STRATEGIES TO CONTROL DICARBOXIMIDE-RESISTANT BOTRYTIS STRAINS IN GRAPES

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ABSTRACT

Dicarboximides replaced benzimidazoles for *Botrytis* control in most situations in the late 1970's and early 1980's. Meanwhile their initially high activity has, at least in part, been lost due to the development of resistance, but their use remains crucial in most crops, since good alternatives are lacking.

Therefore, in long-term trials on grapes, attempts were made to develop a strategy to maintain effective *Botrytis* control by dicarboximides despite the widespread occurrence of dicarboximide-resistant stains. This aim could be achieved by limiting the number of applications to two or at the most three per season or growing cycle and thus reducing the selection pressure. Additionally, the use of combinations with a conventional fungicide (e.g. thiram) is highly recommended since they stabilize the performance of the dicarboximides. As is proved by the results presented, this resistance management strategy works well due to the special characteristics of dicarboximide resistant strains, whose percentage in a given population varies depending on the selection pressure exerted throughout the year.

INTRODUCTION

The dicarboximides iprodione, vinclozolin and procymidone were introduced into the market between 1975 and 1977 for the control of grey mould, *Botrytis cinerea*, in grapes (Beetz and Löcher, 1979). This was shortly after the benzimidazoles could not be used any longer for this indication due to resistance problems.

The first dicarboximide-resistant field strains appeared after about three years of intensive use of these products in 1978 (Holz, 1979; Lorenz and Eichhorn 1980; Schuepp *et al.*, 1982; Leroux *et al.*, 1982). Due to the lack of good alternative fungicides and the fact, that inspite of resistance, no total loss of control occurred, dicarboximide use was continued. As a consequence, the proportion of resistant strains in the pathogen population increased considerably.

Initial studies and research projects on dicarboximide resistance management were started in Germany as early as 1979 (Löcher *et al.*, 1985). The aims of these projects were to determine possible strategies to maintain effective *Botrytis* control by reducing the number of treatments in order to reduce the selection pressure and by using combinations with different fungicides, such as thiram.

In all trials, the population dynamics of dicarboximide-resistant *Botrytis* strains were followed closely by constant and regular monitoring work.

The results of these studies (Löcher *et al.*, 1987; Lorenz and Löcher, 1988) clearly showed that:

1. Due to the special characteristics of dicarboximide-resistant strains (i.e. lower fitness/pathogenicity) their proportion within a population varies greatly depending on the selection pressure throughout the year (Pommer and Lorenz 1982 and 1987). Although they do not disappear completely from a population, their amount may drop to a certain minimum level during periods without selection pressure, but increase again rapidly when a new selection pressure is exerted.

2. With dicarboximides a successful resistance management has to be based on a reduction of the selection pressure and on prolonged times without selection pressure. In this respect, it could be shown that two treatments properly timed, i.e. shortly before berry touch (development stage 32/33) and at the beginning of ripening/softening of berries (stage 34/35), are adequate for satisfactory control, and the effect was not improved by three applications (see Löcher et al. 1987).

3. It is, however necessary for vinclozolin to be supported by an other fungicide with activity against *Botytis* to stabilize control, though in this case the use of combinations is no measure to reduce the selection pressure. This is probably due to the fact that those fungicides (i.e. Thiram) presently available as combination partners for dicarboximides are themselves comparably weak botryticides.

Even though after eight years of trial work results seemed very clear and as a consequence now ready mixes of dicarboximides with thiram are registered and used in France, it was decided to continue these trials in two sites in different regions. This was due to the fact, that at this time (1988) still no new botryticides, besides diethofencarb, were being developed which led to the question how long a resistance strategy based on specific properties of resistant strains (i.e. low degree of resistance, reduced fitness) could be used or whether eventually changes of these characterisics might create further problems in *Botrytis* control.

MATERIAL AND METHODS

The two trial sites were situated at Filzen in the Mosel area and at Wiesbaden in the Hessian area. In both trials, the same plots were used for the same treatments each year and each year the influence of two to three applications of vinclozolin alone or the combination of vinclozolin and thiram on *Botrytis* control and the population dynamics of resistant *Botrytis* strains were evaluated.

The Filzen trial was started already in 1980 and thus represents the most complete history of trial results with vinclozolin and combinations. The Wiesbaden trial was started in 1989 to survey a different region.

Materials and methods used are similar to those already described by Löcher *et al.* (1987).

The fungicides used were wettable powders containing either 50 % vinclozolin or 10 % vinclozolin and 64 % thiram. The spraying dates were determined according to the Eichhorn and Lorenz-scale, which describes the development stages (see Löcher *et al.*, 1987). Metiram was used for downy mildew control in both trials.

Each experimental plot contained 25 vines and covered an area of about 50 m^2. The number of replicates was two to four. To evaluate *Botrytis* attack, six samples, each of 100 bunches of grapes per treatment were classified in six categories. From the data obtained, the % disease intensity was calculated (Löcher *et al.*, 1987).

To determine the sensitivity of *Botrytis* strains to vinclozolin, diseased plant material was sampled several times per year from five to eight sites in each plot. Wood samples were taken in February, inflorescences and leaves were collected in June/July, and grapes and leaves in October shortly before harvest. 10 - 24 isolates per plot were prepared and tested. The procedures and methods used for the preparation of samples, and the isolation and testing of the *Botrytis* strains are the same as those described by Löcher *et al.* (1987).

To check the degree of resistance, each year altogether 50 *Botrytis* isolates from both trials (October sampling) were tested in an agar plate test using a concentration range of vinclozolin. ED_{50}-values were calculated by interpolation analysis from dose-response curves.

RESULTS

Table 1 contains all the data available from the Filzen trial concerning *Botrytis* control and population dynamics of resistant strains for both treatments in relation to the untreated plot for the years 1980 up to 1993, as well as the respective number of applications per year and the time between last application and evaluation. The data from 1980 up to 1987 have already been extensively discussed and published (Lorenz and Löcher 1988) and will, therefore, not be further considered here. An essential fact is that the same pattern repeats itself in the following years from 1988 to 1993.

A comparison of the control values obtained with vinclozolin alone with those of the combination over the years shows, that the performance of the combination in general is slightly to significantly better and results are more stable than with vinclozolin alone. This seems to be independent of the number of treatments and the disease intensity. On the other hand, the relevance of control data becomes slightly doubtful for those years where the time between last application and evaluation stretched beyond six weeks due to the late onset of *Botrytis* attack especially during the last seven years.

As far as the population dynamics are concerned, the data in Table 1 show that the proportion of resistant strains still varies greatly according to the time of year. From 1984 onwards, after only two applications in 1983, a general decrease of resistant strains in all plots could be observed, especially at the sampling dates of February and July. During the following years, in which only two to three applications late in the season were made, the resistant population established itself at a fairly low level in the untreated plots. Due to the prolonged period without selection pressure, seasonal variations became more pronounced, with the lowest levels of resistant strains normally observed during July.

With respect to the selection pressure exerted by the different treatments, data are consistent throughout the years. Independent of the number of treatments and the initial percentage of resistant strains, vinclozolin alone, as well as the combination, cause in general the same increase in the resistant population, even though there sometimes seems to be a slight advantage in this respect for the combination. Three and even two applications are sufficient for the resistant strains to obtain maximum levels (80 - 100 %) again.

The respective data for the Wiesbaden trial are presented in Table 2 and essentially show the same results and facts, though the amount of resistant strains in this area is higher and the yearly variation less pronounced than in the Filzen trial.

The examination of 50 isolates per year (Ocober sampling) from both trials and the calculation of their ED_{50}-values so far has not revealed the presence of strains with an increased degree of resistance. ED_{50}-values of resistant strains still lie between 3 and at maximum 10 ppm a.i. as was the case during the first years of these investigations.

CONCLUSIONS

The special properties of dicarboximide-resistant strains (low degree of resistance, low fitness and low competitive ability) obviously explain the fact, that inspite of the occurrence and rapid spread of resistant strains, no total loss of control occurred. The latter fact and the lack of good alternative botryticides encouraged the development of anti-resistance strategies in the early 1980's, which ensured the further use of these products. The data presented here from 13 years of trial work in the Mosel region (resistance started there), backed up by further results from five years trial work in an other region, clearly show that neither the properties of resistant strains nor the situation in the field have changed so far. That means, that the Fungicide Resistance Action Committee (FRAC) recommendations as regularly published in the Groupement International des Associations Nationales de Fabricants de Produits Agrochimiques (GIFAP) resistance newsletter are still valid.

TABLE 1. The effect of vinclozolin alone and in combinations on *Botrytis* control and on population dynamics of dicarboximide-resistant strains of *Botrytis cinerea* in Müller-Thurgau grapes in the Filzen/Mosel region during the years 1980 - 1993

Year Nr. of appl.	Treatment	% resistant strains			% Disease intensity	weeks from last application to evaluation
		Febr.	July	Oct.	Oct.	
1980	untreated	0	43	42	27	7
	vinclozolin	30	88	92	16	
5	vinclozolin + chlorothalonil	30	88	92	11	
1981	untreated	27	50	70	30	5
	vinclozolin	52	71	100	29	
5	vinclozolin + chlorothalonil	35	66	100	12	
1982	untreated	66	10	0	13	5
	vinclozolin	-	-	-	-	
4	vinclozolin + chlorothalonil	100	85	50	4	
1983	untreated	40	50	20	7	5
	vinclozolin	60	*	95	2	
2	vinclozolin + chlorothalonil	50	*	90	3	
1984	untreated	0	20	20	39	7
	vinclozolin	20	0	80	20	
3	vinclozolin + thiram	0	50	90	13	
1985	untreated	11	20	11	8	5
	vinclozolin	20	14	20	3	
3	vinclozolin + thiram	20	20	30	3	
1986	untreated	20	*	43	62	6
	vinclozolin	10	*	93	58	
3	vinclozolin + thiram	#	#	#	#	

* = no sampling
# = no treatment

TABLE 1. (continued)

Year Nr. of appl.	Treatment	% resistant strains			% Disease intensity	weeks from last application to evaluation
		Febr.	July	Oct.	Oct.	
1987	untreated	35	27	20	28	6
2	vinclozolin	50	13	80	17	
3	vinclozolin + thiram	33	47	93	15	
1988	untreated	47	30	13	31	7
	vinclozolin	53	40	87	30	
3	vinclozolin + thiram	60	10	67	12	
1989	untreated	53	25	60	17	8
2	vinclozolin	53	46	100	12	
3	vinclozolin + thiram	47	18	33	11	
1990	untreated	73	57	33	21	6
2	vinclozolin	80	67	100	18	
3	vinclozolin + thiram	73	36	87	18	
1991	untreated	47	10	33	7	7
2	vinclozolin	60	30	80	5	
3	vinclozolin + thiram	40	0	53	7	
1992	untreated	40	33	40	18	6
	vinclozolin	87	13	73	19	
2	vinclozolin + thiram	33	33	67	12	
1993	untreated	13	14	40	17	9
	vinclozolin	53	13	80	42	
2	vinclozolin + thiram	33	13	40	18	

* = no sampling
# = no treatment

TABLE 2. The effect of vinclozolin alone and in combinations on *Botrytis* control and on population dynamics of dicarboximide-resistant strains of *Botrytis cinerea* Wiesbaden 1989 - 1993

Year	Treatment	% resistant strains			% Disease intensity	weeks from last application to evaluation
		Febr.	July	Oct.	Oct.	
1989	untreated	87	62	73	19	5
	vinclozolin	100	57	80	16	
	vinclozolin + thiram	83	29	100	11	
1990	untreated	60	43	93	41	7
	vinclozolin	87	50	100	50	
	vinclozolin + thiram	80	60	86	33	
1991	untreated	77	37	73	46	5
	vinclozolin	100	29	79	19	
	vinclozolin + thiram	75	0	83	20	
1992	untreated	67	45	79	21	8
	vinclozolin	83	53	90	23	
	vinclozolin + thiram	67	54	90	20	
1993	untreated	83	46	75	17	5
	vinclozolin	88	37	79	10	
	vinclozolin + thiram	88	45	83	10	

* = no sampling
# = no treatment

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THE EPIDEMIOLOGICAL AND GENETICAL BASIS OF BENZIMIDAZOLE AND DICARBOXIMIDE RESISTANCE IN *MONILINIA FRUCTICOLA* ON STONE FRUIT

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ABSTRACT

Examples are provided of the persistence of benzimidazole-resistant strains of *Monilinia fructicola* in commercial orchards and the lack of persistence of dicarboximide-resistant strains. The difference is explained by the apparent lack of fitness of the dicarboximide-resistant strains in host tissues, and their inability to survive between seasons. The implications for management of these resistant types is discussed.

INTRODUCTION

Brown rot is potentially the most damaging disease of stone fruit globally. In New Zealand the commonest causal agent, *Monilinia fructicola* (Wint) Honey, has been exposed to intensive fungicide use in many production systems. Strains of the pathogen resistant to the benzimidazole (Anon, 1979) and dicarboximide (Elmer & Gaunt, 1986) fungicides have been reported. The development of resistant sub-populations is affected by both epidemiological and genetical factors, which influence the selection and persistence of these strains in the production environment. Several aspects of these factors have been studied and these are discussed in this paper in relation to other pathosystems and pesticides.

PERSISTENCE

Disease control failures associated with benzimidazole resistance were first reported in New Zealand in 1979. Thereafter, use of these products was discontinued on most properties. Recently, the frequency of benzimidazole-resistant strains was determined in commercial properties where the products had not been applied for at least the last nine years. Resistant strains were still present in the *M. fructicola* populations, sometimes at high frequencies. This confirmed similar reports from Australia (Penrose *et al,* 1990) and the USA (Zehr *et al,* 1991).

Dicarboximide resistance was first reported in 1986, though the frequency and level of resistance was lower than for the benzimidazole fungicides. The persistence of resistant strains was studied in commercial orchards with different fungicide management strategies (Elmer & Gaunt, 1993). From these studies it was concluded that dicarboximide-resistant strains were maintained in the population only if the products continued to be used frequently, and especially when they were used during both the flowering and the pre-harvest periods. When dicarboximide selection pressure was withdrawn, the frequency of resistant strains in the pathogen population decreased.

EPIDEMIOLOGICAL FACTORS

Pathogenicity, virulence and fitness

For resistant strains to remain in the population, it is assumed that they must show equal levels of pathogenicity, virulence and fitness on the variety of substrates used during the life cycle of the pathogen. If one or more of these factors is reduced relative to the sensitive strains, the resistant strains will be selected against and will decline in the population except when the selection pressure of the fungicide is present. It has been demonstrated that some strains with high levels of resistance to the dicarboximide fungicides, and some with low levels of resistance to the benzimidazole fungicides, were pathogenic but were less virulent and were less fit compared to sensitive strains or those with high levels of resistance to benzimidazole fungicides (Elmer & Gaunt, 1994). For example, the rate of spore production on flower tissue was less with some dicarboximide-resistant strains than sensitive strains, though the durations of the latent period and incubation period were similar. On the other hand, the rate of spore production in some strains was similar to the sensitive strains, thus demonstrating the potential for selection within the resistant sub-population.

Competition

The population dynamics of sub-populations of sensitive and resistant strains may be influenced by the competitive use of substrates. This may be especially true of a pathogen such as *M. fructicola* which has extended periods of saprophytic behaviour interspersed with brief biotrophic and necrotrophic behaviour. Competition between strains on flower and fruit tissues was investigated, and it was found that the characteristics of individual strains was not necessarily a good predictor of the outcome of competition for substrates. Some strains, with equal apparent fitness individually, did not compete well with the sensitive strains in mixed culture in host tissues.

Survival

M. fructicola has clearly defined periods of survival associated with the production of twig cankers, latent infections in immature fruit and mummies from mature fruit. The relative survival of sensitive and resistant strains in host tissues has been studied (Sanoamuang & Gaunt, 1991). Some dicarboximide- and some low-level benzimidazole-resistant strains survived less well in twig cankers and in mummified fruit compared to the sensitive strains. In some dicarboximide resistant strains, this apparent reduced survival was the only factor affected of those measured, thus possibly explaining the lack of persistence observed in the field.

GENETICAL FACTORS

The production of sexual spores on apothecia by *M. fructicola* is observed in the field, especially in moist climates (Batra & Harada, 1986). The production of sexual progeny in the laboratory has met with limited success, but we have developed a reliable method based on the work of Willetts & Harada (1984). The production of sexual progeny provides an opportunity for genetic analysis of the inheritance of resistance to fungicides.

Level of resistance

The benzimidazole-resistant strains were classified into low and high level types. The high level types were distinct, with discretely separated EC_{50} values, but low level types were defined somewhat arbitrarily. The dicarboximide-resistant strains isolated from the field mostly had discretely separated EC_{50} values, unlike the situation reported for *Botrytis cinerea* (Beever *et al*, 1989). Most strains appeared to have some degree of stability, though reversion to greater dicarboximide sensitivity occurred when some dicarboximide-resistant strains were cultured in fruit tissue for nine generations.

Segregation ratios

Sexual progeny were derived from benzimidazole-resistant and sensitive strains (Sanoamuang *et al*, 1991). Progeny from sensitive strains were always sensitive, whereas segregation occurred from resistant strains. Segregation ratios from high level resistant types were not significantly different from 1:1 ratios when both apothecial populations and ascospore sets were examined (Table 1). Low level resistant types segregated at ratios significantly different from 1:1 and 9:7 ratios. Analysis of patterns of distribution of ascospores within the asci was consistent with the hypothesis that high level resistance is controlled by a single gene and that conversion towards resistance occurred occasionally.

CONCLUSIONS

Persistence and survival

The characteristics of benzimidazole-resistant strains was consistent with the observed persistence of these strains in the field. In contrast, it could be expected that the dicarboximide-resistant strains would not persist. Spatio-temporal analyses suggested that dispersal occurred during the season over relatively short distances, and that within-row spread was greater than between-row spread. There was no correlation between seasons at specific tree sites for the presence of dicarboximide-resistant strains. This and other evidence (Ellis *et al*, 1988) suggested that dispersal may occur by splash and insect transfer as well as by wind movement, and that mutations for resistance occurred and were selected each season. This may be a more significant factor in resistance management than the survival of resistant strains between seasons (Milgroom *et al,* 1989).

Resistance management

The findings from our research have been incorporated into recommended resistance management strategies, promoted by the New Zealand Committee for Pesticide Resistance (Elliot *et al*, 1988, Prince *et al*, 1989). These are being updated currently and will be modified for the next growing season based on recent experiences in New Zealand and elsewhere.

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