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POWDERY MILDEW RESISTANCE OF WINTER WHEAT CULTIVARS REGISTERED IN LITHUANIA

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Abstract

The research was done at the Lithuanian Institute of Agriculture during 2004–2007. Resistance to powdery mildew of winter wheat cultivars registered in Lithuania was investigated in the collection nurseries with a natural infection. Our experimental evidence showed that there were no cultivars with effective resistance mono-genes among the genotypes tested. Effective powdery mildew resistance from resumption of vegetation to its end depended mainly on the quantitative resistance level. A few genotypes possessed unknown resistance genes, which were effective in the autumn and after resumption of vegetation. However, these genes were broken by a local pathogen population at later development stages. The most resistant cultivars 'Torrild' and 'Dekan' in the years favourable for disease development were evaluated by score 3 and the area under disease progress curve (AUDPC) values lower than 100. The other two cultivars with the same AUDPC value but higher scores (3.7 and 4.8) were 'Altos' and 'Zentos'. The most susceptible genotypes from the collection nurseries were evaluated by score 9 and AUDPC values over 2000. The cultivars evaluated by 4–5 scores and AUDPC value 100–300 dominated in 2004–2006. The year 2007 was less favourable for powdery mildew; the tested genotypes were evaluated mainly by 2–4 scores and AUDPC value up to 50.

Key words: winter wheat, powdery mildew, partial resistance, AUDPC.

Introduction

Powdery mildew caused by *Blumeria graminis* f. sp. *tritici* (Em. Marshal) is one of the most devastating diseases of common wheat in the regions with a cool or maritime climate. Development of resistant cultivars is the most economical and environmentally safe means for controlling this disease /Griffey et al., 1993/. To date, 38 major genes, designated *Pm1-Pm38*, conferring resistance to wheat powdery mildew has been detected and mapped to specific chromosomes. Part of these genes have several alleles /McIntosh et al., 2007/. Moreover, there are a number of major genes mentioned in publications but up to now with temporary designation /Zhou et al., 2005/. However, the resistance conferred by these major genes is easily overcome by new pathogen races possessing the corresponding virulence genes /Shaner, 1973; Wang et al., 2005/.

Quantitative resistance to powdery mildew, mostly observed at the adult plant stage (APR), is obvious in cultivars possessing no identified *Pm* genes or when the natural population of powdery mildew overcomes the resistance conferred by *Pm* genes. This type of resistance is continuously varying from rather susceptible to highly resistant at the APR. It is usually caused by the simultaneous segregation of several genes and a multitude of non-genetic factors, e. g. environment /Geiger, Heun, 1989/. Since this resistance delays infection, growth and reproduction of the pathogen, it confers partial resistance and is termed either ‘adult resistance’ or slow mildewing partial resistance. Field testing is the most effective way to identify and select for quantitative resistance when matching virulences for all *Pm* genes and gene combinations exist at the given area. Genotypes that have a considerably lower disease severity than the possibly most susceptible cultivar are designated as quantitatively resistant. The level of this resistance type in a given cultivar, however, might be not sufficient to control the disease. Therefore, genotypes that are not considerably different from resistant checks are selected in practical breeding /Bayles, Priestley, 1982/

Investigation of partial resistance in wheat is complicated by the abundance of Quantitative Trait Loci (QTL) present in modern winter wheat cultivars and breeding lines. QTL responsible for resistance level differ among themselves by phenotypical effect and response to different environments /Bougot et al., 2006; Tucker et al., 2007/.

The study was designed to assess types and levels of powdery mildew resistance of winter wheat cultivars recently registered in Lithuania.

Materials and Methods

The research was conducted at the Lithuanian Institute of Agriculture (LIA) during 2004–2007 in the breeding nurseries with a natural infection. Resistance to powdery mildew of 48 cultivars of winter wheat from the collection nurseries (CN) was investigated under natural infection. The plot size in the collection nursery was 2 m^2. As susceptible control the most damaged by powdery mildew genotypes from collection of genotypes of the continental origin (CGCO) were used. Genotype Ab186*3414/Jag'S'// K92 was used in 2004, Hatusha/Omid/3/Agri/Bjy/Vee – 2005, ‘Beijing 841’ – 2006, ‘Abilene/Jagger’ – 2007.

The soil of the experimental site is loam (*Endocalcari-Epihypogleyic Cambisol* (*sicco*) (CMg-p-w-can)) with a clay content of 24–27%, pH 6.5–7.0, organic matter 2.5–2.7%, P_2O_5 190–240, K_2O 185–264 mg kg^{-1} soil. $N_{90}P_{60}K_{60}$ was applied annually. Phosphorus and potassium fertilisers were applied pre-sowing and nitrogen in spring after resumption of vegetative growth. The plots were sprayed with herbicides in spring when weeds started to grow intensively. Other pesticides and additional fertilisation were not applied.

The years 2005 and 2006 with lower precipitation and higher air temperature than long term average during spring and first half of summer were favourable for the development of powdery mildew. The years 2004 and 2007 with similar to long term average of precipitation and air temperature were less favourable for the development of this disease as part of conidia were washed down, moreover, other leaf diseases constituted higher competition than in dryer years. The disease was assessed from stem elongation (BBCH 30–31) to late milk development (BBCH 77). Disease resistance was measured in scores, using 1–9 scale. Score 1 – no visible symptoms of disease, score 9 – plants heavily infected (infection ≥80%). The area under the disease progress curve (AUDPC) was calculated as the total area under the graph of disease severity against time, from the first scoring to the last.

AUDPC = $\Sigma_{i=1}^{n-1} [(t_{i+1} - t_i) (y_i + y_{i+1})/2]$. Where t is time in days of each reading, y is the percentage of affected foliage at each reading and n is the number of readings /Campbell, Madden, 1990/. Means were compared with Duncan's Multiple Range test at the level of significance P = 0.01.

Results and Discussion

Experimental seasons differed in terms of conduciveness to the development of powdery mildew. However, the most susceptible genotypes from (CGCO) varied little by disease severity, score 8 in 2004 and 2006, and score 9 in 2005 and 2007 (Figure 1).

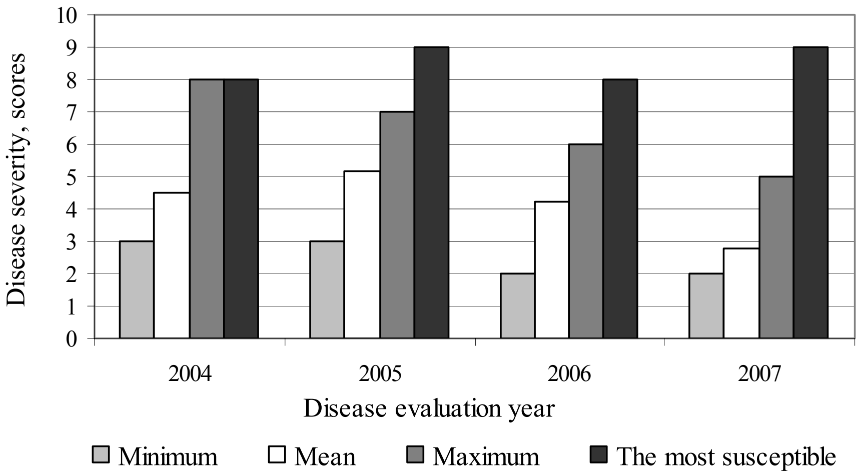

Figure 1. Disease severity scores on screened winter wheat cultivars during 2004–2007

The most susceptible cultivar among the registered ones by maximal disease severity was equal to the most susceptible genotype from CGCO only in 2004. Later, the differences were higher as maximal disease severity was lower by 2 scores in 2005 and 2006, by 4 scores in 2007.

The AUDPC value for the most susceptible genotype from CGCO ranged from 1330 in 2007 to 2220 in 2005 (Figure 2). However, the AUDPC value for the most susceptible registered cultivars ranged from 148 in 2007 to 830 in 2005. The overall mean disease severity for all tested cultivars ranged from 23 in 2007 to 251 in 2005. The AUDPC value of the most resistant cultivars was very low and ranged from 0.8 in 2007 to 22 in 2004. The AUDPC values characterized conditions of year for powdery mildew development better than maximal disease severity scores.

These results prove that the whole experimental period was characterised by heavy epidemic pressure, which enabled us to adequately evaluate the resistance level of the tested cultivars. Despite the very high level of powdery mildew on genotypes from CGCO the disease level on more resistant cultivars was more influenced by yearly weather.

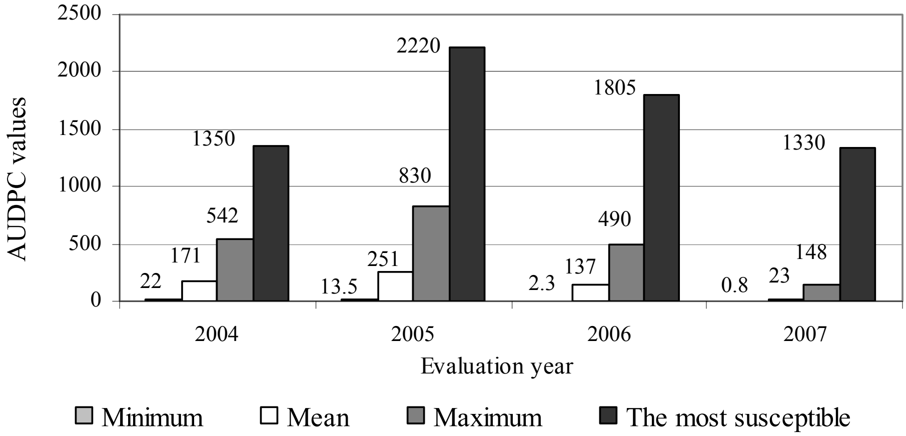

Figure 2. The AUDPC values for screened winter wheat cultivars during 2004–2007

Table shows that winter wheat cultivars considerably varied by the maximal AUDPC value. A total of 48 cultivars were tested during a 4 year period. The period of individual cultivars testing ranged from 1 to 4 years. Only 2 cultivars were tested for a year. Almost half of the cultivars were investigated for 2 years, 8 cultivars for 3 years and 20 cultivars for 4 years.

Table. Powdery mildew resistance of winter wheat cultivars registered in Lithuania during 2004–2007

Dotnuva, 2004–2007

Cultivar	Country of origin	Testing period	Maximal disease values		Minimal disease values	
			AUDPC	Scores	AUDPC	Scores
1	2	3	4	5	6	7
‘Torrild’	DK*	2005–2007	21 a**	3.0 a	0.8 a	2.0 a
‘ Dekan’	DE	2004–2005	33 a	3.0 a	22 ab	3.0 c
‘Altos’	DE	2004–2007	83 b	3.7 b	7.7 ab	3.0 c
‘Zentos’	DE	2004–2007	92 b	4.8 d	0.8 ab	2.3 ab
‘Kodex’	DE	2004–2005	101 bc	5.1 de	80 de	4.0 d
‘Cubus’	DE	2004–2005	126 cd	5.2 de	102 ef	4.0 d
‘Bill’	DE	2004–2007	140 de	3.8 b	1.5 ab	2.0 a
‘Tauras DS’	LT	2004–2007	140 de	4.8 d	21 ab	3.2 c
‘Cardos’	DE	2005–2007	146 de	5.2 de	1.5 ab	2.0 a
‘Kris’	UK	2004–2007	148 de	4.7 cd	0.8 a	2.0 a
‘Buteo’	DE	2004–2007	151 de	5.1 de	7.7 ab	3.0 c
‘Seda DS’	LT	2004–2007	159 ef	5.0 de	8.6 ab	3.0 c

Table continued

1	2	3	4	5	6	7
ʻMilvus’	DE	2004–2007	160 ef	4.0 b	7.7 ab	3.0 c
ʻFlair’	DE	2004–2005	166 ef	4.8 d	80 de	4.1 d
ʻMilda DS’	DE	2004–2007	190 fg	5.2 de	114 ef	4.2 de
ʻBety’	NL	2004	192 fg	4.7 cd	192 jk	4.3 d-f
ʻOlivin’	FR	2004–2007	206 gh	5.0 de	28 bc	3.0 c
ʻBegra’	PL	2004	211 ghi	4.2 bc	211 kl	4.2 de
ʻPegassos’	DE	2004–2005	211 ghi	4.8 d	121 fg	4.2 de
ʻAlma DS’	LT	2004–2007	214 ghi	6.0 f	24 ab	2.9 bc
ʻAspirant’	DE	2004–2006	235 hij	4.8 d	61 cd	4.1 d
ʻBaltimor’	FR	2004–2005	235 hij	5.1 de	211 k	4.3 d-f
ʻŠirvinta 1’	LT	2004–2007	240 ij	5.0 de	7.7 ab	3.0 c
ʻAda’	LT	2004–2007	241 ij	5.0 de	0.8 ab	2.2 a
ʻCompliment’	DE	2004–2005	258 j	6.2 fg	124 fg	5.0 fg
ʻAristos’	DE	2004–2005	260 j	5.2 de	119 fgh	4.2 de
ʻMarshal’	UK	2004–2007	260 j	6.0 f	2.7 ab	2.0 a
ʻAnthus’	DE	2004–2007	261 j	4.7 cd	1.5 ab	2.0 a
ʻJubilatka’	PL	2004–2005	263 j	6.2 fg	167 i	5.0 fg
ʻHereward’	UK	2004–2005	267 j	5.0 de	113 fgh	4.2 de
ʻDorota’	FR	2005–2007	268 j	6.2 fg	102 ef	4.2 de
ʻBussard’	DE	2004–2005	311 k	6.2 fg	254 lm	5.3 g
ʻAstron’	DE	2004–2006	312 k	5.7 ef	160 i	4.3 d-f
ʻEllvis’	DE	2005–2006	340 kl	7.1 i	262 lm	6.2 h
ʻAron’	DE	2004–2006	342 kl	6.0 f	147 ghi	4.3 d-f
ʻIbis’	DE	2004–2005	345 kl	6.1 f	211 jk	5.0 fg
ʻVergas’	DE	2004–2005	345 kl	7.0 hi	292 m	6.9 j
ʻResidence’	NL	2004–2005	350 l	5.0 de	160 hi	4.0 d
ʻSW Maxi’	SE	2004–2007	356 l	5.1 de	14 ab	3.0 c
ʻSW Harnesk’	SE	2004–2007	359 l	5.1 de	0.9 ab	2.0 a
ʻMarabu’	DE	2004–2005	361 l	5.2 de	211 k	4.2 de
ʻKorweta’	PL	2004–2005	429 m	6.1 f	214 ij	5.0 fg
ʻTrend’	DE	2004–2005	439 m	6.2 fg	343 n	4.8 e-g
ʻLina’	LT	2004–2006	445 m	6.2 fg	263 lm	5.3 g
ʻLars’	DE	2004–2007	560 n	6.8 ghi	7.7 ab	3.2 c
ʻMulan’	DE	2005–2007	601 o	7.0 hi	8.6 ab	3.0 c
ʻMeunier’	FR	2004–2005	733 p	7.0 hi	444 o	7.2 j
ʻToronto’	DE	2004–2005	837 q	6.8 ghi	542 p	6.2 h

* LT – Lithuania, DE – Germany, PL – Poland, SE – Sweden, DK – Denmark, FR – France, UK – United Kingdom.

** Significantly different according to Duncan's Multiple Range Test at P=0.01 if letters are different.

Some cultivars exhibited higher fluctuations between maximal and minimal values of AUDPC. Such genotypes among resistant cultivars were 'Zentos' 92 and 0.8, 'Bill' 140 and 1.5. Some susceptible genotypes also were less stable by resistance level than the others. Such cultivars were 'Lars' 560 and 7.7, 'Mulan' 601 and 8.6. Fluctuation of AUDPC values of resistant cultivars was between two resistance groups, whereas, reaction of susceptible cultivars depended more on climatic conditions.

The maximal AUDPC value of the most resistant cultivars did not exceed 100. Cvs. 'Torrild', 'Dekan', 'Altos' possess only ineffective *Pm* genes and cv. 'Zentos' does not posses any known *Pm* resistance gene /Anonymous, 2006/. Therefore, resistance of these cultivars at APR completely depended on QTL. The resistance of other cultivars also depended on the level of partial resistance. The most susceptible cultivars were diseased up to 7 scores and had AUDPC value over 500. These cultivars were 'Lars' (560), 'Mulan' (601), 'Meunier' (733) and 'Toronto' (837). By maximal AUDPC value the cultivars were grouped into 6 classes, with an interval of 100 units up to 500. Cultivars with AUDPC value over 500 were grouped into 1 class. The four cultivars were resistant (AUDPC: 0–100), 12 medium resistant (AUDPC: 101–200), 15 medium resistant-medium susceptible (AUDPC: 201–300), 10 medium susceptible (AUDPC: 301–400), 3 susceptible (401–500) and 4 very susceptible (>500). Classification of cultivars by scores showed similar distribution. Two cultivars had maximal disease severity up to 3 scores, 4 – up to 5 scores, 23 – up to 5 scores, the rest 20 cultivars were infected up to 6 scores and more. Origin of cultivars did not show any considerable effect on resistance. The main reasons were that climatic conditions and pedigree of tested cultivars did not differ essentially. Lithuanian cultivars were medium resistant. The most resistant were 'Tauras DS' and 'Seda DS', maximal AUDPC values 140 and 159, respectively.

Our investigations showed that among the cultivars tested there were no genotypes with effective resistance mono-genes. Actual resistance to powdery mildew of all cultivars tested depended on the level of partial resistance. Therefore, partial resistance to powdery mildew is a significant goal for the Lithuanian wheat breeding programme. Partial resistance, first of all, provides long term resistance /Yu et al., 2001; Wang et al., 2005/, and secondly, it is increasing in the latest European winter wheat genotypes /Anonymous, 2003; 2006/. Partial resistance allows some epidemic development of disease, but at a reduced level /Knudsen et al., 1986/. The quantitative nature of the resistance means that it is more difficult to identify than race-specific resistance, but it may be apparent as relatively low disease severity under high disease pressure.

We observed environmental influence on partial resistance although it was proportionally similar between years. Results of other researchers indicated that genotype x environment interaction exerted only a small impact on quantitative powdery mildew resistance /Keller et al., 1999; Miedaner, Flath, 2007; Tucker et al., 2007/. High environmental stability estimates promise breeders high gain from selection of resistant lines.

Cultivars tested were developed in 7 European countries, which represent the majority of West European territory. Resistance of these cultivars shows that European wheat breeders have already accumulated effective minor genes for powdery mildew resistance in many of the released cultivars. For practical use of resistance, the stability of effectiveness of partial resistance genes under changing pathogen populations is crucial. This is especially valid for resistance to sexually recombining wind-borne pathogens with high evolutionary potential. Cultivars with a high quantitative resistance such as 'Torrild', 'Dekan', 'Altos', and 'Zentos' show that this goal can be reached despite intensive use of cultivars with partial resistance in practical farming. Among these cvs. 'Zentos' has been grown extensively in Lithuania for over a decade. The cv. 'Mironovskaya 808' showed stable resistance in the former GDR over a long period (1970–1982) on up to 43% of the total wheat acreage /Meinel, Unger, 1998/. Another example is the British cultivar 'Maris Huntsman' that was consistently more resistant than other cultivars carrying the *Pm2+6* genes /Bennett, 1984/.

Quantitative resistances are thought to be inherited in a more complex fashion than race-specific resistances. Keller et al. (1999) detected 18 QTL in a wheat x spelt cross that explained 77 % of the phenotypic variance in a simultaneous-fit model. Some cultivars can be protected by fewer genes. Liu et al. (2001) verified these results by QTL mapping of the cultivars Knox62 and Massay and reported that three loci together explained 50% of the total variance for quantitative mildew resistance.

Disease severity for the majority of cultivars (58%) during the experimental period did not exceed 10 %, despite the heavy powdery mildew infection. These cultivars did not demand application of fungicides as their use would not be economically beneficial for the control of a single disease. The use of field scores alone to classify partial resistance to powdery mildew may be unreliable. A cultivar may have low mildew severity either because it has partial resistance or because it has race-specific resistance effective against a large fraction of the pathogen population. Mono-resistance genes provide defence until matching virulences are either not present or very infrequent in pathogen population. The main condition is that pathogen genotypes with matching virulence gene(s) should be so rare that they could not multiply during the vegetation season to considerable level in the population and in turn would not boost epidemic level of the disease. The common situation is when matching virulences in the population reach a few percent, and then the fate of 'efficient gene life' depends mainly on frequency of this gene in grown cultivars. If the gene is present in more than 50% of grown cultivars, it will be efficient only for 1–2 years after appearance of matching virulence. Only frequency less than 10% can prolong 'efficient gene life' up to five years, but not more. Later, defeated genes with residual effects on resistance could be useful as is reported by Chantren et al. (1999) and Tucker et al. (2007). However, our previous research /Liatukas, Ruzgas, 2004/ and experimental evidence from Germany /Anonymous, 2003; 2006/ leave this question open.

There are a few strategies for breeding for resistance to powdery mildew. The short term strategy is based on exploitation of major genes or their combinations. Winter wheat testing in breeding nurseries is rapid and requires very few assessments during the growing season. This strategy is possible when the turnover of cultivars is fast and can be done in one or two years. Moreover, complete resistance screening can be done under laboratory conditions with adequate pathogen isolates or molecular markers. The long term breeding technique is more complicated as it depends on accumulated polygenes. Reliable selecting of resistant lines is secured by continual readings of disease data in field during the growing season. The third strategy is a combination of the first and second techniques. However, it can be successfully done when material selected for crosses possesses high partial resistance and completely effective major genes. If crossing is made using the genotypes with low partial resistance and completely effective major genes we obtain breeding lines which can be very resistant for several or more years until pathogen adapts to new monogenes. Investigation of AUDPC is time-consuming and laborious. Our results show that AUDPC values differ at one disease severity score. Therefore, if partial resistance to powdery mildew dominates, it is better to assess wheat nurseries several times during the vegetation season. On the other hand, at the same moment the other diseases are assessed too, so time inputs only for powdery mildew evaluation is not high.

Conclusions

1. Our investigations showed that among the cultivars tested there were no genotypes with effective resistance mono-genes. Actual resistance to powdery mildew of all wheat cultivars tested depended on the level of partial resistance.

2. The AUDPC values for the most susceptible registered cultivars ranged from 148 in 2007 to 830 in 2005. The mean disease severity for all cultivars tested ranged from 23 in 2007 to 251 in 2005. The AUDPC value of the most resistant cultivars was very low and ranged from 0.8 in 2007 to 22 in 2004.

3. The maximal AUDPC value of the most resistant cvs. ʽTorrild', ʽDekan', ʽAltos' and ʽZentos' did not exceed 100. The maximal disease severity of these cultivars ranged from 3 to 4.8 scores.

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