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POWDERY MILDEW RESISTANCE OF THE LITHUANIAN WINTER WHEAT BREEDING MATERIAL

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At the Lithuanian Institute of Agriculture, during 2004–2006, resistance to powdery mildew of approximately 1,500 winter wheat lines was assessed in check and competitive trial nurseries. Our experimental evidence showed that there were no genotypes with effective resistance single-genes among the lines tested. Effective powdery mildew resistance from start to end of vegetation season depended on the quantitative resistance level. The most resistant lines were evaluated with a score of 2 and area under the disease progress curve (AUDPC) values ranging between 1.0–5.4. The most susceptible genotypes from the collection nurseries had score 8–9 and AUDPC values ranging between 1350–2220. The correlations between maximal disease severity and AUDPC values were strong (r = 0.79–0.92). Genotypes with AUDPC values up to 10 represented 93 lines or 7% in the check trial nursery and 22 lines or 9% in the competitive trial nursery. Lines evaluated with a score 4–5 and AUDPC value 100–300 dominated in 2004. In the next year the dominant genotypes had resistance scores 3–4 and AUDPC value 50–200. The highest powdery mildew resistance (score 2 and AUDPC value 1.0) was identified for the lines Maverich/Victo, Flair/Lut.9392, Strumok/Lut.9321, Zentos/Lut.97-6, Strumok/Lut.9313, Dirigent/Cortez in 2006.

Key words: *winter wheat, powdery mildew, resistanc.*

INTRODUCTION

Powdery mildew caused by *Blumeria graminis* f. sp. *tritici* (Em. Marshal) is one of the most devastating diseases of common wheat in 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 have been detected and mapped to specific chromosomes. Some 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; Miranda *et al*., 2006).

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, is obvious in cultivars possessing no identified *Pm* genes or when the natural population of powdery mildew overcomes the resistance conferred by *Pm* genes. Because 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 (Bayles and Priestley, 1982; Elen and Skinnes, 1988).

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). There is still insufficient knowledge regarding the main genetic defence mechanism of European winter wheat cultivars and the underlying genes, polygenes or combinations of them.

The study was designed to assess the powdery mildew resistance of the Lithuanian winter wheat breeding material.

MATERIAL AND METHODS

The experiment was set up at the Lithuanian Institute of Agriculture (LIA) during 2004–2006 in the breeding nurseries with natural infection. Resistance to powdery mildew of approximately 1,500 breeding lines of winter wheat from competitive trial (generations F7–10) (CTN) and check (generations F6–7) nurseries (CN) was investigated under natural infection. The majority of cultivars used as parental forms were from European counties, some from Russia, Ukraine, Kazakhstan and USA. Cultivars used for breeding possessed single gene resistance to powdery mildew, however, these genes were totally inefficient (Anonymous, 2003; 2006; Liatukas and Ruzgas, 2004; Wang *et al.*, 2005).

Plot size in the competitive trial nursery was 17 m^2, replicated four times. Plot size in the check nursery was 7.5 m^2, without replications. Soil of the experimental site was loam (*Endocalcari-Epihypogleyic Cambisol* (*sicco*) (CMg-p-w-can)) with a clay content of 24–27%, pH 6.5–7.0; organic mater 2.5–2.7%; P_2O_5 190–240; K_2O 185–264 $mg \cdot kg^{-1}$ soil. $N_{90}P_{60}K_{60}$ was applied annually. Phosphorus and potassium fertilizers were applied before sowing and nitrogen in spring after resumption of vegetative growth. Plots were sprayed with herbicides in spring when weeds started to grow intensively. Other pesticides and additional fertilization were not applied.

Diseases were assessed from stem elongation (BBCH 30–31) to late milk development (BBCH 77). Resistance to diseases was measured using a 1-9 scale: score 1 no visible symptoms of diseases, score 9 plants heavily infected (infection ≥ 80%). The highest disease severity was used as the disease index (DI).

The area under the disease progress curve (AUDPC) from plots of disease severity against time, from the first scoring to the last.

$$AUDPC = \sum_{i=1}^{n-1} [(t_{i+1} - t_i)\,(y_i + y_{i+1})/2],$$

where “t” is time in days, “y” is the percentage of affected foliage at each reading and “n” is the number of readings (Campbell and Madden, 1990).

RESULTS

Figure 1 shows the level of partial resistance in winter wheat breeding lines. The most resistant lines with AUDPC value not exceeding 10 had the disease index 2; the most susceptible ones had score 9 and AUDPC value over 1000.

Experimental seasons differed in terms of development of powdery mildew. The most susceptible genotypes varied little by disease index, score 8 in 2004 and 2006, score 9 in 2005 (Fig. 2). However, the AUDPC value of these genotypes differed up to 1.6 times, 1350 and 2220 in 2004 and 2006, respectively.

The relationship between DI with AUDPC is shown in Figure 3 A–F. Correlation between DI and AUDPC was strong (r = 0.79–0.92) during all years. A few genotypes deviated considerably from the overall relationships. Nevertheless, the variability of AUDPC was high, particularly in years

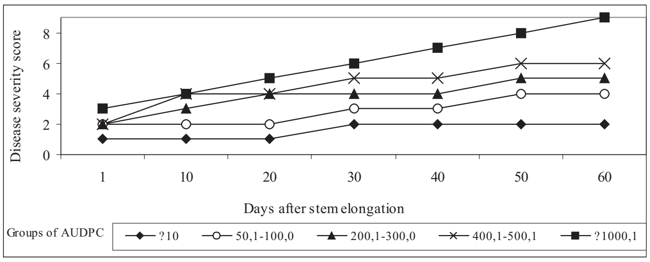

Fig. 1. Powdery mildew development on winter wheat genotypes with different area under the disease progress curve (AUDPC) value.

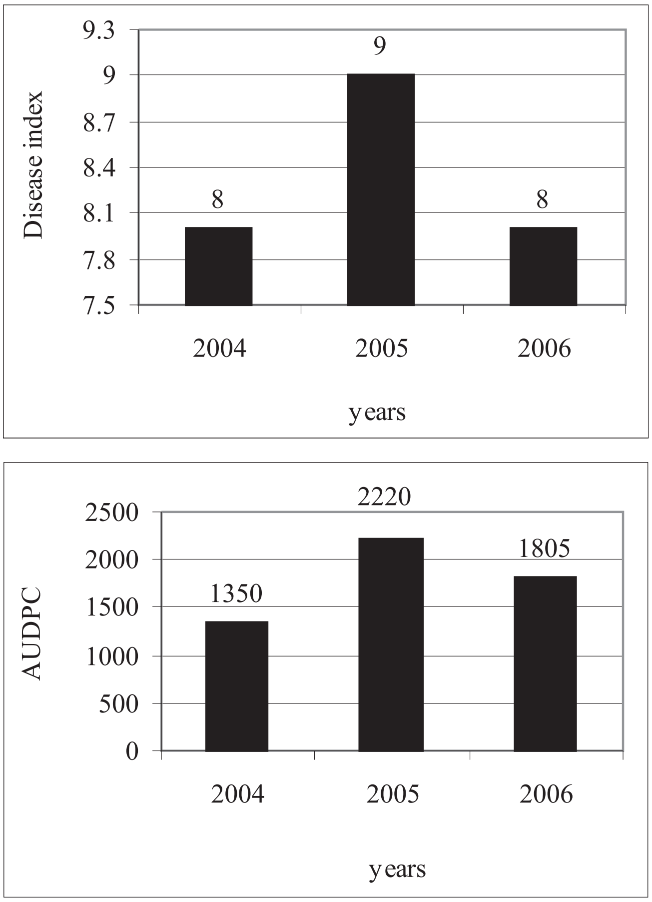

Fig. 2. Powdery mildew on the most susceptible genotypes during 2004–2006. For AUDPC see Fig. 1.

more favourable to powdery mildew, when differences between genotypes were more evident.

The largest differences were in 2005, when the weather conditions were most favourable for powdery mildew. At the check nursery, lines with DI 7 had AUDPC values from 300 to 800 (difference 2.6 times) (Fig. 3C). Lines with DI 6 differed in AUDPC from 140 to 580, or by more than 4 times. The other lines with lower DI also had high differences in AUDPC. A similar situation was in this nursery in 2004 (Fig. 3B). Comparison of DI and AUDPC values in CN and CTN shows that in 2004 the highest DI in CTN was score 6, with the exception of 1 line with DI score 7, whereas in CN DI reached score 8. The next year was more

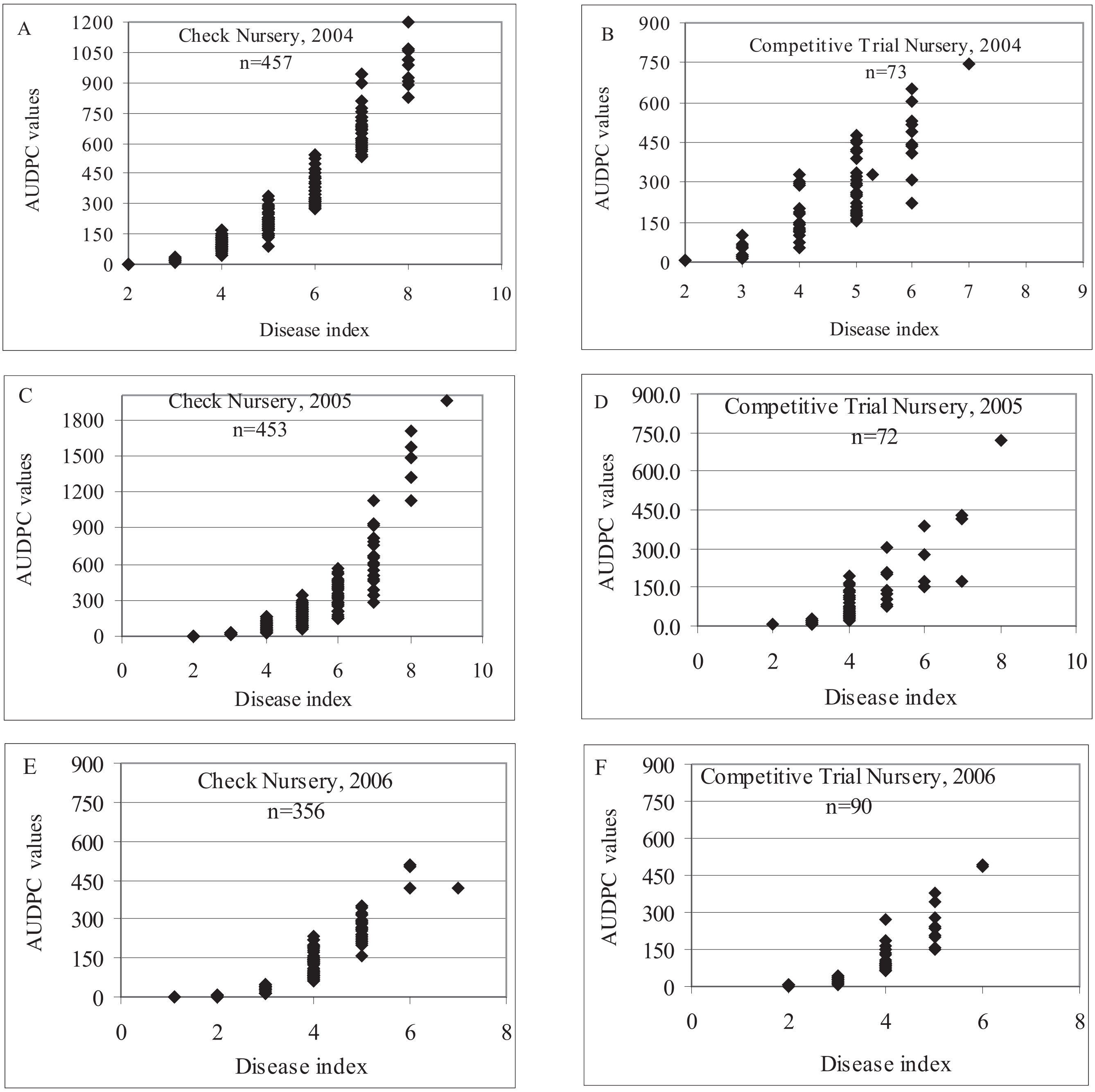

Fig. 3. Relation of DI with AUDPC in lines from Check and Competitive Trial Nurseries in 2004–2006. For AUDPC see Fig. 1.

favourable for characterisation of genotypes by powdery mildew resistance. The lines in CN showed disease level up to score 9 and in CTN up to score 7, with the exception for 1 line with DI score 8. The year 2006 was not favourable for clear discrimination of lines by AUDPC with the same DI. The AUDPC values in all years in every DI group were lower in CTN than in CN. Frequently, genotypes with a lower AUDPC value reflect a positive effect of even one year selection for resistance.

The data on winter wheat breeding lines presented in Figures 4–6 show a close to normal distribution of genotypes in powdery mildew resistance. This distribution is typical of genotypes possessing a partial resistance type. The number of resistant lines in 2004 was higher in CTN. The lines with DI up to score 4 accounted for 36% in CN and 50% in CTN, and lines with AUDPC value up to 100 accounted for 22 and 26%, respectively. In 2005, the lines in CN were less resistant than in CTN. The number of lines with DI up to score 4 made up 55 and 77% in CN and CTN, respectively. The number of most resistant lines with AUDPC up to 100 was similar in the both years, 57 and 61% in CN and CTN, respectively. Distribution of lines in 2006 to resistance was similar to that in previous years. However, dry weather allowed the powdery mildew to develop a higher score 5 only in a few most susceptible lines. The lines in CTN were

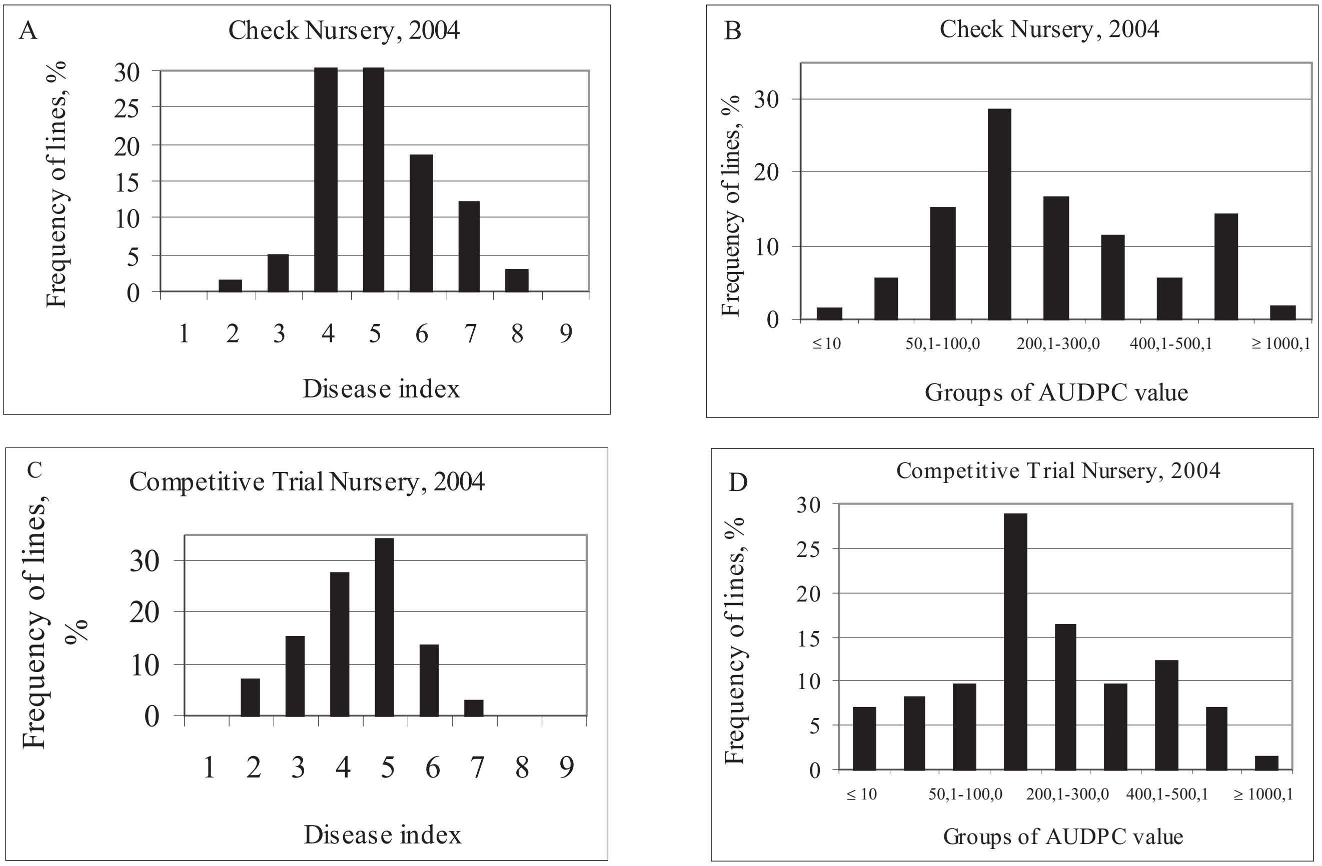

Fig. 4. Distribution of lines from check and competitive trial nurseries by resistance to powdery mildew in 2004. For AUDPC see Fig. 1.

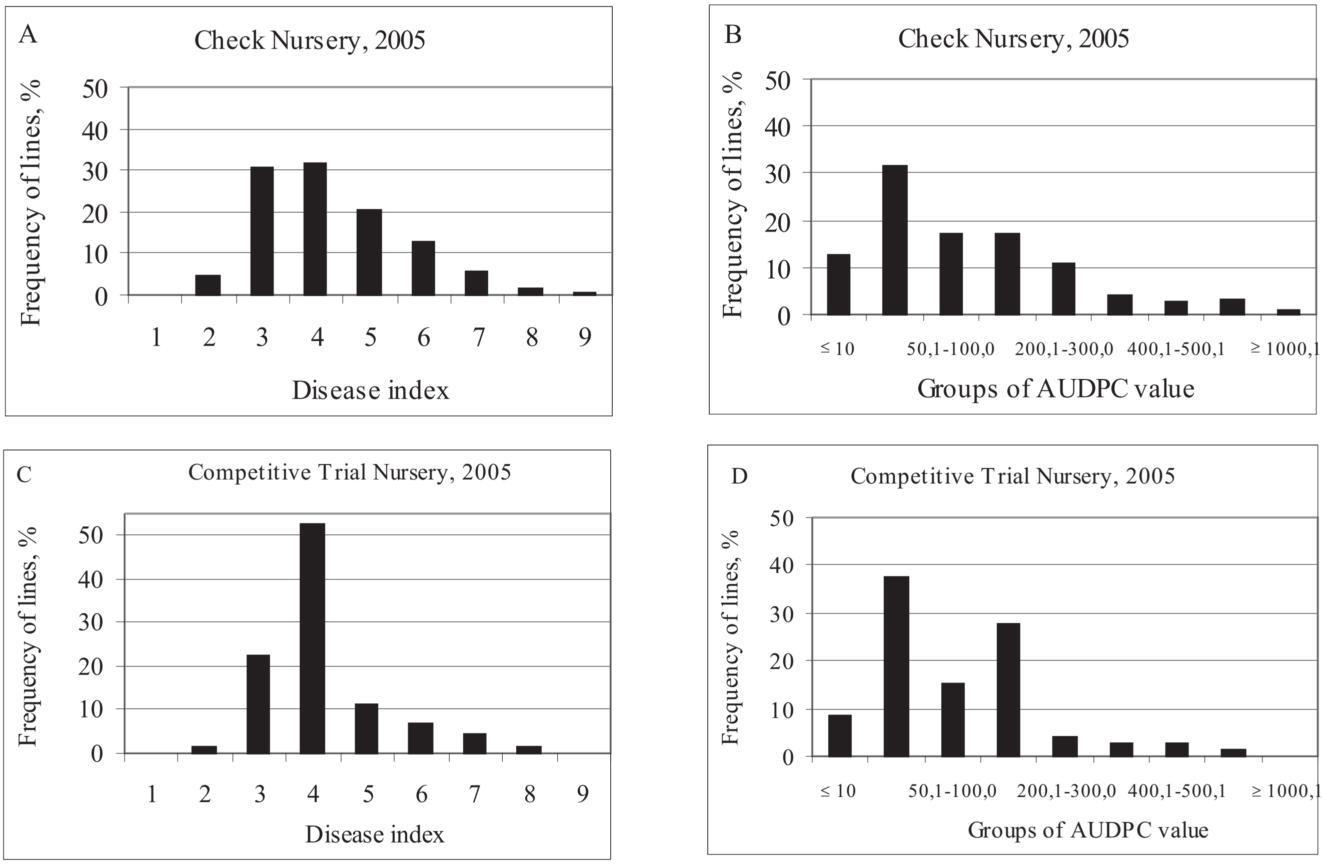

Fig. 5. Distribution of lines from check and competitive trial nurseries by resistance to powdery mildew in 2005. For AUDPC see Fig. 1.

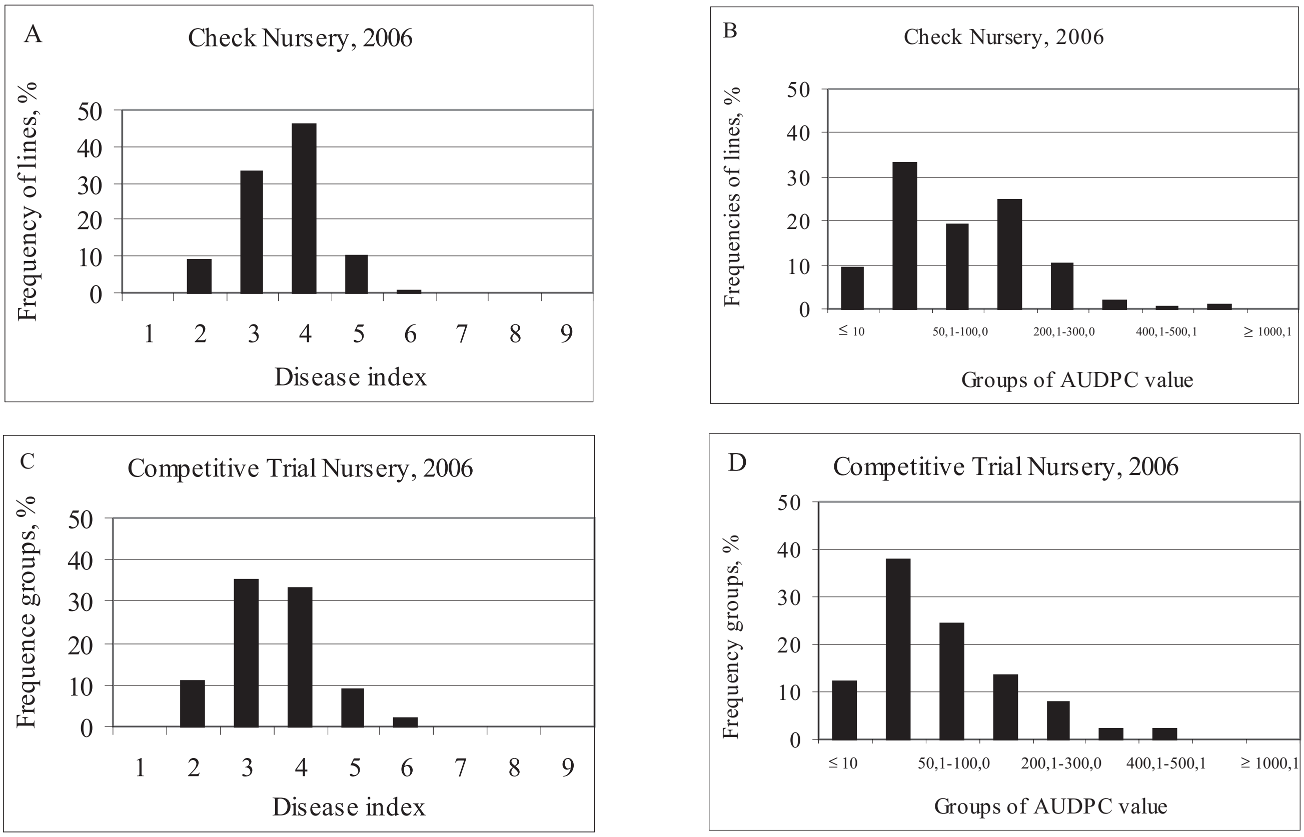

Fig. 6. Distribution of lines from check and competitive trial nurseries by resistance to powdery mildew in 2006. For AUDPC see Fig. 1.

more resistant than in previous years. The number of lines with DI up to score 3 accounted for 41 and 75% in CN and CTN, respectively.

The lines most resistant to powdery mildew in CN and CTN in 2004–2006 are presented in Tables 1–3. In total 120 lines

Table 1

WINTER WHEAT LINES MOST RESISTANT TO POWDERY MILDEW IN 2004

Check nursery	DI	AUDPC	Competitive trail nursery	DI	AUDPC
Miron.61/Lut 26247	2	3.0	VTPT128WM/Lgovskaya110	2	3.6
Moskovskaya 39/Kraka	2	3.4	Miron.61/Lut.26247	2	3.9
Širvinta1/VTPT128WM	2	3.4	Lgovskaya110/Torfrida	2	5.4
Flair/Alidos	3	13.3	Lgovskaya110/Alidos	3	16.6
Bussard x Longos	3	15.1	WW36298/Mermaid	3	22.0
WW37257/Zentos	3	15.1	Siesta/Alidos	3	24.4
Elena/V956	3	15.1	Pegasos/Nika Kubani	3	26.5
Marabu/Flair	3	15.1	Miron.61/Batis	4	57.0
Bussard/Longos	3	21.9	Lgovskaya110/Pegassos	3	58.2
Flair//A940145/Tarso	3	21.9	Širvinta1//Haven/Dean	3	66.9
WW36298/Zentos	3	21.9	Pegasos/DLF3	4	76.8
Širvinta1/Dacha	3	25.5	WW36298/Portal	4	100.2
Bussard//Wase/Rendezvous	3	34.0	Natalka/Torfrida	4	115.2
WW36298/Dacha	3	34.0	Zentos//TAW 5/Kosack	4	117.2
Alidos/Kiyanka	4	40.2	Belisar/Rostovchanka	4	117.6
Elena/Sj965407	4	48.7	Pepital/Tjelvar	4	117.8
Moskovskaya39/Bussard	4	64.0	VTPT128WM/Briz	4	138.8
Flair//Mermaid/Alidos	4	64.0	Zentos/Bussard	4	149.6
Bussard/Longos	4	67.1	WW36298/Pegassos	5	178.1
Flair/V957	4	67.1	Širvinta1/Batis	5	180.0

DI, disease index; AUDCP, area under the disease progress curve

Table 2

WINTER WHEAT LINES MOST RESISTANT TO POWDERY MILDEW IN 2005

Check nursery	DI	AUDPC	Competitive trail nursery	DI	AUDPC
Bill/Aspirant	2	3.6	Elena/V956	2	3.8
Biscay/Pesma	2	3.6	Flair/Asketis	3	7.6
Bussard/OL95-11	2	3.6	Širvinta1/Batis	3	9.9
Bussard/Purdue4930//Kris	2	3.6	Širvinta1/VTPT128WM	3	9.9
Dream/Asketis	2	3.6	Flair/DLF3	3	11.5
Dream/Lut.9329	2	3.6	Mermaid/Alidos	3	16.2
Pegassos/Biscay	2	3.6	Belisar/Rostovchanka	3	21.6
Pegassos/Pesma	2	3.6	Torfrida/Tarso	3	22.0
Rector/Briz	2	3.6	Marabu/DLF2	3	26.4
Rostovchanka/Bold	2	3.6	Flair/V9-329	4	28.3
Astron/Tarso//Rector	3	9.5	Zentos/V9-371	4	30.7
Biscay/Dream	3	9.5	Flair/V9-365	4	34.2
Bussard/OL95-1	3	9.5	Rufa/Elena	4	66.7
Dream/Aspirant	3	9.5	Rufa//Contra/Astron	4	75.1
Dream/Pesma	3	9.5	Bandit/Tarso	4	76.0
Hussar/Konsul B//Flair	3	9.5	Flair/Ukrainka Odesskaya	4	102.7
Pegassos/Aspirant	3	9.5	Alidos//Haven/Astron	4	105.9
Pegassos/Dream	3	9.5	Moskovskaya39/Lars	5	106.3
Pegassos/Lut.9321	3	9.5	1905B/Alidos	4	120.0
Pegassos/Lut.9328	3	9.5	Mironovskaya61/Batis	5	125.4

DI, disease index; AUDCP, area under the disease progress curve

Table 3

WINTER WHEAT LINES MOST RESISTANT TO POWDERY MILDEW IN 2006

Check nursery	DI	AUDPC	Competitive trail nursery	DI	AUDPC
Maverich/Victo	2	1.0	Pegasos/Aspirant	2	3.6
Flair/Lut.9-392	2	1.0	Širvinta1/A940145	2	4.1
Strumok/Lut.9-321	2	1.0	Rostovchanka/Chvilia	2	4.1
Zentos/Lut.97-6	2	1.0	Rufa/Elena	2	4.7
Strumok/Lut.9-313	2	1.0	Elena/Lut.956	2	4.8
Dirigent/Cortez	2	1.0	Rector/Briz	2	4.8
Zentos/Lut.97-1	2	2.6	Rostovchanka/Lars	2	4.8
Aspirant/Cubus	2	2.7	Pegasos/Dream	2	5.4
Mironovskaya61/Batis	2	2.7	Pegasos/Biscay	3	10.4
Pegasos/BUL.1032-1204	2	2.7	Rufa/Lut.96-10	3	14.2
Pegasos/Lut 96-6	2	2.8	Bussard/OL95-1	3	16.1
Zentos/Camino	2	2.9	Flair/Lut.3-96	3	16.1
Dream/Pesma	2	2.9	Hussar/Konsul A//Lut.96-6	3	16.1
Maverich/Lut.9-321	2	3.3	Rostovchanka/Lut.96-3	3	16.7
Dream/Aspirant	2	3.3	Lars/Lut.96-3	3	17.1
Flair/Pentium	2	3.8	Hussar/Konsul A//Bussard	3	17.2
Flair/Kris	2	3.9	Flair/Lut.9-365	3	17.9
Elena/Lut.956	2	3.9	Pegassos/Pesma	3	17.9
Marabu/Lut.96-3	2	4.5	Flair/Lut.9-329	3	18.5
Mironovskaya61/STH1096	2	4.5	Bill/Aspirant	3	22.8

are presented. Each year 20 lines are characterised by DI and AUDPC per nursery.

In 2004, the lines in CN were characterised by DI from 2 to 4, AUDPC 3.0–67.1 and CTN lines had CI ranging 2–5 and AUDPC 3.6–180.0. The most resistant lines were Mironovskaya61/Lut.26247, Moskovskaya39/Kraka and Širvinta/VTPT128WM from CN with DI 2 and AUDPC ranging 3.0–3.4.

The next year lines were more resistant. Lines from CN had DI from 2 to 3 and AUDPC ranging from 3.6 to 125.4. The lines from CTN had DI from 2 to 5 and AUDPC ranging from 3.8 to 125.4. The most resistant lines were Bill/Aspirant, Biscay/Pesma, Bussard/OL95-11 from CN with DI 2 and AUDPC 3.6.

In 2006, the lines of 2006 were more resistant than those in previous years, but this was more influenced by unfavourable weather conditions for powdery mildew rather than rapid progress in resistance breeding.

DISCUSSION

Our investigations showed that among the lines tested there were no genotypes with effective single resistance genes. Actual resistance to powdery mildew of the tested wheat lines depended on the level of partial resistance. Therefore, partial resistance to powdery mildew is likely to be a significant goal for the Lithuanian wheat breeding programme. This type of resistance first of all provides long-term resistance (Yu *et al*., 2001; Wang *et al*., 2005), and secondly, it is likely that 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.

The use of field scores alone to classify partial resistance to powdery mildew may be unreliable. A variety 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. Single resistance genes provide defence until in pathogen population matching virulences are not present or they are very infrequent. 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 a considerable level in the population and in turn would not boost to an epidemic level of the disease. The common situation is when matching virulences in the population reach a few percent, 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 reported by Chantren *et al.* (1999) and Tucker *et al.* (2007). However, our data (Liatukas and Ruzgas, 2004) and experimental evidence from Germany (Anonymous, 2003; 2006) leave this question open.

AUDPC was highly correlated with DI. Investigation of AUDPC is time-consuming and laborious, so the high correlation implies that wheat breeders may be able to asses their lines by a single scoring at an appropriate time. Our results show that AUDPC values greatly differ at one DI 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 time the other diseases are assessed also, so time inputs only for powdery mildew evaluation is not so high.

There are a few strategies for resistance to powdery mildew breeding. The short-term strategy is based on exploitation of major genes or their combinations. Winter wheat testing in breeding nurseries is rapid and requires few assessments during the vegetation season. This strategy is possible to use 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. This breeding strategy was used in LIA till 1990 and was inefficient as well as across all Europe. 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 vegetation season. At present, breeding for accumulation of monogenes is dominating in the winter wheat breeding programme in LIA and this resistance type is very efficient in newly developed lines. Some breeders after a long period have tried to develop a third strategy, which is a combination of the first and second techniques. However, it can be successful when material selected for crosses possess high partial resistance and completely effective major genes. If crosses are made among 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 the pathogen adapts to new single genes. The majority of such lines will be rejected due to one reason — susceptibility to powdery mildew. As a result, before crossing cultivars with effective *Pm* genes should be checked for level of partial resistance. This strategy still has no wider application in winter wheat breeding in LIA, as available cultivars with new and efficient genes are too uncommon.

Generally, the geographical origin of ancestors of the tested lines suggests that ancestors of continental origin ('Mironovskaya61', 'Moskovskaya39', 'Dacha', 'Kiyanka', 'Nika Kubani', 'Lgovskaya110', 'Purdue4930', 'Pesma', 'OL95-1', 'Rostovchanka' and so on) were not constraints for developing of powdery mildew resistant genotypes due to successful crossing of such germplasm with highly powdery mildew-resistant cultivars.

Concluding the results obtained, developing cultivars with high partial resistance will serve for at least one breeding cycle (12–15 years), as agronomically acceptable cultivars with high partial resistance and cultivars with effective resistance single genes are still very uncommon.

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LIETUVAS ZIEMAS KVIEŠU SELEKCIJAS MATERIĀLA MILTRASAS IZTURĪBA

Konstatēts, ka Lietuvas ziemas kviešu selekcijas materiālā ir sastopama galvenokārt kvantitatīvā miltrasas izturība. Tiek apspriestas perspektīvākās selekcijas stratēģijas, lai paaugstinātu kviešu miltrasas izturību.