PARTIAL RESISTANCE OF WHEAT VARIETIES TO POWDERY MILDEW - A FACTOR PREVENTING RESISTANCE TO FUNGICIDES

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ABSTRACT

Systemic fungicides help farmers in their fight against plant disease. Their ease of application and rapid effect resulted in their wide-spread use, which brought about the development of resistance of pathogens to them. The efficacy of propiconazole (Tilt 250 EC) fungicide against the powdery mildew pathogen lasts about 15-18 days. It is possible to make this period longer if the chosen varieties possess partial (incomplete) resistance to the pathogen. In the case of the highly susceptible variety "Sadovska ranozreika-4", one generation of the pathogen is accomplished in 8 days. With a combination of the variety Charodeika and the fungicide, the generation time of the pathogen is doubled, while combination of the variety "Dobroudja" and the fungicide increased the generation time by a factor of approximately six. The probable number of generations is inversely proportional to the varietal resistance, but it does not vary with the fungicide applied.

INTRODUCTION

The application of the new and efficient systemic fungicides seemed to offer a solution to the problem of powdery mildew, but their wide-spread use resulted in the development of resistance by the pathogen. Thus, it became necessary to develop schemes for applying the fungicides and a basic principle proved to the rotation of the latter, depending on the mode of action of the active ingredient. Wheat growers found this problematical.

The present study aims to illustrate the role and the importance of partial resistance of some common winter wheat varieties against the pathogen of powdery mildew *Erysiphe graminis* f.sp. *tritici* in prolonging the efficacy of systemic fungicides and preventing the pathogen from developing resistance to them.

MATERIALS AND METHODS

The investigation was carried out at the "Dobroudja" Institute of Wheat and Sunflower near General Toshevo. The materials tested were common wheat varieties, bred at the Institute and possessing partial (incomplete) resistance to the powdery mildew pathogen (i.e. varieties Charodeika and Dobroudja-1). Sadovska ranozreika-4, a highly susceptible wheat variety, served as a control variety (C).

The trial was carried out under laboratory conditions with plants at the 2nd-leaf stage of development. Seeds were sown in pots of size 28x28x6cm and grown under controlled temperature at 18-20°C with natural light. A genetically homogeneous powdery mildew culture, race 7430, was used in the investigation (Iliev, 1992). The two varieties used in the trial are susceptible to that isolate. Prior to the inoculation with the pathogen, wheat plants were treated with the systemic fungicide, propiconazole (50ml/ha), by spraying the leaves. Several hours later, when the vapour effect had faded away, plants were inoculated by shaking inoculated wheat material sharply over them. Up to the 10th day, inoculation was carried out every second day, then the same procedure was followed every 8th day. The type of infection, serving as a qualitative expression of pathogen development, was duly recorded, using Mains and Dietz scale (by Kounovski, 1973) for types of infection from 0 to 4. (0 - no infection, 1 - formation of mycelium without formation of spores, 2 - formation of mycelium with evident sporulation [small tufts], 3 - formation of medium large tufts with normal sporulation, 4 - formation of large tufts with abundance of sporulation).

Trials were carried out with 3 replicates, using untreated wheat plants of the three varieties as controls. Recording began for the first time on the second day after the application of the fungicide and continued every second day.

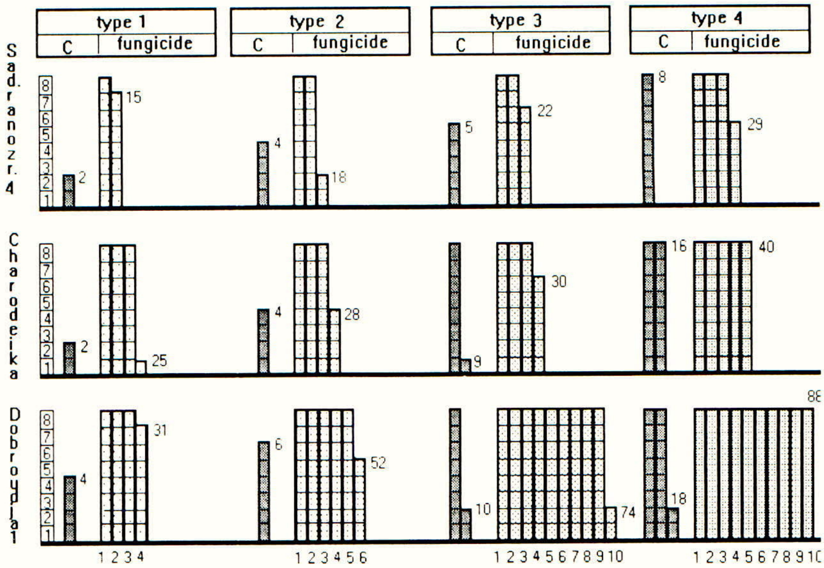
RESULTS AND DISCUSSION

Results showing powdery mildew development on untreated wheat plants of varieties Sadovska ranozreika-4, Charodeika and Dobroudja-1 are presented in the columns on the left for the 1st, 2nd, 3rd and 4th type of infection respectively. Results obtained with plants treated with propiconazole have been put in the columns on the right (Fig. 1). The development of the pathogen to type-1 infection can be achieved in 3 days with varieties Sadovska ranozreika-4 and Charodeika. Variety Dobroudja-1 needed 1 more day. When lacking genetically controlled resistance to the pathogen, as in the case of variety Sadovska ranozreika-4, the activity of the fungicide remains good. The maximum period of time during which the beneficial effect of the fungicide is in force is 15 days, i.e. 1.9 "standard generations" of the pathogen. With Charodeika, a variety of moderate susceptibility to the pathogen, the effect of the propiconazole in combination with the presence of genetic resistance to the pathogen can increase the generation time by a factor of 3.1 to 25 days. With variety Dobroudja-1, possessing greater genetically controlled resistance to the pathogen, the generation time increases by a factor of 3.9, to 31 days.

The development of the pathogen up to type-2 infection occurs on the fourth day after inoculating varieties Sadovska ranozreika-4 and Charodeika with conidiospores (in the absence of fungicide treatment).

With variety Dobroudja-1, the period needed is up to 6 days. The presence of that type of infection is characterised by the presence of developed conidia-carriers with conidiospores. In plants treated with propiconazole, type-2 infection appears on the 18th day with variety Sadovska ranozreika-4; on the 28th day with variety Charodeika and on the 52nd day with variety Dobroudja-1.

Type of infection



Number of generations of the pathogen (one generation is completed in 8 days with the standard variety S.r.-4, in the absence of fungicide).

Fig. 1. Powdery mildew development expressed as the type of infection at the second leaf stage, under laboratory conditions.

The squares represent the number of days required for development of the pathogen to types 1, 2, 3 and 4 infection respectively. Eight days are normally necessary for the completion of one generation (type-4 infection) of the pathogen on the variety "Sadovska ranozreika-4", in the absence of fungicide treatment. This interval is termed "standard generation time" for the purposes of this discussion. Type 2 infection occurs after 4 days.

When fungicide (propiconazole) is applied to this variety, the generation time is extended, so that type 2 infection develops after 18 days.

When the fungicide is applied to the variety "Charodeika", the time taken for "type 2" infection to develop is increased to 28 days. This represents 3.5 "standard generations". In the case of Dobroudja-1, the generation time is extended to 52 days (6.5 times greater than the standard generation time).

Thus, variety Charodeika is able to increase the generation time of the pathogen by a factor of 1.3 (10 days).

In the presence of propiconazole, the time taken to reach type 2 infection is 34 days longer with variety Dobroudja-1 than Sadovska ranozreika-4. The difference between the time taken for the varieties Dobroudja-1 and Charodeika to develop type 2 infection when treated with propiconazole is 3 "standard generations", or 24 days. This difference is due to the different qualitative and quantitative genetically conditioned resistance of the varieties studied.

Type 3 infection on the highly susceptible variety Sadovska ranozreika-4, with no treatment with propiconazole, is achieved on the 5th day after inoculation with conidiospores of the pathogen. Type-3 infection is characterised by the presence of physiologically mature conidiospores on a well-developed pustule of the pathogen. At this stage, secondary infections by the pathogen are possible.

With varieties Charodeika and Dobroudja-1, type-3 infection develops on the 9th or 10th day after inoculation. The application of the fungicide prolongs the period before formation of type-3 infection to 22 days with the highly susceptible variety Sadovska ranozreika-4, to 30 days with the moderately susceptible variety Charodeika and to 74 days with the resistant variety Dobroudja-1. When calculating the number of "standard generations" likely to occur in variety Dobroudja-1, the ratio established was 1:9.3. One fully-developed generation of the pathogen on that variety, when treated with propiconazole, protects the plants against 9.3 "standard generations" of the pathogen. This is 6.6 "standard generations" longer than with propiconazole-treated Sadovska ranozreika-4, and 6 "standard generations" longer than with propiconazole-treated Charodeika.

One of the differences between type-4 and type-3 infection is the size of the pustule. This shows that the vegetative (mycelial) part of the pathogen is larger with type-4 infection, which means that the reproductive abilities of a type-4 pustule are correspondingly greater than type-3 pustules. When considering the results concerning type-4 infection, possible generations are measured in 1 unit quantities, without considering the multiplication effect, which is considerably higher and is determined by the number of conidiospores formed from a single pustule per unit time. It proved to be physically impossible to include this index in the present investigation. Infection type-4 was recorded on the 8th day after inoculating the highly susceptible variety Sadovska ranozreika-4 with conidiospores of the pathogen, when no fungicide was applied. When fungicide was applied, type-4 infection was recorded on the 29th day (Fig. 1). The generation time on treated plants (cv. Sadovska ranozreika-4) was increased by a factor of 3.6 compared with untreated plants. With the moderately susceptible variety Charodeika, type-4 infection occurred on the 16th day after inoculating untreated plants. When propiconazole was applied, no formation of type-4 infection was established. Throughout the experiment, the growth of the mycelium was limited to type-3, hence the quantity of developed conidiospores, and hence the number of possible pathogen generations were limited too. The ratio here is similar to that of variety Charodeika, i.e. one generation to great numbers of generations for the untreated variant. In this case, type-4 infection cannot be taken as a criterion, as secondary *infections* are quite possible at infection type-3 or type-2. Here, the presence of type-4 infection is an index for the significance of the resistance possessed by the variety, i.e. for the increase of the total effect giving protection against the pathogen.

When summing up the results of the present investigation, it can be concluded that the effectiveness of the fungicide applied is constant, varying little in its value. The genetically conditioned varietal resistance affects the duration of activity of the fungicide. The effect is most vigorously expressed in variety Dobroudja-1, followed by variety Charodeika and is least expressed in variety Sadovska ranozreika-4. The effect of the genetically controlled resistance is greater than the independent effect of the fungicide. On the other hand, the greater duration of the fungicidal effect prevents the reproduction of the pathogen. Thus, conditions can be manipulated to prevent the development of resistance to the fungicide.

CONCLUSIONS

The efficacy of the applied fungicide is a constant, varying from 15 to 18 days.

The combination of fungicide and a variety with genetically controlled resistance to powdery mildew lengthens the period of protection against the pathogen. This period is directly proportional to the degree of varietal resistance.

Growing varieties with partial (incomplete) resistance to powdery mildew limits the number of reproductive generations of the pathogen, and helps prevent development of resistance to the fungicide.

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RESISTANCE TO INHIBITORS OF STEROL C-14 DEMETHYLATION IN THE CEREAL EYESPOT FUNGUS, PSEUDOCERCOSPORELLA HERPOTRICHOIDES

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ABSTRACT

According to their mycelial growth rate and their in-vitro sensitivity towards prochloraz and other inhibitors of sterol C-14 demethylation, five types of P. herpotrichoides were characterized. Among them, the slow-growing ones could result in inadequate control of eyespot in winter wheat treated by these fungicides.

INTRODUCTION

In France, eyespot caused by P. herpotrichoides, is the major stem-base disease in winter wheat. In the last ten years, inhibitors of sterol C-14 demethylation (DMIs) have replaced the benzimidazole fungicides (e.g. carbendazim) because of the development of benzimidazole-resistant strains. The DMIs registered in France are the imidazole prochloraz and several triazoles (e.g. bromuconazole, flusilazole). From the survey assessing the susceptibility of P. herpotrichoides to these DMIs, several types of resistant strains were characterized.

IN-VITRO EFFECTS OF FUNGICIDES

Field isolates of P. herpotrichoides produced either fast-growing (type I) or slow-growing (type II) mycelial colonies when cultivated on agar media (Leroux and Gredt, 1988). According to their in-vitro response towards DMIs, five types of strains were identified (Leroux and Migeon, 1993 ; Table 1).

- Type Ia : fast-growing strains sensitive to both prochloraz and triazoles,
- Type Ib : fast-growing strains sensitive to prochloraz but resistant to triazoles to some extent (Leroux and Gredt, 1988) Their frequencies have increased recently since they were first detected several years ago. (Migeon et al., 1994). However, it has never been established that such strains could reduce the efficacy of triazoles in the field.

TABLE 1. Effects of some DMIs and cyprodinil on the germ-tube elongation of various strains of *P. herpotrichoides*[a]

Fungicides	Mean EC 50 (mg/l) of types				
	Ia	Ib	Ic	IIs	IIp
prochloraz	0.005	0.006	0.75	0.007	0.25
bromuconazole	0.03	0.50	2.0	0.50	0.50
epoxyconazole	0.02	0.30	1.2	0.25	0.40
flusilazole	0.008	0.10	1.5	0.10	0.40
hexaconazole	0.01	0.50	1.0	0.30	0.15
cyprodinil	0.006	0.005	0.005	0.007	0.006

[a] : the tests were conducted according to the method of Leroux and Gredt (1988), with 2 to 8 strains of each type. The strains Ib were chosen among the most triazole-resistant ones.

- Type Ic : fast-growing strains resistant to both prochloraz and triazoles. They were found in 1992 and 1993 but remained rare in France.

- Type IIs : slow-growing strains naturally resistant to triazoles but sensitive to prochloraz. When such strains were prevalent in the field, triazoles were less effective than prochloraz (Leroux *et al*., 1990).

- Type IIp : slow-growing strains resistant to prochloraz (resistance levels between 30 and 40) and to triazoles. They were detected in France for the first time in 1990 (Leroux and Marchegay, 1991).

All these types were equally sensitive to cyprodinil, an anilinopyrimidine recently introduced in France (Bocquet *et al*., 1994).

FIELD RESISTANCE TO PROCHLORAZ

Twenty one field trials were conducted in 1992 and 1993, on winter wheat, by the Plant Protection Service. According to the efficacy of prochloraz (450 g/ha), these trials could be subdivided into two categories (Table 2). The first one corresponded to locations where this fungicide was effective and where the percentages of prochloraz-resistant strains in the control plots were low. In the other trials, located in Northern France, the presence of high frequencies of prochloraz-resistant strains (mainly IIp) resulted in inadequate control of eyespot.

LONG-TERM FIELD EXPERIMENTS

In 1988, a long-term field trial was started by ACTA, ITCF and INRA at Villiers-le-Bâcle near Versailles. (rotation : winter wheat/rape).

Prochloraz one or two times per year and flusilazole (twice per year) were applied every year to the same plots until 1992 ; in 1993 no fungicide was used in the plots previously treated twice a year (Table 3).

TABLE 2. Efficacy of prochloraz and population composition of P. herpotrichoides in trials conducted by the Plant Protection Service in 1992 and 1993

Number of trials	% strains in control plots[a] type II	type IIp	% efficacy of prochloraz[b]
11	41 (16 - 87)	3 (0 - 15)	62 (48 - 79)
10	89 (65 - 100)	63 (43 - 95)	9 (0 - 21)

[a] : extreme percentages in parentheses.
[b] : prochloraz (450 g/ha) was applied at GS 31, whereas the estimates of necrosed sections and the analyses of strains were carried out at GS 71-75.

TABLE 3. Evolution of fungicide efficacies and populations of P. herpotrichoides in a long-term field trial in winter wheat

years	control		prochloraz (x 1)[a]		prochloraz (x 2)		flusilazole (x 2)	
	% IIs	% IIp	% Ef.[b]	% IIp	% Ef.	% IIp	% Ef.	% IIp
1988	68	0	67	0	82	0	23	0
1989	93	0	60	0	62	0	28	0
1990	83	0	56	24	95	50	16	0
1991	80	0	18	50	27	86	7	13
1992	63	23	19	88	7	100	24	94
1993	42	42	22	100	-[c]	72	-[c]	52

[a] : prochloraz (450 g/ha) or flusilazole (200 g/ha) were applied between GS 29 and GS 32 whereas the estimates of necrosed sections and the analyses of strains were carried out at GS 75.

[b] : percentages of efficacy in comparison to the control plots for necrosed sections.

[c] : no treatment in 1993.

In this location the slow-growing strains (IIs) were prevalent even in the control plots from 1988. This probably explains why, between 1988 and 1990, flusilazole was less effective than prochloraz. Since 1991, prochloraz has failed to control eyespot because of the development of type IIp strains. The selection pressure was greater with two applications of prochloraz per year than with one application as judged from the higher frequency of type IIp isolates in plots receiving two applications of prochloraz (Table 3). Application of flusilazole also selected for these prochloraz-resistant strains. The relative increase of strains of type II p in the control plot in 1992 and 1993 suggests that they are more fit than those of type IIs. Conversely the slight decrease in the percentage of type IIp strains, observed in 1993 when prochloraz or flusilazole were stopped, suggests that strains IIp are less competitive than the type IIs strains (Table 3).

CONCLUSION

The reduced efficacy of triazoles is a well known phenomenon in locations where the slow-growing strains of P. herpotrichoides (type II) are prevalent (Leroux et al., 1990). More recently, in several departments of Northern France, the development of a sub-population of slow-growing strains resistant to prochloraz (type IIp) resulted in field resistance to this fungicide. Prochloraz and also the triazole flusilazole can select for these II p type strains. However this phenomenon does not seem to occur with all triazoles (e.g. hexaconazole) (Leroux, unpublished data).

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SENSITIVITY DISTRIBUTION TO VARIOUS FUNGICIDES IN EYESPOT (*PSEUDOCERCOSPORELLA HERPOTRICHOIDES*) IN THE RHINELAND/GERMANY

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ABSTRACT

Fungal isolations were made in 1992 from leaf sheaths of winter wheat at GS 30-32 growing at different locations in the Rhineland (Cologne-Aachen). In vitro sensitivity tests were carried out with carbendazim fungicides (MBC), either alone (Derosal), or in combination with prochloraz (Sportak alpha), or flusilazole (Harvesan). Carbendazim alone had no fungicidal effect on any of the *Pseudocercosporella* isolates from 7 localities, even at the highest concentration tested (20 mg/l). The combination of carbendazim and prochloraz inhibited mycelium growth and conidium production in isolates from 5 localities at a concentration of 0.2 mg/l (the lowest concentration tested), and all isolates at a concentration of 20 mg/l. Isolates of *P. herpotrichoides* from 7 localities reacted differently to the combination of carbendazim and flusilazole than to carbendazim alone.

INTRODUCTION

The first fungicides used for the control of eyespot (*Pseudocercosporella herpotrichoides*) in winter wheat were multi-site inhibitors with an unspecific mode of action (Buchenauer, 1984b). The control of eyespot became more effective after the introduction into cereal production of systemic fungicides, which were mostly single-site inhibitors (Obst, 1989). Carbendazim fungicides were first approved for use in Germany for the control of eyespot in winter wheat in 1973 (Fehrmann, 1976). At that time it was well known that after continuous applications of MBC fungicides their controlling effect was lost against some pathogens and resistant pathotypes could be identified in several groups of fungi (Buchenauer, 1984a).

In 1974 Rashid and Schlösser (1975) detected MBC resistance in eyespot for the first time in Germany, in a pathogen population at Giessen; resistance was present in 2 to 4% of their isolates. Owing to the fact that only a single application was made to control eyespot each season, Fehrmann and Horsten (1980) and Fehrmann (1984) considered the threat of the development of MBC resistance in eyespot to be unimportant. However, in a long term monitoring experiment which started in 1983 in Germany, Fehrmann *et al.* (1989) showed a reduction in sensitivity to MBC fungicides in *P. herpotrichoides*. Since 1982 a rapid increase in the frequency of MBC resistant isolates has been observed in northern Germany (Fehrmann, 1985). More recently MBC resistance in *Pseudocercosporella* was found in Mecklenburg-Vorpommern (Seidel *et al.*, 1988) and Thuringia (Schinke and Breitenstein, 1992).

MATERIALS AND METHODS

In 1992, fungal isolations were made in winter wheat at 8 localities (Büsdorf, Kapellen, Kuchenheim, Erkelenz, Hürth, Wiedenfelder Höhe, Weilerswist and Beckrath) in the Rhineland where an intensive cereal crop was included in the rotation. One hundred plants at GS 30-32 were collected, and fungal isolates were obtained from the outer and inner leaf sheaths. The fungal population was differentiated into species and varieties within species known to be involved in the foot rot disease complex. Thereafter, single conidial isolates were made for each species and 4 replicates of each were used in all further investigations.

To test the fungicide sensitivity of *Pseudocercosporella* isolates mycelial growth rate (colony area) was measured on potato dextrose agar (PDA) supplemented with 0.2, 2.0, and 200 mg/l of carbendazim (360 g/l), or carbendazim (80 g/l) + prochloraz (300 g/l) and of carbendazim (125 g/l) + flusilazole (250 g/l). Unsupplemented PDA was used as a control in each case. The cultures were incubated at 20°C in darkness until 21 days after inoculation, when the radial growth of the fungal colonies was measured by an electronic planimeter.

RESULTS

P. herpotrichoides var. *acuformis* was isolated at 6 of the 8 localities (Büsdorf, Kapellen, Kuchenheim, Erkelenz, Hürth, and Weilerswist), whereas *P. herpotrichoides* var. *herpotrichoides* was isolated at only 2 (Wiedenfelder Höhe and Beckrath). All isolates collected at 7 of the 8 localities proved to be resistant to carbendazim (Table 1). In a number of cases, there was a stimulation of fungal growth when carbendazim alone was added to the PDA, with the largest fungal colonies recorded at the highest concentration of the fungicide. The mixture of carbendazim and prochloraz showed a strong inhibition of growth of all *P. pseudocercosporella* isolates. The mixture of carbendazim and flusilazole did not suppress growth significantly at low concentrations. These results are constistent with those obtained by Bateman (1990).

TABLE 1: Mycelial growth (mm^2) of *P. herpotrichoides* after fungicide treatment

		Location							
Fungicide	mg/l	Büsd.	Kap.	Kuch.	Erk.	Hürth	Weil.	Wied.	Beck.
	0	319.0	391.0	145.5	342.1	160.9	371.3	1842.2	1542.0
carben-	0.2	298.3	420.8	221.5	340.3	261.8	477.9	1777.4	0.0
dazim	2.0	406.0	471.1	224.6	449.4	197.9	547.8	1788.1	0.0
	20.0	424.4	556.7	244.0	578.5	107.6	519.2	1625.2	0.0
	0	482.0	814.1	531.1	509.6	212.3	426.2	2401.2	1682.4
prochloraz	0.2	0.0	314.8	0.0	0.0	0.0	221.8	0.0	0.0
	2.0	0.0	0.0	0.0	0.0	0.0	22.4	0.0	0.0
	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prochloraz	0	432.0	814.0	525.4	502.3	233.2	426.2	2420.0	1079.4
+	0.2	0.0	301.8	0.0	0.0	28.5	325.8	0.0	0.0
carben-	2.0	0.0	0.0	0.0	0.0	0.0	37.3	0.0	0.0
dazim	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
flusilazole	0	431.2	814.0	576.5	538.6	233.2	426.2	2406.0	1709.4
+	0.2	497.0	313.8	358.1	349.8	326.6	276.6	373.3	0.0
carben-	2.0	29.2	120.4	52.2	44.5	60.8	89.7	0.0	0.0
dazim	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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SENSITIVITY OF BROWN AND YELLOW RUST POPULATIONS ON WHEAT TO CYPROCONAZOLE

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ABSTRACT

In order to evaluate whether cyproconazole treatments cause changes in sensitivity of *Puccinia recondita* f. sp. *tritici* and *Puccinia striiformis* populations, a monitoring program was carried out with bulk samples collected from wheat fields in several countries for several years. The mean EC 50 values of Swiss brown rust populations varied from 0.3 mg/l (1990) to 1.2 mg/l (1991) to 1.7 mg/l (1992) to 0.4 mg/l (1993). In 1993, the French and the German brown rust populations had average EC 50 values of 0.4 and 2.0 mg/l, respectively. No influence of cyproconazole on the sensitivity distribution was detected when DMI-treated and -untreated samples were compared. The sensitivities of yellow rust populations from France and Germany were not different from each other, but was unambiguously higher than those of brown rust.

INTRODUCTION

The aim of this survey was to evaluate the variability in sensitivity to cyproconazole among strains of *Puccinia recondita* f. sp. *tritici* and *Puccinia striiformis* from Switzerland, France and Germany, as well as to compare the sensitivity of DMI-treated and-untreated samples over several years. The sensitivity of Swiss brown rust populations has been analysed since 1990. In 1993, brown rust populations were also monitored for France and Germany. For yellow rust, the survey started in 1993 with populations from France and Germany.

MATERIALS AND METHODS

Infected leaf samples were taken from fields treated with DMIs and from fields not treated with DMIs. In a modified leaf piece test (brown rust) and with whole plants (yellow rust), the sensitivity of bulk samples was determined with a range of fungicide concentrations; dose-response correlations were established to calculate EC 50 values (effective concentrations resulting in 50 % disease suppression). For the leaf piece test 7-day-old wheat plants were treated, the leaves cut into 3 cm pieces after 24 hours, placed on water agar, inoculated with an urediospore suspension of the field sample of brown rust and incubated for 10 days at 18°C. Since yellow rust has a long incubation period, this test was carried out on whole plants in a similar manner as described previously for brown rust (Stähle-Csech and Gisi, 1991).

RESULTS AND DISCUSSION

The sensitivity of Swiss brown rust populations has been analysed since 1990 (Table 1). Until 1992, the lowest EC 50 values were around 0.01 mg/l and the highest EC 50 values were 6.8 mg/l (1991) and 5.0 mg/l (1992), respectively. The sensitivity of the 1993 populations were unchanged, since both the mean and the highest values were in the same range as in previous years. Nevertheless, the most sensitive strains were no longer detected, which might be a result of the small number of samples in 1993.

In 1993, the sensitivity of the brown rust populations from Switzerland and France showed a mean EC 50 value of 0.4 mg/l, whereas in Germany the value was 2.0 mg/l (Table 2). The highest EC 50 values for single samples were found in France and Germany. The sensitivity of the German isolates was generally lower compared to Switzerland and France, a phenomenon which is also known to occur for powdery mildew on wheat and barley but in a more pronounced manner (Felsenstein, this volume).

The samples originating from DMI-treated fields in France showed sensitivities between 0.05 and 10 mg/l as compared to 0.07 and 2 mg/l for samples from fields not treated with DMIs (Fig. 1). Although the mean and upper end of the treated distribution are numerically slightly higher than those of the untreated distribution, no difference in sensitivity can be claimed between the two distributions.

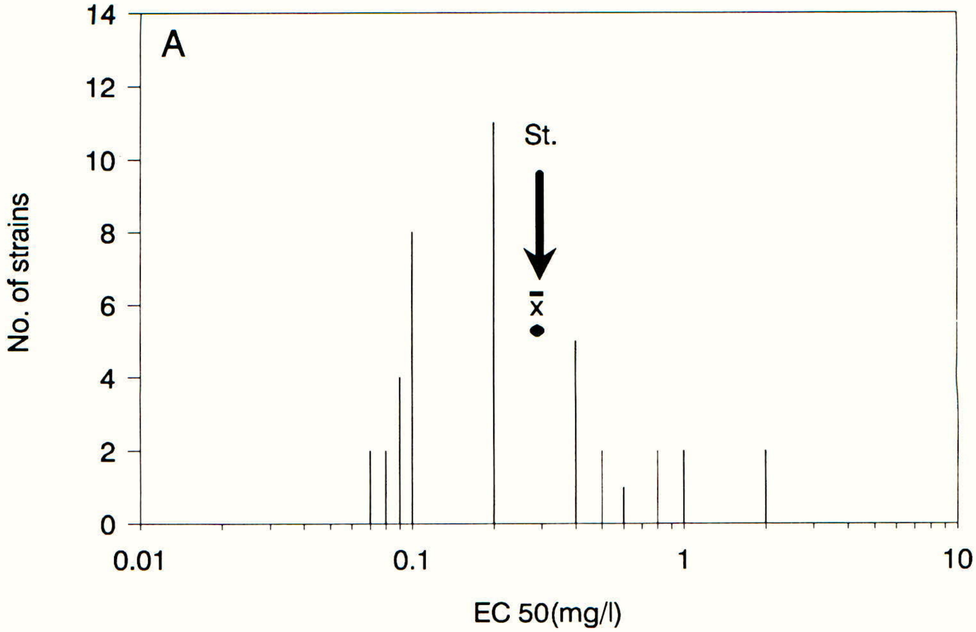
TABLE 1. Sensitivity of *P. recondita* f. sp. *tritici* samples to cyproconazole in Switzerland, 1990-1993

year	no. of samples	$\bar{x}$ EC50	lowest EC50	highest EC50
1990	35	0.3	0.01	1.7
1991	42	1.2	0.01	6.8
1992	22	1.7	0.01	5.0
1993	13	0.4	0.07	1.8

TABLE 2. Sensitivity of *P. recondita* f. sp. *tritici* samples to cyproconazole in Switzerland, France and Germany in 1993

country	no. of samples	$\bar{x}$ EC50	lowest EC50	highest EC50
Switzerland	13	0.4	0.07	1.8
France	87	0.4	0.05	9.8
Germany	46	2.0	0.10	10.0
standard isolate[a)]	1	0.3	-	-

[a)]standard isolate was collected before 1967 in Switzerland



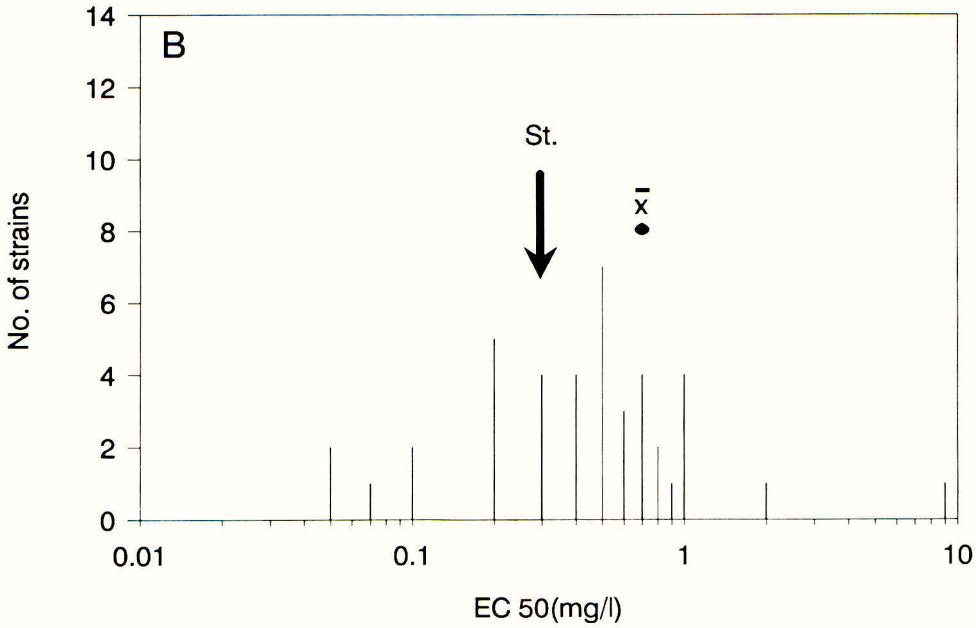


FIGURE 1: Sensitivity distribution of French brown rust populations in 1993 from DMI-untreated fields (A) and fields treated with DMIs (B). St.= standard isolate, $\overline{x}$ = mean

Only a small number of yellow rust samples were analysed from France and Germany (Table 3). The sensitivity ranged from 0.01 to 0.6 mg/l (France) and from 0.01 to 0.3 mg/l (Germany), with a mean EC 50 value of 0.1 mg/l in both countries.

TABLE 3. Sensitivity of *P. striiformis* samples to cyproconazole in France and Germany in 1993

country	no. of samples	$\bar{x}$ EC50	lowest EC50	highest EC50
France	12	0.10	0.01	0.6
Germany	7	0.10	0.01	0.3
standard isolate [a)]	1	0.15	-	-

[a)]standard isolate was collected before 1967 in Switzerland

CONCLUSIONS

No differences in sensitivity to cyproconazole were found for the Swiss brown rust populations between 1990 and 1993. The mean EC 50 value varied over the years between 0.3 and 1.7 mg/l and the width of the distribution (between the lowest and highest EC 50 values) was a factor of 25 (1993) to 680 (1991). This may represent rather broad variation within the populations. The populations from France and Switzerland had the same mean EC 50 value, whereas the value of the German population was higher. The range of EC 50 values from Germany was higher than those of Switzerland and France. The sensitivities of yellow rust samples from France and Germany were both in the same range and the mean EC 50 values were close to that of the standard isolate. Yellow rust seems to be generally more sensitive to cyproconazole than brown rust.

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