trials with sufficient disease severity (the mean of trials with low severity and the mean of trials with high disease severity) and the proportion of resistant varieties. High differences in these means were found in 1980–1984, i.e. in the same period that had the highest proportion of resistant varieties (Dreiseitl & Pařízek 2003). However, this coherence was not valid in the reverse relation, i.e. between low differences in the means of infection of trials with sufficient disease severity and a low proportion of resistant varieties.

There was no relationship between the mean of infection of non-resistant varieties in the trials with high disease severity and the other characteristics described. The mean of infection of non-resistant varieties in trials with high disease severity comprises data on infection of non-resistant varieties only, although their proportions may differ (for example, 20% of the varieties in 1982, against 100% in 1987–1989). Also, these means come from trials with high disease severity, the proportion of which again differed (for example, only 9% of the trials in 1982, but 75% of them in 1988). Therefore, differences between means of years are low (4.60 in 1984 and 5.78 in 1976). However, they still document the continuous presence of the pathogen at the sites of the trials.

In variety trials, the plots planted with non-resistant varieties may alternate with plots of resistant varieties. The latter do not allow the pathogen to reproduce and spread so that plots of non-resistant varieties tend to be infected less than in a larger field. Therefore, in this type of trials, the average infection of non-resistant varieties decreases, particularly with an increasing proportion of resistant varieties. The proportion of trials with high disease severity also decreases for the same reason. In fact, it limits accuracy of variety trials for evaluating disease severity. Therefore, the actual severity of the disease in a region may even be higher than can be inferred from the results of such trials.

The mean of infection of non-resistant varieties in the trials with high disease severity is an important characteristic. However, it indicates infection of a selected set of trials only, regardless of the extent of these trials. Therefore, we put the mean of infection of non-resistant varieties in the trials with high disease severity in relation to the proportion of these trials. We designated this characteristic "disease severity coefficient". This coefficient comprises both intensity of variety infection in the trials with high disease severity and the proportion of these trials in the total number of trials conducted.

The disease severity coefficient is influenced less by the actual resistance of tested varieties since results from resistant varieties are not involved in this characteristic. Using the coefficient, one of the lowest powdery mildew severities was found in 1984. In this year, however, non-resistant varieties in the trials with a high disease severity had the highest infection recorded for the whole period studied even though the proportion of such trials was only 14% of the total number of trials conducted in that year. Thus, the highest infection of the varieties was considerably reduced by the low proportion of these trials.

The data mentioned in the previous paragraph may document best the fact resulting from this work that powdery mildew severity is considerably affected by actual resistance of varieties, but that even in years with low disease severity (that is influenced by a high proportion of resistant varieties) powdery mildew is able to induce high infection of susceptible varieties. Therefore, one of the goals of variety testing is to limit registration of varieties with very low resistance.

Based on values of the disease severity coefficient, the highest powdery mildew severity in the Czech Republic was found in 1988, 1972, and 1995. That is also confirmed by results of most other characteristics. According to an average value of the coefficient and some other characteristics, the highest severity of this disease fell into the period of 1971–1975; but according to still other characteristics, it was the period 1985–1989. The latter period is overlapped by the period of 1984–1988 when the highest average infection of the most susceptible variety was also recorded (Dreiseitl & Pařízek 2003). By contrast, the lowest severity was found in 1982 and 1977, and according to several other characteristics also in 1984, though this year ranked only sixth based on values of the disease severity coefficient. The lowest disease severity was almost unambiguously characteristic for 1976–1980.

From the beginning of the period studied, resistant varieties were part of the trials and their numbers significantly increased during 1975–1985. These varieties possessed the highly effective resistance genes *Mla1*, *Mla3*, *Mla9*, *Mla12*, *Mla13*, *Ml(Kr)*, *Mlat* and *MlLa* that had not been used in the Czech Republic before (Dreiseitl & Jørgensen 2000). Varieties with these resistance genes were registered in 1977–1986 and since 1982 they were planted in the Czech Republic on the whole area of spring barley (Dreiseitl 1993). That inevitably contributed to the fact that the lowest powdery mildew severity was recorded in 1982.

Among the varieties carrying one or more of the eight above-mentioned resistance genes, varieties possessing gene *Mla13* dominated. During 1983–1990 they were annually planted on over 50% of the spring barley area (Dreiseitl 1993). Though the variety assortment was diversified, its resistance was unbalanced and unable to curtail the selection of pathotypes virulent on *Mla13*.

During the period studied, the area planted to winter barley dramatically increased (Appendix 1).

Appendix 1. Barley area in the Czech Republic (1971–2000)*

Period	Number of years	Average of harvested area (1000 ha)		
		Winter barley	Spring barley	Barley in total
1971–1977	7	6	574	580
1978–1982	5	67	629	696
1983–1987	5	152	443	595
1988–1991	4	214	359	573
1992–1997	6	179	441	520
1998–2000	3	164	374	538

*Data of the Czech Statistical Office

While the proportion of winter barley of the total barley area was about 1% in 1971–1977, it exceeded 10% in 1980 and 25% in 1985, and a historical maximum of almost 42% was reached in 1991. Though varieties of this crop possessed specific resistance genes (Dreiseitl & Jørgensen 2000), their practical effect was minimal due to the high frequency of matching virulences in the pathogen population (Dreiseitl unpublished).

The dramatic increase in growing varieties of winter barley that enabled the pathogen to reproduce played a crucial role in the increase of actual inoculum potential facing spring barley varieties. It increased severalfold the probability of successful selection and increase of identified, but still very rare, pathotypes that could infect resistant varieties possessing gene *Mla13* (Brückner 1982; Limpert & Fischbeck 1987).

There was an outbreak of powdery mildew at Chrastava (northern Bohemia, about 10 km from the Czech-German-Polish state border) in 1985. Here, the varieties Bonus, Perun and Zenit carrying gene *Mla13* were heavily infected for the first time. A year later, very high infection of varieties possessing this gene was recorded at the locations Sedlec (near Prague, Central Bohemia) and Chrlice (near Brno, Central Moravia). In 1987, these varieties were highly infected in eight and in 1988 in 13 trials. In 1987 and 1988, Bonus became one of the most susceptible varieties tested (following the extremely susceptible HE-3527 and HE-3611), and during 1989–1992 and 1997–2000 the varieties possessing gene *Mla13* were the most susceptible varieties tested. This illustrates the total breakdown of resistance conditioned by gene *Mla13* across the Czech Republic.

Varieties possessing gene *Mla13* were grown at that time in both the Czech Republic and Denmark. The first such variety was Rupal, registered in 1972 (Brown & Jørgensen 1991). Its area and/or area planted with other varieties possessing this gene did not surpass 10% of the area of spring barley in Denmark, except in 1985 and 1986 (Munk *et al*. 1991). The first Czech variety with gene *Mla13* was Koral, registered in 1978. As early as 1983 the proportion of varieties carrying gene *Mla13* exceeded 55% of the area under spring barley in the Czech Republic and Slovakia, and this proportion remained stable until 1990 (Dreiseitl 1993). The increase in growing area of winter barley and a high percentage of varieties possessing gene *Mla13* were undoubtedly the main reasons why the pathogen adapted to gene *Mla13* faster and more thoroughly in the Czech Republic than in Denmark.

In the first half of the 1980s, the susceptible varieties were mostly varieties of winter barley. Since the pathogen adapted to gene *Mla13* (Dreiseitl 2003), the varieties in the major part of the spring barley area in the Czech Republic that had so far been completely resistant became susceptible within 2 to 3 years (Dreiseitl 1993). This also increased the actual inoculum potential of the pathogen. Susceptible winter and more than 50% of spring varieties then also susceptible allowed the pathogen to reproduce and spread easily. The resulting high inoculum potential accelerated the adaptation of the pathogen population so that other genes of specific resistance present in spring barley varieties (*Ml(Kr)*, *Mla1*, *Mla3*, *Mlat*) were also overcome. Consequently, there were no resistant varieties in the Czech Republic during 1987–1989, and no highly resistant ones even in the 11-year period 1985–1995, while during the other years such varieties were absent only in 1972 (Dreiseitl & Pařízek 2003).

The analysis of data from a large number of field trials conducted at various locations for a period of 30 years confirmed that powdery mildew is an important disease of barley in the Czech Republic. A higher proportion of resistant varieties in the trials led to a decrease in the proportion of trials with high disease severity. The probable general decrease in powdery mildew severity that could have taken place as a consequence of growing resistant spring barley varieties was overlapped by a considerable increase in the area of winter barley grown to susceptible varieties or, at least, by varieties enabling the pathogen to reproduce and spread. High powdery mildew severity was found in the trials every year and very high infection of varieties occured in 25 out of the 30 years studied. Evidently, the presence of spring barley varieties with an insufficient resistance to powdery mildew allows a lasting high inoculum potential of the pathogen.

References

Brown J.K.M., Jørgensen J.H. (1991): A catalogue of mildew resistance genes in European barley varieties. In: Jørgensen J.H. (ed.): Integrated Control of Cereal Mildews: Virulence and Their Change. Risø National Laboratory, Roskilde: 263–286.

Brückner F. (1982): Nález rasy padlí na ječmeni (*Erysiphe graminis* DC. var. *hordei* Marchal) překonávající geny rezistence *Mla9* a *Mla14*. Ochr. Rostl., **18**: 101–105.

Dreiseitl A. (1993): Analýza pěstováni československých odrůd jarního ječmene odolných k padlí travnímu. Rostl. Výr., **39**: 337–344.

Dreiseitl A. (1997): Odolnost k padlí travnímu u novošlechtění ječmene. Genet. a Šlecht., **33**: 45–54.

Dreiseitl A. (2003): Adaptation of *Blumeria graminis* f.sp. *hordei* to barley resistance genes in the Czech Republic in 1971–2000. Plant Soil Environ., **49**: 241–248.

Dreiseitl A., Jørgensen J.H. (2000): Powdery mildew resistance in Czech and Slovak barley cultivars. Plant Breeding, **119**: 203–209.

Dreiseitl A., Jurečka D. (1996): Výskyt chorob ječmene jarního v České republice v letech 1989–1995. Ochr. Rostl., **32**: 221–229.

Dreiseitl A., Jurečka D. (1997): Výskyt listových chorob ječmene ozimého v České republice v letech 1989–1996. Ochr. Rostl., **33**: 177–186.

Dreiseitl A., Pařízek P. (2003): Resistance of spring barley varieties to powdery mildew in the Czech Republic in 1971–2000. Czech J. Genet. Plant Breed., **39**: 31–44.

Limpert E., Fischbeck G. (1987): Distribution of virulence and of fungicide resistance in the European barley mildew population. In: Wolfe M.S., Limpert E. (eds): Integrated Control of Cereal Mildews: Monitoring the Pathogen. Martinus Nijhoff Publ., 1987, Brussels-Luxembourg: 9–30.

Munk L., Jensen H.P., Jørgensen J.H. (1991): Virulence and disease severity of barley powdery mildew in Denmark 1974–1989. In: Jørgensen J.H. (ed.): Integrated Control of Cereal Mildews: Virulence and Their Change. Risø National Laboratory, Roskilde: 55–65.

Received for publication December 11, 2002
Accepted after corrections January 28, 2003

Souhrn

Dreiseitl A., Jurečka D. (2003): **Výskyt padlí travního na ječmeni jarním v České republice v letech 1971–2000**. Plant Protect. Sci., **39**: 39–51.

Byly analyzovány výsledky hodnocení odolnosti 127 odrůd ječmene jarního k padlí travnímu, které byly postupně zařazeny v 923 odrůdových pokusech Ústředního kontrolního a zkušebního ústavu zemědělského. Odolnost odrůd byla zjišťována na základě jejich napadení chorobou. Údaje lze využít i k posouzení výskytu choroby. Bylo posuzováno několik charakteristik udávajících výskyt choroby včetně koeficientu výskytu choroby (= průměrné napadení neodolných odrůd v pokusech se silným výskytem choroby/podíl těchto pokusů). Hodnota koeficientu je nepřímo úměrná výskytu choroby. Ukazuje na nejvyšší výskyt padlí travního v letech 1988, 1972 a 1995 a v období let 1971–1975, což potvrzují i výsledky dalších charakteristik. Podle jiných charakteristik však bylo období s nejvyšším výskytem padlí travního v letech 1985–1989. Nejnižší výskyt choroby byl zjištěn v letech 1982 a 1977 a v období let 1976–1980. Silný výskyt padlí travního na ječmeni jarním byl zjištěn v každém roce, a to v 9–75 % pokusů (v průměru v 33 %). Diskutovány jsou některé charakteristiky výskytu choroby, ale také vliv podstatného rozšíření ječmene ozimého (reprezentován jen neodolnými odrůdami) na zvýšení inokulačního potenciálu a na následné zrychlení adaptace patogena k odolnosti odrůd ječmene jarního, zvláště ke genu *Mla13*.

Klíčová slova: *Hordeum vulgare*; *Blumeria graminis* f.sp. *hordei*; ječmen jarní; padlí travní; výskyt choroby

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