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Effects of wheat foliar fungicides on the aphid endoparasitoid *Aphidius rhopalosiphi* DeStefani-Perez (Hym., Aphidiidae) on glass plates and on plants

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Abstract: The side-effects of several fungicides used in wheat to control disease at heading growth stage were assessed on the aphid parasitoid *Aphidius rhopalosiphi* by tests conducted in the laboratory on glass plates and in the greenhouse on young wheat plants. Very few formulations containing only one active ingredient (carbendazim, cyproconazole or epoxyconazole) or combinations of two (carbendazim + cyproconazole, carbendazim + hexaconazole) were harmless to *A. rhopalosiphi* in the glass-plate tests. There was no apparent synergism between fungicides tested in combinations. The parasitoid mortalities in tests carried out on plants were less and chlorothalonil, epoxyconazole, fenpropidin, fenpropimorph, flusilazole, flutriafol, prochloraz, tebuconazole, tridemorph and a number of combinations (carbendazim + flutriafol, chlorothalonil + cyproconazole, epoxyconazole + tridemorph, chlorothalonil + hexaconazole, chlorothalonil + flutriafol, cyproconazole + prochloraz, epoxyconazole + fenpropimorph, fenpropimorph + propiconazole, propiconazole + tridemorph, triadimenol + tridemorph) were harmless or only slightly harmful to the aphid parasitoid. Several combinations (carbendazim + epoxyconazole, carbendazim + fenpropimorph, carbendazim + flusilazole, carbendazim + tebuconazole, chlorothalonil + fenpropimorph, chlorothalonil + flusilazole, fenpropimorph + fenpropidin, fenpropimorph + prochloraz, fenpropidin + propiconazole, fenpropidin + tebuco nazole, tebuconazole + triadimenol) were toxic for wasps on plants. The parasitoid mortalities were less on plants than on glass plates but the wasps spent less time on treated leaves and in some cases parasitism of aphids was reduced to a large extent. These results suggest that in addition to study of the direct effects of pesticides on beneficial insects (mortalities, reduction of fertility) their effects on the behaviour of the insects should also be studied. Products that induced a repellent effect need further testing in field or semi-field conditions. However, many fungicide combinations that have little or no effect on *A. rhopalosiphi* can protect wheat against a wide range of diseases and the results obtained in this study indicate that an appropriate and effective protection of wheat at earing growth stage can be achieved with products that have no effects on aphid parasitoids.

1 Introduction

In Western Europe, *Sitobion avenae* (F.) and *Metopolophium dirhodum* (Walker) (Hom., Aphidiidae) are major pests of wheat (Ankersmit, 1989). The populations of these insects can be limited by a number of natural enemies. Among these, parasitic hymenoptera, mainly represented by Aphidiidae, play an important role; they are often active early in the season and are able to parasitize aphids at very low aphid/shoot densities (Hagvar and Hofsvang, 1991). In Belgium, Latteur and Oger (1991) found that in some years, low cereal aphid densities in spring are correlated with a relative abundance of aphidiid mummies. Several species are able to parasitize cereal aphids, but *Aphidius rhopalosiphi* is considered to be the most important one in Western Europe (Starý, 1970) and has been selected for this work.

This species is exposed to pesticide applications in wheat during the wheat aphid infestation period, which usually occurs in Belgium from end of May till beginning of July. These treatments generally include an insecticide, which is normally applied when aphid populations exceed their economic injury threshold, and at least one fungicide application at heading growth stage.

The susceptibility of *A. rhopalosiphi* to several insecticides has been demonstrated in laboratory studies (Krespi et al., 1991; White et al., 1991; Borgemeister et al., 1993; Jansen, 1996) and in the field (White et al., 1991). In comparison, no work has been carried out to investigate the possible effects of fungicides on this species. Data on other aphidiid species may be relevant. Several fungicides were included in the fourth, fifth and sixth joint pesticides testing programmes of the IOBC working group 'Pesticides and Beneficial Organisms' and tested on *Aphidius matricariae* Haliday in laboratory (Hassan et al., 1988, 1991, 1994). Maneb, sulphur and fenpropimorph were toxic to the adult wasps while flutriafol, propiconazole, triadimenol and tridemorph had no effects. Delorme (1976) tested benomyl and mancozeb on *Diaeretiella rapae* (M'Intosh) on plants and concluded that these products were harmless. Kuhner et al. (1985) showed that pyrazophos was toxic to this species, but not benomyl and mancozeb.

In comparison with the number of active substances

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that can be used in wheat to control diseases, there is a lack of knowledge of the possible effects of these compounds on aphidiid wasps. Furthermore, mixtures or combinations of fungicides have never been tested even though most farmers are using them. The aim of this work was to study the toxicity of a number of fungicides commonly used in wheat for the parasitic wasp *A. rhopalosiphi*. Products containing one active substance or combinations of two of them were tested in the laboratory on glass plates. The most toxic ones were then tested on wheat plants in the greenhouse.

2 Materials and methods

2.1 Chemicals

Fungicides formulations were obtained from commercial sources. They included only products containing one active ingredient, i.e. carbendazim (Agrichim carbendazim, 500 g/l, SC), chlorothalonil (Daconil 500 flowable, 500 g/l, SC), cyproconazole (Alto 100SL, 100 g/l, SL), epoxyconazole (Opus, 125 g/l, SC), fenpropidin (Mildin 750EC, 750 g/l, EC), fenpropimorph (Corbel, 750 g/l, EC), flusilazole (Capitan, 250 g/l, EC), flutriafol (Impact, 125 g/l, SC), hexaconazole (Sirocco, 250 g/l, SC), prochloraz (Sportak, 450 g/l, EC), propiconazole (Tilt 250EC, 250 g/l, EC), tebuconazole (Horizon, 250 g/l, EC), triadimenol (Bayfidan 250EC, 250 g/l, EC) and tridemorph (Calixin, 750 g/l, EC). These products were tested separately and as tank-mixes of two of them. As the number of possible combinations of fungicides was great, mixtures were selected on the basis of commercially available formulations containing two active ingredients. Combinations were tested at the maximum recommended field rate of the corresponding existing formulation. Single products were also tested at their maximum recommended field rate and for some of them also at the rate at which they were used in the combinations.

2.2 Initial toxicity–glass-plate test

Initial toxicity of fungicides to adults of *A. rhopalosiphi* was investigated in two steps, following the IOBC standard procedure for testing the side-effects of pesticides on beneficial arthropods (Hassan, 1992). Adults wasps were exposed for a 24 h-period to dried pesticide residues applied to glass plates and subsequently, the reproductive performance of the surviving females was assessed. All these operations, as well as the method of rearing of *A. rhopalosiphi* and the application of chemicals are described in a previous paper (Jansen, 1996). Two or three single formulations or mixtures were tested at the same time, with a water-treated control. Three units of 12 wasps were tested for each product and for the control. The reproductive performance of eight females or of all surviving females when less than eight survived in the glass-plate tests was assessed. The reduction of the beneficial capacity (E) was calculated by means of the Overmeer–Van Zon formula (1982):

$$E(\%) = 100 - ((100 - M_c) \times R_t/R_c)$$

where M_c is the mean corrected mortality of wasps (initial exposure), R_t is the mean reproductive performance of treated wasps and R_c is the mean reproductive performance of the control. As each set of experiments was conducted in similar conditions in a controlled environment cabinet, the results of the reproductive performance of the control females were grouped together to increase the number of replicates and make statistical analysis more powerful. According to the degree to which they reduced the beneficial capacity, fungicides were classified in the four IOBC categories relative to their initial toxicity on inert surfaces (Hassan, 1992).

Mortalities caused by fungicide mixtures were compared with the expected mortalities (P_{1+2}) predicted from the separate effects of the components (P_1, P_2). Expected mortalities were calculated for each replicate using a formula proposed by Bliss (1939):

$$P_{1+2} = P_1 + P_2 - (P_1 \times P_2)$$

Expected and observed mortalities of mixtures were compared using the Student's t-test at $P = 0.05$ level (Dagnelie, 1970).

2.3 Toxicity on plants

Single products and mixtures that were toxic to *A. rhopalosiphi* on glass plates were tested on wheat plants. Exposure units of wasps to fungicides comprised pots containing five to eight 10–15 cm high young wheat plants (cv Estica) grown on compost and infested by about 150 cereal grain aphids (*S. avenae*) of all instar per unit. The pots were covered with a perspex cylindrical cage (diameter, 12 cm; height, 20 cm) with the top and two rectangular lateral openings covered with nylon gauze as shown in the figure. The aphids were added to each pot 1 day before chemical application to produce honeydew. Just before chemical application, the perspex cages were removed and fungicides solutions were sprayed on the plants and

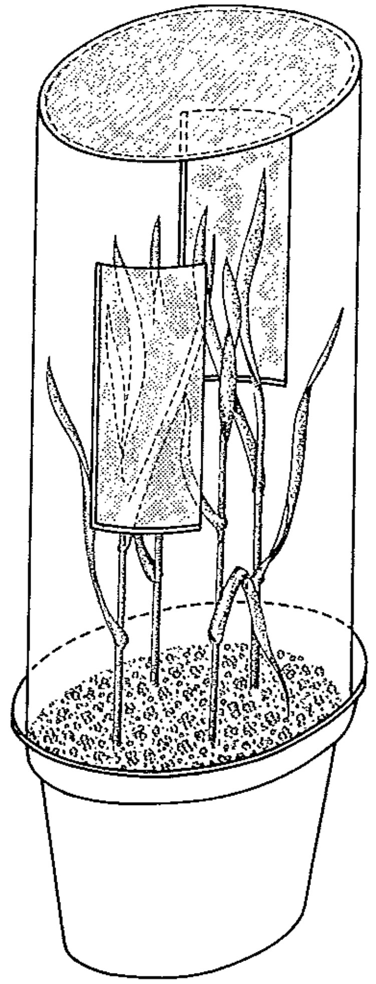

Figure. Exposure unit of A. rhopalosiphi *to fungicides on wheat. Plants were infested with 150 cereal grain aphids and were treated with fungicides. Six wasps were released into the cages for a 24 h period* aphids to run-off with a hand-sprayer. Tap water was used as control. The rates of dilution were calculated so that the application rate corresponded to the maximum recommended field rate. After 1 h, the perspex cages were replaced on the pots and six adults wasps (three males, three females), slightly anaesthetized with CO_2, were released in each unit. Four to five products and a water control were tested at the same time, with five replicates of one unit for each product and for the water control. The surviving wasps were counted 24 h after application. Wasps that were not found were considered as dead. The observed mortality in the treated pots were corrected from the mortality of the corresponding controls using the ABBOTT formula (1925).

To express the potential repellent effect of the tested products, each unit was carefully observed eight times for 30 s throughout the 24 h exposure period. The position of the wasps on treated plants and on the untreated cage or nylon gauze was noted. The percentages of wasps found on the treated surfaces were calculated from the total number of wasps found at each count. These percentages were compared with that of the control by means of a Student's t-test at $P = 0.05$ level (DAGNELIE, 1970).

When the parasitized aphids became mummified (generally 10–12 days after the start of experiment), they were counted in each exposure unit and the mean numbers of mummies were compared with the control using a Student's t-test at $P = 0.05$ level. The reduction in the beneficial capacity was calculated from the reduction in the production of mummies. From these data, the fungicides were classified according to the four IOBC categories defined for the extended laboratory test (HASSAN, 1992). Tests were conducted in a glasshouse with the temperature maintained between 15 and 25°C and under natural lighting.

3 Results

The results of the glass-plate tests with single products are listed in table 1. Only corrected mortality rates are given. Control mortalities ranged from zero to 5.6%. There was a wide variation between fungicides in their effects on *A. rhopalosiphi*. Some of them, including fenpropidin, tebuconazole and tridemorph killed all the insects. Other products (epoxyconazole, fenpropimorph, flusilazole, prochloraz) also caused high mortality and reduced the reproductive performance of females, sometimes greatly. Even chlorothalonil, hexaconazole and triadimenol, which did not cause mortalities significantly different from the controls, reduced the reproductive performances of the wasps. Carbendazim and cyproconazole were the only two compounds that did not affect *A. rhopalosiphi* in the glass-plate tests.

Mixtures of two active substances gave more or less similar results to those of the single compounds in the glass-plate tests (table 2), with an increase in the adverse effects. Only two tested combinations, carbendazim + cyproconazole and carbendazim + hexaconazole, reduced the beneficial capacity of *A. rhopalosiphi* by less than 30%. Other mixtures gave high mortalities or low or intermediate mortalities combined with a reduction in the reproductive performance. Most mixtures reduced the beneficial capacity of the insects in the laboratory to zero.

A comparison of the observed mortalities causes by the mixtures with those calculated from the individual effects of the components (table 3) indicated that the effects of mixtures were mostly similar to the sum of the separate effects of the components, except for two combination out of 15 (carbendazim + epoxyconazole and chlorothalonil + flutriafol), where the observed mortalities were significantly lower than expected and for one combination (cyproconazole + prochloraz), where the observed mortality was higher. Comparison of reproductive performance was not investigated because of the variation in the data.

Both single and combinations of active substances found toxic in the glass-plate experiments were further tested on wheat plants in the glasshouse. The effect of other mixtures, that had not been tested before because they included one component that gave 100% mortality in the glass-plate tests were also assessed on plants. Results are given in table 4. The adverse effects of single active substances on *A. rhopalosiphi* were lower on plants than on glass plates. Only two of them, epoxyconazole and flusilazole, reduced the beneficial capacity of wasps by slightly more than 25% and were classified as slightly harmful (Class 2). Only fenpropidin caused mortality significantly higher than the control, but it did not affect the reproductive performance of the females. The results obtained with mixtures of two active substances were more pronounced. Most mixtures affected the beneficial capacity of *A. rhopalosiphi*. Mortalities were generally less than 50% except for fenpropidin + propiconazole and fenpropidin + tebuconazole, but the majority of fungicide combinations reduced the parasitization of aphids. Observations of wasps during the exposure period showed that most of mixtures had a repellent effect. The wasps spent more time on untreated surfaces than on leaves, compared with the controls. Linear regression analysis showed that the percentage of wasps found on plants and the reproductive performance were correlated, with a correlation coefficient $r = 0.816$, suggesting that the reduction in parasitism was caused by the repellent effect of the treated surfaces.

4 Discussion

To test the side-effects of pesticides on beneficial insects, only field testing provides results that reflect agricultural conditions. However, field tests are time consuming and expensive. Furthermore, the results are sometimes difficult to interpret because of the variability in numerous environmental factors. For this reason laboratory and semi-field methods have been developed and used over many years. Important progress in the standardization of these methods has been accomplished, especially by the IOBC working group 'Pesticides and Beneficial Organisms'. Laboratory experiments using glass plates as inert surfaces are considered as worst-case studies and are only used to prove the harmlessness of a product. Products shown to be toxic in these tests need more appropriate experimentation for an adequate evaluation. In the present experiments, the results of glass-plate tests with single fungicides showed that only two out of 14, carbendazim (SC) and propiconazole (EC) are harmless to *A. rhopalosiphi* and do not need

Table 1. Toxicity of fungicides for A. rhopalosiphi; *results of glass-plate tests carried out in laboratory (worst case study). IOBC toxicity class (HASSAN, 1992): 1 = harmless (< 30%), 2 = slightly harmful (30–79%), 3 = moderately harmful (80–99%), 4 = harmful (> 99%)*

Active substance	Dose (a.i./ha)	[1]Corrected mortality ± SD	[2]Reproductive performance mummies/females ± SD	*n*	Reduction of beneficial capacity (%)	Toxicity class
Control		–	17.1 ac ± 16.7	104	–	–
Carbendazim	200 g	0.0% a ± 0.0	35.4 b ± 16.0	8	0.0	1
Chlorothalonil	500 g	15.7% a ± 9.2	9.8 acde ± 9.5	8	51.9	2
	750 g	5.8% a ± 7.7	10.9 acd ± 10.4	8	40.1	2
	900 g	13.9% a ± 14.1	9.9 acd ± 8.8	8	50.3	2
	1250 g	5.0% a ± 17.7	10.4 acde ± 11.7	8	42.3	2
Cyproconazole	80 g	36.1% a ± 14.2	21.3 ab ± 13.4	8	20.6	1
Epoxyconazole	125 g	25.7% b ± 6.8	1.9 ef ± 3.3	8	91.8	3
Fenpropidin	188 g	100.0% b ± 0.0	no surviving females		100.0	4
	563 g	100.0% b ± 0.0	no surviving females		100.0	4
Fenpropimorph	375 g	93.6% b ± 4.6	4.0** ± 1.0	2	98.5	3
	563 g	87.1% b ± 5.3	2.0** ± 0.0	1	98.5	3
	750 g	70.0% b ± 8.5	3.8 cdef ± 5.7	5	93.3	3
Flusilazole	200 g	69.7% b ± 22.7	0.0** ± 0.0	2	100.0	4
	250 g	58.1% b ± 12.4	0.1 f ± 0.3	8	99.7	4
Flutriafol	125 g	44.5% b ± 3.9	3.2 def ± 7.1	6	89.7	3
Hexaconazole	250 g	16.7% a ± 11.8	13.4 acdef ± 19.2	8	34.8	2
Prochloraz	450 g	53.0% b ± 15.0	0.1 f ± 0.3	8	99.7	4
Propiconazole	125 g	–3.9% a ± 11.9	13.3 acdef ± 19.1	8	19.5	1
Tebuconazole	250 g	100.0% b ± 0.0	no surviving females		100.0	4
Triadimenol	125 g	–3.0% a ± 4.3	9.3 acd ± 8.0	8	44.3	2
Tridemorph	350 g	100.0% b ± 0.0	no surviving females		100.0	4
	750 g	100.0% b ± 0.0	no surviving females		100.0	4

[1]Statistical analysis: Corrected mortality, mean conformity test, a = not different from 0.0%; b = differs from 0.0% at P = 0.05 level.
[2]Reproductive performance: Student's *t*-test, numbers followed by same letter(s) not different at P = 0.05 level; **too few data for analysis.

Table 2. Toxicity of combinations of fungicides for A. rhopalosiphi; *results of glass-plate tests carried out in laboratory (worst case study). IOBC toxicity class (HASSAN, 1992): 1 = harmless (< 30%), 2 = slightly harmful (30–79%), 3 = moderately harmful (80–99%), 4 = harmful (> 99%)*

Active substance	Dose (a.i./ha)	[1]Corrected mortality ± SD	[2]Reproductive performance mummies/females ± SD	*n*	Reduction of beneficial capacity (%)	Toxicity class
Control		–	17.1 a ± 16.7	104	–	
Carbendazim + cyproconazole	150 g + 80 g	11.4% a ± 10.3	15.8 ab ± 16.4	8	18.4	1
Carbendazim + epoxyconazole	150 g + 125 g	–0.3% a ± 7.1	9.4 ad ± 8.9	8	45.0	2
Carbendazim + fenpropimorph	188 g + 563 g	93.4% b ± 9.3	no surviving females		100.0	4
Carbendazim + flusilazole	100 g + 200 g	79.0% b ± 24.0	0.0 bde ± 0.0	5	100.0	4
Carbendazim + flutriafol	250 g + 118 g	28.1% a ± 26.5	0.0 ce ± 0.0	8	100.0	4
Carbendazim + hexaconazole	150 g + 250 g	2.8% a ± 10.6	21.4 a ± 16.4	8	0.0	1
Chlorothalonil + cyproconazole	750 g + 80 g	37.1% b ± 10.2	0.1 ce ± 0.3	8	99.5	4
Chlorothalonil + fenpropimorph	1250 g + 750 g	94.4% b ± 7.9	0.0** ± 0.0	2	100.0	4
Chlorothalonil + flusilazole	500 g + 200 g	85.1% b ± 7.1	0.0** ± 0.0	2	100.0	4
Chlorothalonil + flutriafol	900 g + 118 g	23.2% a ± 10.3	8.4 ad ± 9.2	8	62.4	2
Chlorothalonil + hexaconazole	750 g + 188 g	43.2% a ± 23.7	5.1 bd ± 5.8	8	83.0	3
Cyproconazole + prochloraz	72 g + 480 g	100.0% a ± 0.0	no surviving females		100.0	4
Fenpropimorph + epoxyconazole	375 g + 125 g	88.6% b ± 10.3	25.0** ± 0.0	1	83.4	3
Fenpropimorph + prochloraz	563 g + 450 g	97.0% b ± 4.3	0.0** ± 0.0	1	100.0	4
Fenpropimorph + propiconazole	375 g + 125 g	94.2% b ± 4.1	0.0** ± 0.0	3	100.0	4

[1]Statistical analysis: Corrected mortality, mean conformity test, a = not different from 0.0%; b = differs from 0.0% at P = 0.05 level.
[2]Reproductive performance: Student's *t*-test, numbers followed by same letter(s) not different at P = 0.05 level; **too few data for analysis.

further testing. No clear relation between chemical family or type of formulation and toxicity can be established. For example, the reduction in beneficial capacity of triazoles ranged from 19.5% (propiconazole) to 100.0% (tebuconazole).

Out of 13 combinations of two fungicides that were

Table 3. Toxicity of fungicides for A. rhopalosiphi. *Comparison of observed mortalities caused by combinations of two fungicides and expected mortalities calculated from mortalities caused by the components of combinations, corrected with* Bliss *formula (1939)*

Active substances	Doses (a.i./ha)	Corrected mortality ± SD Observed	Expected	[1]Statistical analysis
Carbendazim[2] + cyproconazole	150 g + 80 g	11.4% ± 10.3	36.1% ± 14.2	NS
Carbendazim[2] + epoxyconazole	150 g + 125 g	–0.3% ± 7.1	25.7% ± 6.8	*
Carbendazim[2] + fenpropimorph	188 g + 563 g	93.4% ± 9.3	87.1% ± 5.3	NS
Carbendazim[2] + flusilazole	100 g + 200 g	79.0% ± 24.0	69.7% ± 22.7	NS
Carbendazim[2] + flutriafol[2]	250 g + 118 g	28.1% ± 26.5	44.5% ± 3.9	NS
Carbendazim[2] + hexaconazole	150 g + 250 g	2.8% ± 10.6	16.7% ± 11.8	NS
Chlorothalonil + cyproconazole	750 g + 80 g	37.1% ± 10.2	42.1% ± 9.6	NS
Chlorothalonil + fenpropimorph	1250 g + 750 g	94.4% ± 7.9	70.4% ± 12.7	NS
Chlorothalonil + flusilazole	500 g + 200 g	85.1% ± 7.1	76.0% ± 17.1	NS
Chlorothalonil + flutriafol[2]	900 g + 118 g	23.2% ± 10.3	52.3% ± 8.0	*
Chlorothalonil + hexaconazole[2]	750 g + 188 g	43.2% ± 23.7	22.4% ± 4.1	NS
Cyproconazole + prochloraz[2]	72 g + 480 g	100.0% ± 0.0	69.2% ± 12.3	*
Fenpropimorph + epoxyconazole	375 g + 125 g	88.6% ± 10.3	95.0% ± 3.6	NS
Fenpropimorph + prochloraz[2]	563 g + 450 g	97.0% ± 4.3	93.7% ± 3.2	NS
Fenpropimorph + propiconazole	375 g + 125 g	94.2% ± 4.1	93.8% ± 4.4	NS

[1]Statistical analysis: Student's *t*-test, NS = no significant differences; * = difference significant at P = 0.05 level.
[2]Mortalities used for calculation corresponding to doses: carbendazim 200 g (0.0%), flutriafol 125 g (44.5%), hexaconazole 250 g (16.7%), prochloraz 450 g (53.0%).

tested on glass plates, only two, carbendazim + cyproconazole and carbendazim + hexaconazole were not toxic for *A. rhopalosiphi* and can be considered as harmless under field conditions. Examination of mortalities caused by combinations and the separate effects of the components of these combinations seems to indicate that no strong synergistic effects of fungicides on *A. rhopalosiphi* occur; the effects of most of the combinations being no different to the sum of the effects of the components. The relatively high toxicity of the majority of single products explains why most of the mixtures were very toxic for the wasps in the laboratory.

In conclusion, in the glass-plate tests, a great majority of single products and combinations of two active substances were toxic for *A. rhopalosiphi*. If glass-plate tests are considered as worst-case studies and do not reflect the field situation, the results indicated that these products are potentially toxic for this insect. However, parameters, that could not be taken into consideration during laboratory tests, may greatly reduce this potential. In the field, fungicides are applied in a heterogeneous way to the cereal canopy and there are great differences in pesticide concentrations between the ear, flag leaf and other leaves. The insects have thus the opportunity to escape from lethal doses, in a way impossible in the laboratory where pesticides are applied in a more or less homogeneous way to even, inert surfaces. Furthermore, interactions between fungicides and plants (absorption, adsorption, penetration of systemic compounds), and exposure of residues to climatic degradation agents (sunshine, wind, rain) can greatly reduce the pesticide residue concentrations with which aphid parasites make contact, and consequently diminish their negative effects.

The second part in this work was to study the side-effects of fungicides to *A. rhopalosiphi* in more or less controlled conditions using experiments in which glass plates were replaced by a natural substrate (young wheat plants). Single products which caused high mortalities in glass-plate tests failed to cause more than 30% mortality in the plant tests. Furthermore, the fertility of females was not reduced on the treated wheat. Thus, the effects of the individual products on aphidiids in field will probably be insignificant.

However, tank-mixes of two or three active substances or formulations containing more than one compound are usually applied in agricultural practice to protect wheat against a wide range of diseases. In the present experiments, among combinations that have been tested on plants, only two of them, fenpropidin + tebuconazole and fenpropidin + propiconazole, gave high mortalities although in the glass-plate tests most combinations were quite toxic. Despite this, significant reductions in aphidiid fertility were observed after treatment with nine fungicide combinations out of 21. If IOBC toxicity classes are used, 11 combinations fall in class 3 (moderately harmful) and 4 (harmful). Combinations including fenpropidin, fenpropimorphe, flusilazole or tebuconazole were the most toxic. For products that reduced the fertility of aphidiid wasps, observations during the exposure period showed that this reduction was mostly the consequence of a repellent effect of the fungicides. Female wasps spent more time on untreated surfaces than on plants and consequently less time in searching for aphids and in oviposition, compared with the control units. These results show that the effects of pesticides on insect behaviour can play an important part on their ability to exert a beneficial activity and that determination of side-effects of pesticides on beneficial organisms must not be limited to the measurement of mortality rates or reduction of fertility. However, extrapolation of these results obtained in controlled conditions to a wheat field is

Table 4. Toxicity of fungicides for A. rhopalosiphi, *results of tests carried out in greenhouse on wheat plants. IOBC toxicity class for extended lab-test (Hassan, 1992): 1 = harmless (< 25%), 2 = slightly harmful (25–50%), 3 = moderately harmful (50–75%), 4 = harmful (> 75%)*

Active substance(s)	Dose (a.i./ha)	Corrected mortality ±SD	Repellent effect: % of wasps on treated plants	Mummies/ females	Reduction (%) of beneficial capacity	Toxicity class
Set 1						
Control	–	–	35.3 a ± 22.9	49.2 a ± 5.1	–	–
Flusilazole	250 g	2.7% a ± 18.5	22.4 b ± 16.5	34.6 a ± 11.8	29.7	2
Flutriafol	125 g	12.7% a ± 36.2	28.0 ab ± 23.4	49.8 a ± 13.4	0.0	1
Prochloraz	450 g	–1.3% a ± 19.5	26.9 ab ± 20.7	46.8 a ± 22.1	4.9	1
Tebuconazole	250 g	0.0% a ± 12.6	21.4 b ± 13.6	45.4 a ± 11.1	7.7	1
Set 2						
Control	–	–	51.2 a ± 30.4	57.8 a ± 10.8	–	–
Epoxyconazole	125 g	–1.3% a ± 16.4	47.8 a ± 30.6	34.2 b ± 12.7	40.8	2
Fenpropidine	563 g	27.3% b ± 16.7	42.5 a ± 32.5	49.6 ab ± 11.9	14.2	1
Fenpropimorph	750 g	–1.3% a ± 16.4	42.0 a ± 28.9	47.4 ab ± 15.2	18.0	1
Tridemorph	750 g	16.7% a ± 14.9	41.2 a ± 33.0	65.2 a ± 16.4	0.0	1
Epoxyconazole + fenpropimorph	125 g + 375 g	10.0% a ± 13.3	39.6 a ± 28.9	55.2 a ± 9.1	4.5	1
Set 3						
Control	–	–	38.9 a ± 23.4	22.2 a ± 14.9	–	–
Carbendazim + tebuconazole	200 g + 250 g	28.5% a ± 33.9	15.1 b ± 22.0	0.4 c ± 0.8	98.2	4
Fenpropimorph + prochloraz	563 g + 450 g	27.7% b ± 17.7	6.0 c ± 13.9	3.6 b ± 2.4	82.9	4
Fenpropimorph + fenpropidin	563 g + 188 g	22.1% a ± 16.1	11.7 bc ± 17.0	3.4 bc ± 3.0	84.7	4
Triadimenol + tebuconazole	125 g + 250 g	8.1% a ± 21.4	1.3 d ± 3.9	1.4 bc ± 1.0	93.7	4
Set 4						
Control	–	–	23.0 a ± 18.2	21.8 a ± 7.0	–	–
Carbendazim + flusilazole	100 g + 200 g	28.7% a ± 29.0	9.5 b ± 17.2	2.4 b ± 2.6	89.0	4
Carbendazim + flutriafol	250 g + 118 g	–20.7% a ± 24.4	22.3 a ± 22.3	11.4 ab ± 8.5	47.7	2
Chlorothalonil + flusilazole	500 g + 200 g	2.3% a ± 19.0	22.1 a ± 19.9	6.6 b ± 7.8	69.7	3
Tridemorph + propiconazole	350 g + 125 g	37.0% b ± 27.5	19.1 a ± 23.2	16.8 ab ± 18.7	22.9	1
Set 5						
Control	–	–	18.8 a ± 12.5	17.2 a ± 8.2	–	–
Carbendazim + fenpropimorph	188 g + 563 g	6.3% a ± 21.5	8.9 bc ± 12.9	8.4 a ± 6.0	51.2	3
Chlorothalonil + cyproconazole	750 g + 80 g	29.0% a ± 34.6	19.5 a ± 20.5	10.0 a ± 8.4	41.9	2
Chlorothalonil + fenpropimorph	1320 g + 750 g	–2.3% a ± 17.6	6.1 c ± 10.4	8.4 a ± 7.8	51.2	3
Chlorothalonil + flutriafol	940 g + 118 g	–2.7% a ± 25.1	13.1 ab ± 14.8	18.2 a ± 6.4	0.0	1
Set 6						
Control	–	–	29.8 a ± 14.3	33.4 a ± 9.9	–	–
Epoxyconazole + tridemorph	125 g + 375 g	12.7% a ± 25.3	21.3 b ± 19.9	21.6 a ± 7.9	35.3	2
Fenpropidin + propiconazole	375 g + 125 g	86.7% b ± 26.7	5.3 c ± 13.5	5.0 b ± 10.0	85.0	4
Fenpropidin + tebuconazole	375 g + 250 g	75.0% b ± 30.7	6.0 c ± 18.6	7.0 b ± 8.6	79.0	4
Fenpropimorph + propiconazole	375 g + 125 g	16.7% b ± 9.1	25.8 ab ± 21.6	28.8 a ± 14.8	13.8	1
Set 7						
Control	–	–	30.4 a ± 17.9	45.8 a ± 13.0	–	–
Carbendazim + epoxyconazole	125 g + 125 g	12.7% a ± 29.4	32.8 a ± 24.5	10.2 b ± 4.0	77.7	4
Chlorothalonil + hexaconazole	750 g + 188 g	3.3% a ± 6.7	34.3 a ± 22.7	52.8 a ± 16.7	0.0	1
Cyproconazole + prochloraz	72 g + 480 g	2.7% a ± 13.6	32.1 a ± 19.8	47.0 a ± 8.9	0.0	1
Triadimenol + tridemorph	125 g + 375 g	20.7% b ± 12.3	18.9 b ± 15.0	38.0 a ± 12.8	17.0	1

Statistical analyses: corrected mortality, mean conformity test, a = not different from 0.0%; b = differs from 0.0% at P = 0.05 level. Repellent effect and mummies/females, Student's *t*-test, numbers followed by same letter(s) in the same set are not different at P = 0.05 level.

difficult. Although fungicide application in the field is rather heterogeneous, insects cannot find totally untreated and artificial areas, like the perspex cage used in the glasshouse experiments. In practice, the repellent effect of fungicides can have both advantages and disadvantages. Parasitoids are moved away from treated leaves that are toxic for them and then their population can be preserved from adverse effects. On the other hand, they cannot exert their beneficial activity on aphids populations. A further point that has not been taken into consideration is that all of the tested fungicides, except chlorothalonil, are systemic and their toxicity or repellent effect will be relatively short-lived in field conditions.

In conclusion, the present experiments have shown that all tested fungicides, when applied separately, and some in combinations of two will probably have no adverse effects on aphidiid wasps in the field. Other combinations were potentially toxic for *A. rhopalosiphi*, but further tests need to be carried out before an adequate assessment of their negative effects can be made. However, many combinations protect wheat effectively against a wide range of diseases, and the results obtained in this study seem to indicate that an appropriate and effective protection of wheat at heading can be achieved with products that have no effect on aphid parasitoids.

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