Reaction of Winter Wheat Cultivars and Breeding Lines to *Blumeria graminis* f.sp. *tritici*

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Abstract

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During 4 years, 27 cultivars and breeding lines of winter wheat (*Triticum aestivum*) were tested in small plot experiments for resistance to powdery mildew fungus. The most resistant were Frimegu, RE9607, Runal, Asset, Folke and Wasmo. The cultivars Asta (*Pm*2,6) and Vlasta (*Pm*2,6 and another not determined specific gene or minor genes of resistance) fall into resistant cultivars. It seems that the specific genes of resistance *Pm*2 and *Pm*6 are still very effective against the present Czech population of powdery mildew on wheat. Resistance of the cultivars Hereward and Tarso, having the gene of resistance *Pm*8, can be ascribed to an additional undetermined gene that is effective only in mature plants. The cultivars Mikon and Ramiro with partial resistance had a higher infection type and disease severity than resistant cultivars, but lower disease severity than the susceptible cultivar Kanzler.

Keywords: *Triticum aestivum*; powdery mildew; disease severity; resistance

Besides maize and rice, common wheat (*Triticum aestivum* L. Em. Thell.) is one of the three most important crops in the world. Wheat powdery mildew, caused by the obligate fungus *Blumeria graminis* DC. E.O. Speer f.sp. *tritici* Em. Marchal (syn. *Erysiphe graminis* DC) (Friebe *et al.* 1996; Hsam *et al.* 1998; Shi *et al.* 1998), is one of the most destructive foliar diseases of wheat in regions with cool or temperate climates. Yield losses range from 5% to 45% among different countries and growing seasons (Namuco *et al.* 1987; Jia *et al.* 1996). Growing resistant wheat cultivars is one of the most economical and effective methods of control of powdery mildew. Race-specific resistance genes, following the gene-for-gene relationship, have been used extensively in breeding, but only one mutation is generally needed for a pathogen to change from avirulence to virulence. Thus, race-specific resistance is readily overcome by matching virulent pathotypes when varieties containing these resistance genes are used on a large scale for a sufficient length of time (Yu *et al.* 2001). To prolong the effectiveness of specific resistance, several methods, such as "pyramiding", i.e. combining several resistance genes in one variety (Vanderplank 1968), multilines (Browing & Frey 1969; Kølster *et al.* 1989) and cultivar mixtures (Wolfe & Barrett 1977; Wolfe 1985) have been proposed or used. Another type of resistance, partial resistance, is characterised by a compatible interaction in all growth stages but with a lower infection frequency, a longer latent

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period, or a lower rate or shorter period of spore production (Parlevliet & van Ommeren 1975; Kranz 1983). Partial resistance has provided durable control of powdery mildew in wheat (Shaner 1973). Therefore, tests for resistance of wheat cultivars to powdery mildew are important sources of information for breeders.

The aim of the present tests was to determine the resistance of winter wheat cultivars and lines to a natural population of powdery mildew fungus as judged by disease severity and infection type over several years.

MATERIALS AND METHODS

In 4 years of small plot-experiments, 27 winter wheat cultivars and lines were used in two time periods. Table 2 lists the tested entries; they originated from seven European countries and from the Ring test of winter wheat varieties for partial resistance to powdery mildew (project COST817, WG4 2000).

In the first group (1999 and 2000) of experiments, 17 cultivars were used. In the second group (2001 and 2002), 13 cultivars and 14, respectively were used. In 2002 the cultivar Alka (also used in 1999 and 2000) was added. The cultivars were sown in three rows (length of row 1 m) vertically to one row (15 m) of the susceptible cultivar Kanzler. The tests were carried out in four replicates.

Natural infection by powdery mildew was used. Evaluation of disease intensity of the pathogen was made on all live leaves of plants (15 plants for each replicate) by means of a 9-point assessment scale (Saari & Prescott 1975) and expressed as disease severity. It is the percentage of relevant host tissue or organ covered by symptoms of the disease (Kranz & Rotem 1988). The disease severity was estimated on five sampling dates in the year 1999 and on four dates in 2000, 2001 and 2002 (Table 1).

Disease severity of the whole plant was expressed as the cumulative proportion of leaf area diseased – CPLAD (Věchet & Kocourek 1987; Brière *et al.* 1994). The tested cultivars and lines were classified into four groups, relative to the disease severity on the susceptible cultivar Kanzler; the groups were VR – very resistant, MR – medium resistant, MS – medium susceptible and S – susceptible. Thus, the levels of disease severity of the four groups in single years were in 1999: VR 0–9.05, MR 9.06–18.1, MS 18.2–27.2, S 27.3–36.2; in 2000 VR 0–1.6, MR 1.7–3.2, MS 3.3–4.8, S 4.9–6.55; in 2001: VR 0–17.5, MR 17.6–34.98, MS 34.99–52.5, S 52.6–69.9; and in 2002: VR 0–8.75, MR 8.76–17.5, MS 17.6–26.25, S 26.26–35.0. Reaction of cultivars to powdery mildew was expressed as infection type – IT (Torp *et al.* 1978) in five categories (for growth of mycelium: 0 – none, 1 – weak, 2 – moderate, 3 – plentiful, 4 – strong; for sporulation: 0 – none, 1 – none, 2 – weak, 3 – moderate, 4 – strong). Usually, infection types 3 and 4 are considered as a susceptible reaction (Wolfe 1972). Program STATISTCA (STATSOFT, Inc., Tulsa, USA) was used for statistical evaluation of disease severity in single years (average and standard deviation). The growth stage was assessed using a decimal code (Zadoks *et al.* 1974).

Table 1. Sampling dates and the corresponding averaged Zadoks growth stages of winter wheat cultivars tested 1999 to 2002

Year	Sampling date	Growing stage
1999	SD1 (27.5.)	49
	SD2 (4.6.)	55
	SD3 (10.6.)	61
	SD4 (24.6.)	65
	SD5 (1.7.)	73
2000	SD1 (25.5.)	51
	SD2 (7.6.)	61
	SD3 (14.6.)	69
	SD4 (28.6.)	73
2001	SD1 (25.5.)	49
	SD2 (13.6.)	55
	SD3 (26.6.)	65
	SD4 (10.7.)	75
2002	SD1 (30.5.)	49
	SD2 (12.6.)	59
	SD3 (19.6.)	69
	SD4 (26.6.)	71

RESULTS

The highest disease severity occurred in 2001 and the lowest in 2000. The levels in 1999 and 2002 were approximately the same and intermediate between those extremes (Figure 1). The majority of

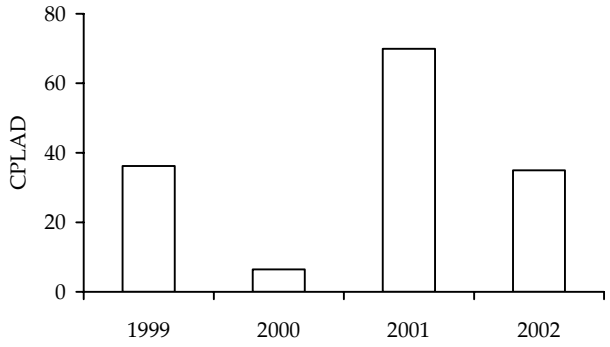

Figure 1. Disease severity on cultivar Kanzler, the susceptible standard, expressed as CPLAD – cumulative proportion of leaf area diseased

tested cultivars and breeding lines in both groups of the experiments (1999–2000; 2001–2002) fell into the resistant group (Table 3). The disease severities in 1999 and 2000 were very different; it was rather high in 1999, but very low in 2000. Most tested cultivars (except Kanzler, Mikon and Charger) had a very low infection type (1) in 2000. The cultivars RE9607, Runal, Folke, Frimegu and Asset had the highest resistance in the first group of cultivars, tested in 1999–2000. They also had a very low infection type (1) in both years. On the other hand, the cultivars Mikon (in 1999 and 2000), Hereward and Charger (in 1999) had a higher infection type (3) than the other cultivars and higher disease severity as well. In 1999 the cultivars Alka, Bor5456, Bold, Astella and Zentos had medium resistance, with infection type 2. Cultivar Kanzler had the highest disease severity and highest infection type in all four years of experiments.

The disease severity in 2001 was the highest of all 4 years of experiments. It was much higher than in the years of high severity of powdery mildew in 1999 and 2002. From the second group of cultivars, tested in 2001 and 2002, the lowest disease severity and infection type was shown by Wasmo and Vlasta, and by Bill in 2001, although the latter had high disease severity in 2002. The cultivars Šárka, Samson, Ramiro and the cultivars Altos, Bill and Tarso had high infection types (3) and medium disease severity in 2002. The higher disease severity of cultivars Šárka, Bill and Altos in 2002 than in 2001 differed from the trend in

Table 2. Genes for resistance to powdery mildew fungus in tested cultivars and breeding lines of winter wheat and the country of origin

Cultivar	Genes of resistance	Origin	Cultivar	Genes of resistance	Origin
Alka	–	CZ	Hereward	*Pm*8, *MlHe2*	UK
Altos	–	G	Charger	–	UK
Asta	*Pm2,6*	CZ	Kanzler (SS)	–	G
Astella	–	CZ	Mikon (PRS)	–	G
Asset	–	UK	Ramiro (PRS)	–	G
Bill	–	DM	RE9607	–	F
Bold	–	G	Runal	–	SW
Bor5454	–	FIN	Tarso	*Pm8*	G
Bor5456	–	FIN	Samson	–	AUS or UK
Corvus	–	G	Šárka	–	CZ
Folke	–	SW	Vlasta	*Pm2,6*•	CZ
Frimegu	–	G	Zentos	–	G
Galicia	–	DM	Wasmo	–	DM
Habicht	–	G			

(SS) = susceptible standard to powdery mildew; (PRS) = partial resistant standard; • = additional, not yet defined specific or minor gene of resistance

AUS – Austria, CZ – Czech Republic, DM – Denmark, FIN – Finland, G – Germany, SW – Switzerland, UK – United Kingdom

Table 3. Disease severity (DS), expressed as CPLAD, and infection type (IT) of powdery mildew on tested winter wheat cultivars and breeding lines. Average and standard deviation of the disease severity in single years (Prague-Ruzyně 1999–2002)

	1999		2000		2001		2002	
	DS	IT	DS	IT	DS	IT	DS	IT
Kanzler	36.2	4	6.55	4	69.9	4	35.0	4
Mikon	59.0	3	0.75	3	–	–	–	–
Asta	1.8	1	0.5	1	–	–	–	–
Alka	4.8	2	0.6	1	–	–	4.3	2
RE9607	0.3	1	0.2	1	–	–	–	–
Bor5456	9.8	2	3.01	1	–	–	–	–
Bor5454	5.0	2	0.92	1	–	–	–	–
Bold	5.1	2	0.3	1	–	–	–	–
Charger	20.5	3	0.9	2	–	–	–	–
Astella	9.7	2	2.2	1	–	–	–	–
Vlasta	–	–	0.03	1	2.2	2	1.7	2
Šárka	–	–	0.6	1	7.1	3	11.1	3
Hereward	8.9	3	0.33	1	–	–	–	–
Runal	0.4	1	0.2	1	–	–	–	–
Folke	0.9	1	0.8	1	–	–	–	–
Frimegu	0.1	1	0.2	1	–	–	–	–
Zentos	4.3	2	–	–	9.5	3	1.7	2
Asset	0.7	1	0.3	1	–	–	–	–
Habicht	–	–	–	–	6.1	2	1.5	2
Tarso	2.9	2	–	–	5.5	2	6.7	3
Galicia	–	–	–	–	3.2	2	3.2	2
Wasmo	–	–	–	–	1.1	1	0.4	1
Samson	–	–	–	–	12.5	3	7.0	3
Bill	–	–	–	–	1.3	2	13.9	3
Ramiro	–	–	–	–	13.3	3	9.8	3
Corvus	–	–	–	–	3.4	2	3.2	2
Altos	–	–	–	–	3.3	2	7.4	3
Average	10.0235		1.0818		10.6466		7.6357	
Standard deviation	15.1051		1.5558		17.5286		8.5231	

disease severity of all other cultivars. Of the cultivars Vlasta and Šárka, tested for 3 years (2000, 2001 and 2002), Vlasta was the more resistant one. Cultivars Ramiro and Samson showed very similar disease severity and infection type.

DISCUSSION

The differences in levels of powdery mildew severity between years of the experiment were probably caused by the course of weather fac-

tors, in particular by temperature. The majority of tested cultivars and breeding lines were resistant to powdery mildew. Most resistant were RE9607, Runal, Folke, Frimegu, Asset, Wasmo and Vlasta. In the first group (1999–2000) of tested cultivars and lines the entries Asta, Alka, RE9607, Bor5454, Bold, Runal, Folke, Frimegu, Zentos, Asset and Tarso were highly resistant; they also had low infection types. In the second group (2001–2002), very resistant cultivars were Vlasta, Tarso, Galicia, Wasmo, Bill, Corvus and Altos. The cultivars Asta and Vlasta have the same genes of specific resistance (*Pm2, Pm6*), but Vlasta has in addition some other, not determined specific or minor gene of resistance to powdery mildew. Vlasta gave very effective protection against powdery mildew during three of the tested years. When we compare our results of powdery mildew resistance of cultivars Vlasta and Šárka with those of the Central Control and Testing Institute of Agriculture of the Czech Republic it is evident that the cultivar Vlasta offers a higher degree of resistance than Šárka. Hanušová and Bartoš (1993) reported that genes *Pm2* and *Pm8* were not effective in conditions of the Czech Republic. But good specific resistance to powdery mildew of these cultivars at maturity is conditioned by the pair of genes *Pm2+Pm6* that give a medium resistant or resistant reaction in field conditions. It seems that the genes *Pm2+Pm6* for specific resistance are still very effective against the present population of powdery mildew on wheat in the Czech Republic. Švec and Miklovičová (1998) think that virulence on *Pm2* dropped in central Europe. Zeller *et al*. (1993) quote that in European countries, genes *Pm3d*, *Pm4b* and *Pm6* are more effective. Huszár (1996) found that in the analysed population, virulence on genes *Mld+mlha* was not developed, and that virulence to *Pm2+Pm6* was at the same level as in the previous period (27% in 1991–1993, 24% in 1995). In our tests, the level of disease was lower in 2000 than in 1999. On cultivar Hereward both disease severity and infection type were drastically lower in 2000. But so sharp a decline in disease severity was not registered with other cultivars. Resistance of the two cultivars Hereward and Tarso, having the gene of resistance *Pm8*, can possibly be ascribed to genes that are activated only in mature plants.

The cultivars Mikon and Ramiro with partial resistance to powdery mildew had a higher infection type than resistant cultivars, but lower disease severity than the susceptible cultivar Kanzler. Partial resistance, sometimes called adult plant resistance (APR), retards infection and reproduction of the pathogen in adult plants but not in seedlings. APR to powdery mildew is more durable than race-specific resistance (Liu *et al*. 2001). Parlevliet (1988) characterised partial resistance by a reduced rate of epidemic development despite a high or susceptible infection type. A very similar disease severity and infection type as the partial resistant cultivar Ramiro was shown by cultivar Samson in two years (2001, 2002) of the experiments. We can suppose that the cultivar Samson could have partial resistance to powdery mildew, although it will be necessary to check this supposition. If we compare the cultivars Mikon and Ramiro in two years (1999 and 2002) when the disease severity of the susceptible cultivar Kanzler was practically the same, the cultivar Mikon had lower disease severity than Ramiro. It is possible that variability in disease severity exists among cultivars with partial resistance.

To sum up, most of the tested cultivars and breeding lines of winter wheat were resistant to powdery mildew, some of them had partial resistance. The cultivar Vlasta had excellent resistance. The level of infection by powdery mildew in individual years can be influenced by daily temperatures and by occurrence of temperatures over 25°C.

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