HEXACONAZOLE - USEFUL PROPERTIES IN THE CONTROL OF APPLE, COFFEE AND PEANUT DISEASES

M.C. BROWN, M.C. SHEPHARD

ICI Agrochemicals, Jealott's Hill Research Station, Bracknell, Berks, RG12 6EY

J.A. FRANK

ICI Agrochemicals Western Research Centre, Richmond, California

ABSTRACT

The fungicidal properties of hexaconazole were evaluated in glasshouse and field studies on apples, coffee and peanuts. Excellent activity was demonstrated against Venturia inaequalis, Hemileia vastatrix, Cercospora spp., Sclerotium rolfsii and Rhizoctonia solani. Hexaconazole appears to have an optimum balance of protectant, curative and translaminar activity, combined with rapid speed of penetration and a broad spectrum of activity. Hexaconazole should provide apple, coffee and peanut growers with robust but flexible disease control.

INTRODUCTION

Hexaconazole is a new broad spectrum triazole fungicide developed by ICI Agrochemicals for use on a wide range of crops including apples, coffee and peanuts (Shephard *et al.* 1986). The sterol biosynthesis inhibiting (SBI) fungicides, of which triazoles form the major component, are the fastest growing group of systemic fungicides (Kuck & Scheinpflug 1986). Their widespread use results from improved disease control, at low dose rates and the possibility of flexible application schedules. The curative, redistributive and penetrative properties of these fungicides represent a major advance in the protection of plants against fungal pathogens. The activity spectrum of the SBI's includes all major fungal classes except the Oomycetes.

Curative activity is particularly valuable in the control of pathogens with a latent period of greater than 60 hours and where optimum conditions for infection may restrict fungicide application. When combined with effective disease prediction schemes, appropriate curative applications will provide high levels of disease control and reduce the total number of sprays required (Ellis *et al.* 1984). It is important that curative activity is not achieved at the expense of protectant activity or rainfastness. Redistribution within leaf and other tissue enhances disease control in untreated areas remote from the sprayed tissue - thus increasing overall effectiveness and permitting a reduction in spray volume. Rapid penetration of plant tissue reduces the effects of weathering and therefore the risk of disease control failure during unfavourable weather conditions. Broad spectrum fungicidal activity facilitates use in disease control programmes.

From 1984 to 1988, glasshouse and field studies were undertaken to evaluate these properties in hexaconazole.

MATERIALS AND METHODS

Glasshouse studies

Active ingredients were formulated in an acetone/water mixture. Formulated product was used when available. These formulations were diluted in water. Chemical and inoculum were applied using a DeVilbiss spray gun at 10 psi. Leaf surfaces were sprayed to maximum retention. Coffee and apple seedlings were grown in 7 cm pots. Three or four replicates/treatment within a fully randomised design were used in all experiments.

Apples/*Venturia inaequalis*

A single susceptible leaf (cv. Red Delicious) was inoculated on the abaxial leaf surface with a conidial suspension (2×10^5 conidia/ml). Inoculated plants were incubated at 18°C and 100% r.h. for 48 h and subsequently at 24°C, 64% r.h. and a 16 h day, prior to assessment.

The percentage leaf area with sporulating lesions was assessed 8 to 12 days after inoculation.

Protectant activity

Plants were inoculated 1 or 4 days after chemical application.

Curative activity

Chemical was applied to the abaxial leaf surface 4 or 5 days after inoculation.

Penetration test

Chemical was applied to the abaxial leaf surface 3 days after inoculation. Thirty minutes after chemical application, plants received the equivalent of 1.25 cm rain in a rainwashing tower.

One set of plants was reinoculated the following day.

Coffee/*Hemileia vastatrix*

One pair of susceptible leaves was inoculated with a spore suspension (15×10^3/ml) on the abaxial leaf surface. Inoculated plants were incubated at 21°C, 100% r.h. for 48 h and subsequently maintained under glasshouse conditions at 20-28°C until assessment 28-33 days later. The percentage leaf area with sporulating lesions was recorded.

Translaminar tests

Chemical was applied to the adaxial leaf surface and the abaxial surface inoculated 7 days later.

Post symptom sporulation

Spores were removed from 28 day-old lesions using a camel hair brush. Chemicals were applied to the abaxial leaf surface. Subsequent resporulation was estimated from leaf washings 52 days after the initial inoculation.

Field studies

The control of peanut leafspots (*Cercospora arachidicola* and *Cercosporidium personatum*) white mould (*Sclerotium rolfsii*) and limb rot

(Rhizoctonia solani) was investigated in fully replicated trials using randomised block designs. Sites were selected in regions with established disease problems and disease development was the result of natural infection. Fungicide sprays were applied using a pressurised knapsack sprayer (150 l/h) and commenced at the appearance of leaf spots; subsequent applications were made at 14 day intervals. Leaf spot and white mould were assessed before harvest, whilst limb rot was assessed after peanuts were inverted. Two central rows 15.25 m long in each plot were harvested for yield assessment.

RESULTS

Glasshouse studies

TABLE 1

Persistence of protectant activity of hexaconazole and commercial standards against V.inaequalis on apple

Treatment	Rate mg/l	% Disease as a mean of the untreated leaves	
		1 Day*	4 Day
Untreated	-	100 (68)	100 (67)
Hexaconazole	10	0	0
Hexaconazole	2.5	0	0
Flusilazol	10	0	98
Flusilazol	2.5	0	100
Captan	1200	0	0

* Interval between chemical application and inoculation
( ) Actual % disease on untreated leaves

Hexaconazole was more active than a leading triazole fungicide when applied as a 4 day protectant treatment against V.inaequalis (Table 1).

TABLE 2

Curative activity of hexaconazole against V.inaequalis

Treatment	Rate mg/l	% Disease as a mean of the untreated leaves	
		4 Day*	5 Day
Untreated	-	100a (84)	100a (87)
Hexaconazole	15	9b	47b
Fenarimol	15	6b	53b
Penconazole	15	10b	56b

* Interval between inoculation and chemical application
** Values followed by a common letter are not statistically different at P = 0.05. Analysis of arc/sin transformed data.

When applied 4 days after inoculation, hexaconazole provided good curative activity against V.inaequalis ((Table 2). When sprays were applied 5 days after inoculation, disease control with all treatments was greatly reduced.

TABLE 3

Translaminar* activity of hexaconazole and commercial standards against H.vastatrix

Treatment	Rate mg/l	% Sporulating as mean of untreated leaves
Untreated	-	100a (61)
Hexaconazole	25	0b
Triadimefon	250	0b
Cuprous Oxide	1500	32c

* Chemical applied to the adaxial leaf surface 7 days prior to inoculation of the abaxial surface.

Hexaconazole completely controlled H.vastatrix when applied to the adaxial leaf surface 7 days prior to inoculation of the abaxial surface (Table 3). The translaminar activity of hexaconazole at 25 mg/l was comparable with triadimefon at 250 mg/l and significantly better than that observed with cuprous oxide.

TABLE 4

Effect of rainwashing on the curative and subsequent protectant activity of hexaconazole against V.inaequalis on apple leaves

Treatment	Rate mg/l	% Disease as a mean of untreated leaves Rainwash and reinoculation*
Untreated	-	100 (80)
Hexaconazole	15	0

* Rainwash 30 minutes after chemical application. Reinoculation 1 day after rainwash

Treatment Diary a) Inoculate-day 1, b) Chemical treatment-day 3,
c) Rainwash treatment 30 minutes after b) day 3
d) Reinoculate - day 4

In penetration studies, hexaconazole at 15 mg/l provided complete control of V.inaequalis (Table 4). A single application of hexaconazole controlled previously initiated infection and protected tissue from subsequent infection.

TABLE 5

Post symptom antisporulant activity of hexaconazole against H.vastatrix

Treatment	Rate mg/l	Spore production* ($X10^3$/ml)
Untreated	-	370a
Hexaconazole	25	5c
Hexaconazole	5	20c
Triadimefon	250	178b
Cuprous oxide	1500	415a

* Sporulation assessed 24 days after chemical treatment

Post symptom application at 25 and 5 mg/l significantly reduced the resporulation of H.vastatrix (Table 5). At 5 mg/l hexaconazole was significantly more effective than triadimefon at 250 mg/l. Cuprous oxide had no effect on sporulation.

Field Studies

TABLE 6

Control of foliar and soil-borne peanut diseases with hexaconazole

Treatment	Rate g ai/ha	Foliar disease	Soil-borne diseases		Yield
		% Defoliation caused by C.arachidicola & C.personatum	White mould foci/24 m. row (S.rolfsii)	% Limb rot (R.solani)	Kg/h
Untreated	-	32.5a	17.2ab	77.5a	1877a
Hexaconazole	22	7.1bc	12.5bc	42.5b	2844bc
Hexaconazole	45	4.0c	16.0b	32.5bc	3275cd
Hexaconazole	87	2.1c	6.5cd	22.5c	3433d
Hexaconazole	135	1.0c	3.5d	3.7d	4155e
Hexaconazole	179	2.2c	3.0d	3.7d	3971e
Chlorothalonil	1122	11.4b	24.2a	62.5a	2705b

Hexaconazole provided excellent control of peanut leafspot at all use rates (Table 6). At rates of 87 g a.i./ha and above, hexaconazole provided good control of white mould and limb rot. Peanut yield increased with application rate from 22 to 135 g a.i./ha.

DISCUSSION

The strong protectant activity of hexaconazole and persistence of disease control, observed here against V.inaequalis, is very different to the protectant activity of other SBI fungicides (Szkolnik 1981). The translaminar activity of hexaconazole in the control of H.vastatrix demonstrated here was also observed in other host/pathogen combinations (Shephard *et al.* 1986). It is suggested that the activity of cuprous

oxide in the translaminar test on H.vastatrix is related to the redistribution of chemical during incubation at 100% r.h.

Significant differences between the activity of the SBI fungicides as 4 and 5 day curative treatments against V.inaequalis is in accordance with previous studies (O'Leary & Sutton 1985). The curative activity of the SBI fungicides have already proved valuable when combined with scab prediction schemes. However, it is suggested that fungicides should be applied no later than 96 h after an infection period. While the SBI fungicides demonstrate weak post symptom activity against V.inaequalis (Szkolnik 1981), hexaconazole was very effective when applied in this way against H.vastatrix. Reduction in resporulation will reduce the progression of disease. This property is particularly significant in coffee rust control, where applications are often initiated after disease is established. Appropriately timed applications of hexaconazole will clearly permit a reduction in the total number of sprays per season.

It is suggested that the high activity, relatively low solubility in water (17 mg/l) and log P value (3.9) contribute to the rapid penetration of hexaconazole (Shephard 1985).

The control of white mould and limb rot of peanuts with hexaconazole adds to proven control of leaf spot (Shephard *et al*. 1986) and further demonstrates the broad spectrum activity of hexaconazole.

CONCLUSIONS

Glasshouse and field studies indicate that hexaconazole has an optimum balance of protectant, curative and translaminar activity. When these properties are combined with rapid speed of penetration and broad spectrum activity it is clear that hexaconazole will provide apple, coffee and peanut growers with robust but flexible disease control.

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REFERENCES

Ellis, M.A.; Madden, L.V.; Wilson, L.L. (1984) Evaluation of an electronic apple scab predictor for scheduling fungicides with curative activity Plant Disease 68 , 1055-1057.

Kuck, K.H.; Scheinpflug, H. (1986) Biology of sterol-biosynthesis inhibiting fungicides. In : Chemistry of Plant Protection 1, Springer-Verlag Berlin Heidelberg, pp.65-93.

O'Leary, A.L.; Sutton, T.B. (1986) Effects of post infection applications of the ergosterol-biosynthesis inhibiting fungicides on lesion formation and pseudothecial development of Venturia inaequalis. Phytopathology, 76 , 119-124.

Shephard, M.C. (1985) Fungicide behaviour in the plant-systemicity in Fungicides for Crop Protection. BCPC Monograph No. 31, pp.99-106.

Shephard, M.C.; Noon, R.A.; Worthington, P.A.; McClellan, W.D.; Lever, B.G. (1986) Hexaconazole : A novel triazole fungicide. Proceedings 1986 British Crop Protection Conference - Pests and Diseases. I. 19-26.

Szkolnik, M. (1981) Physical modes of action of sterol inhibiting fungicides against apple diseases. Plant Disease 65 , 981-985.

PROSPECTS FOR THE CHEMICAL CONTROL OF ARMILLARIA SPECIES.

JUDITH A. TURNER AND R. T. V. FOX.

Department of Horticulture, School of Plant Sciences, University of Reading, 2, Earley Gate, Reading. RG6 2AU.

ABSTRACT

The potential of hexaconazole, flutriafol, and fenpropidin (all ergosterol-biosynthesis inhibitors (EBI's), a guanide, a phenolic and mixture of cresylic acids for control of Armillaria mellea, A. ostoyae, and A. bulbosa was investigated in the laboratory. Experiments, in which agar discs of inoculum were drenched with fungicide, showed that all the chemicals were highly inhibitory to the growth of Armillaria spp at a concentration of 500 mg/l ai. At lower concentrations the EBi's and the guanide proved more effective than the two phenolic fungicides. The species showed marked differences in sensitivity to the EBI's, particularly to fenpropidin and hexaconazole. A protectant assay using wood blocks soaked in the chemicals confirmed the fungistatic activity of the EBI's and supported the view that chemicals of this type could be used for control of Armillaria.

INTRODUCTION

The genus Armillaria consists of numerous species worldwide. It is an important cause of root and butt rot of trees, shrubs and vines throughout the world. The disease spreads by rhizomorphs or transfer of mycelium in root to root contact; spores are not thought to play a major role (Rishbeth, 1970). Woody and starchy roots are particularly prone to colonisation and subsequent decay. Of the six species occurring in Britain three have been found to be pathogenic. These species: A. mellea, A. ostoyae and A. bulbosa vary in pathogenicity and host preference (Rishbeth, 1982).

Control of Armillaria has proved difficult. Although many chemicals and cultural methods have been considered, none have been both successful and easy to implemement (Cheo, 1968; Rahman, 1974). A mixture of cresylic acids ("Bray's Emulsion"), has been marketed for control of Armillaria for over a decade but despite many claims of eradication and control there are problems with phytotoxicity and lack of permanent eradication. The need for an effective non-phytotoxic, non-hazardous eradicant and protectant chemical treatment for this disease is therefore clearly evident.

In a preliminary experiment fungicides from different groups (with different modes of action) were evaluated in plate tests. Five chemicals and "Bray's Emulsion" showed activity against Armillaria and were further investigated.

The activities in vitro of the five chemicals and the cresylic acid mixture against Armillaria were determined. The results are reported here.

MATERIALS AND METHODS

Chemicals

Two triazoles: hexaconazole and flutriafol, a piperidine: fenpropidin, a guanide, a phenolic and a mixture of cresylic acids ("Bray's Emulsion") were used in all experiments. Hexaconazole, flutriafol and fenpropidin are ergosterol-biosynthesis inhibitors (EBI's).

Isolates

Isolates representing the three major species of Armillaria in Britain were selected. These were originally obtained and identified by Dr.J. Rishbeth as Armillaria mellea (Vahl: Fr) Kummer (isolate 1), A. ostoyae (Secr.) Romagn. (isolate 4) and A. bulbosa (Barla) Kile & Watling (isolate 6).Their identification has been confirmed in incompatibility tests by several workers (Mohammed, Pers. Comm., 1987). All isolates were stored under liquid nitrogen to reduce the risk of genetic change.

In vitro sensitivity of isolates.

Concentrations of fungicide containing 500, 50 and 5 mg/l active ingredient were prepared by dilution in sterile distilled water. Fifteen ml of each dilution was pipetted into sterile petri dishes. Discs, 6 mm in diameter, were cut from the margin of fifteen day old colonies of the three test species and placed, mycelium downwards, in each dish. Six replicates per concentration were set up and distilled water was used for the control. After one hour the discs were removed and placed mycelium uppermost on 3% malt extract agar plates (3 replicates per plate). All plates were incubated at 25 C in the dark for 8 to 13 days. Colony diameter measurements were made and percentage inhibition of radial growth, compared to the untreated controls, was calculated.

In vitro assessment of protectant activity.

Malt extract agar plates were inoculated with isolates 1 (A. mellea), 4 (A. ostoyae) and 6 (A. bulbosa) using a 6mm cork borer and incubated at 25 C in the dark for 9 days. Hazel billets, 5.0 cm long x 2.5 cm wide, were sliced into discs using a circular saw and then divided into quarters using a wood chisel and mallet.The blocks were autoclaved for 30 minutes at 121 C. Serial dilutions of the fungicides were prepared to produce concentrations of 3000, 2000, 1000 and 500 mg/l active ingredient. Sterile distilled water was used as a control. After soaking in fungicide solution for 90 minutes the blocks were placed on the margins of the agar cultures.

After a further 16 days incubation assessments were made by estimation of percentage colonisation of the blocks.

RESULTS

In vitro sensitivity of isolates

Hexaconazole

A. mellea was the least sensitive of the three species to this fungicide showing less than 50% inhibition at 500 mg/l ai after 10 days. Trends in the sensitivity of A. ostoyae and A. bulbosa were similar, both species showing 100% inhibition after treatment at 500

and 50 mg/l ai. The two species showed 76.6% and 85% inhibition respectively after the 5 mg/l treatment.

Fig 1.

Effect of fungicides on Armillaria spp in vitro.

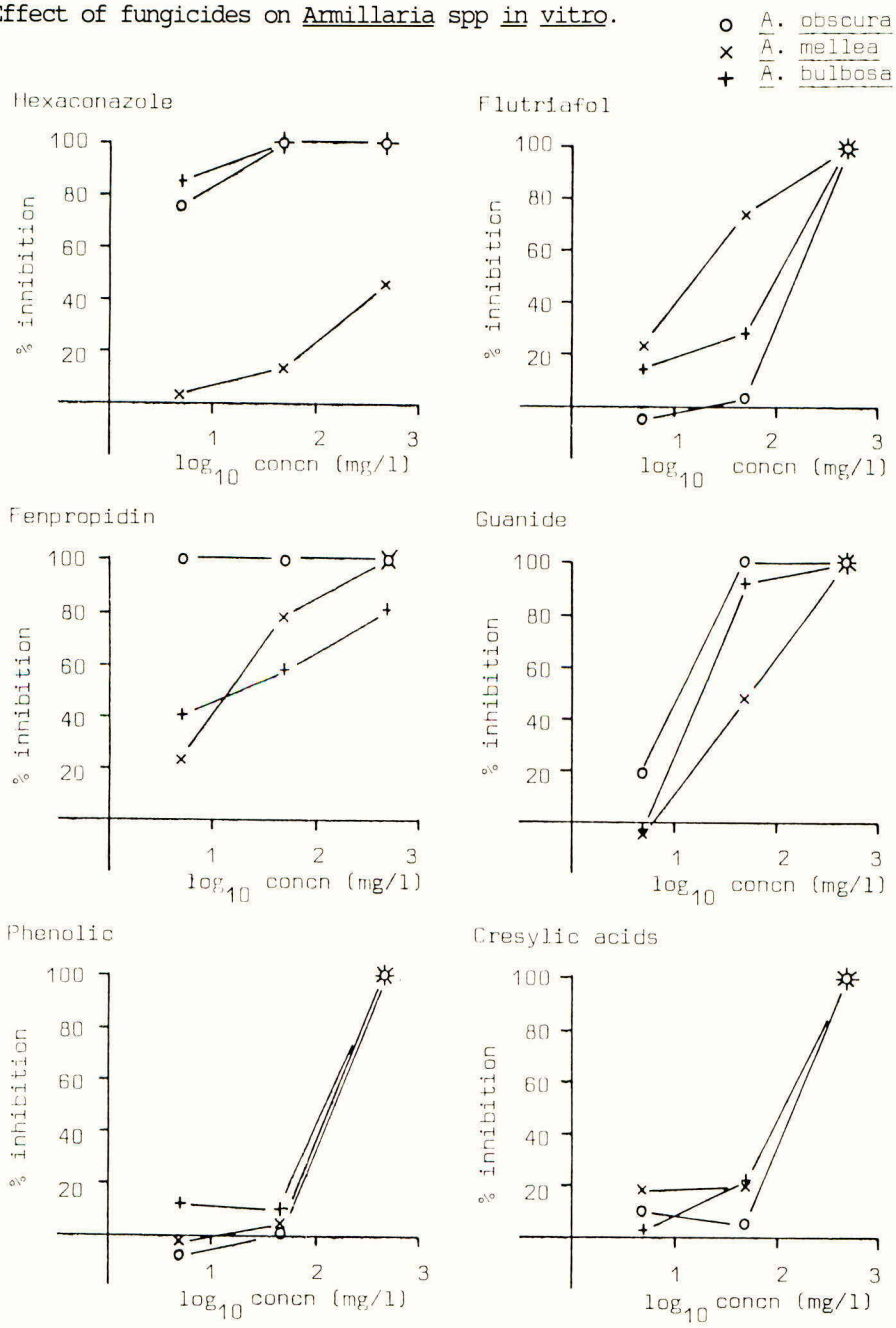
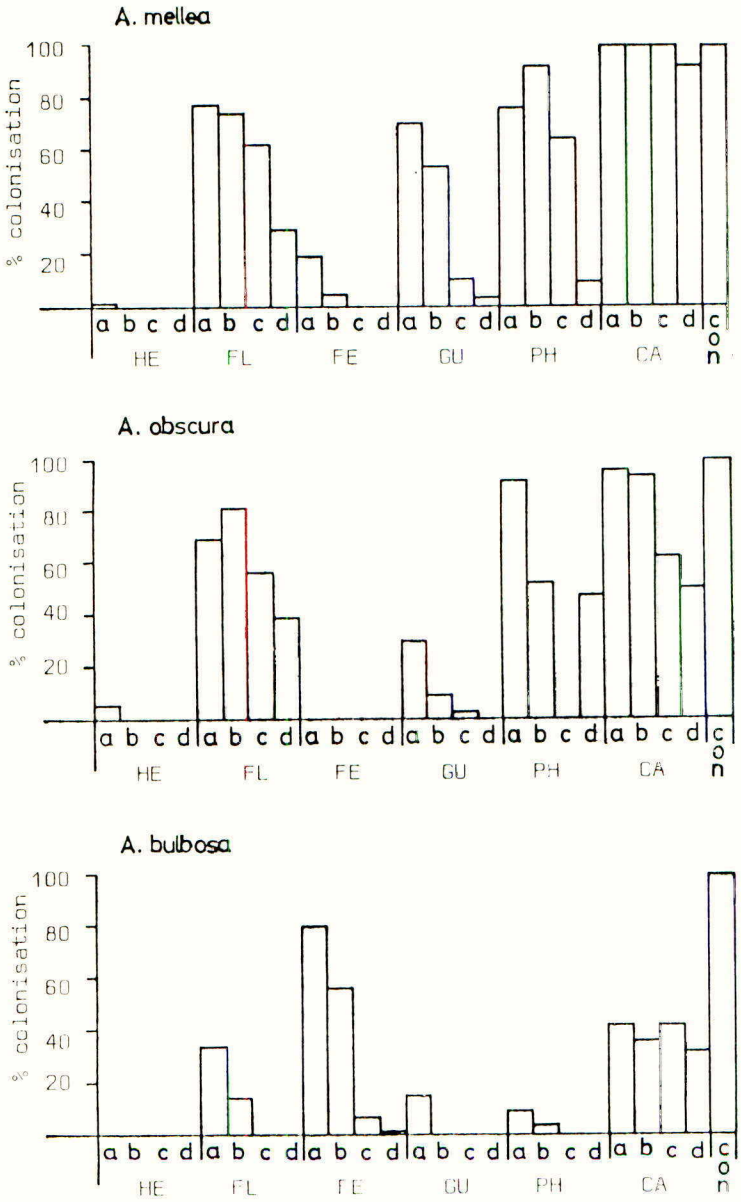


Fig 2.

Percentage colonisation by Armillaria spp of fungicide treated blocks



KEY

HE - hexaconazole
FL - flutriafol
FE - fenpropidin
GU - guanide
PH - phenolic
CA - cresylic acids

a - 500 mg/l
b - 1000 mg/l
c - 2000 mg/l
d - 3000 mg/l

Flutriafol

Growth of all isolates was completely inhibited by the 500 mg/l treatment. At lower concentrations A. mellea was more sensitive than the other species (74% inhibition at 50 mg/l ai), and A. ostoyae the most resistant showing little or no inhibition at the 50 and 5 mg/l treatments. A. bulbosa was intermediate in sensitivity showing 28% inhibition at 50 mg/l ai.

Fenpropidin

Treatment with fenpropidin produced complete inhibition of A. ostoyae at all concentrations tested. Treatment of A. mellea with 500 mg/l ai gave 100% inhibition and a steady decline in sensitivity with decreasing concentration. A. bulbosa showed 81.5% inhibition at 500 mg/l and was the most resistant.

Guanide

Treatment of A. mellea, A. ostoyae, and A. bulbosa with 500 mg/l ai gave 100% inhibition, however A. mellea proved more resistant at lower concentrations. At 50 mg/l ai A. mellea showed 48.1% inhibition, A. bulbosa showed 92.6% inhibition and A. ostoyae was completely inhibited.

Phenolic

At 500 mg/l this chemical completely inhibited all isolates. At 50 and 5 mg/l ai activity was greatly reduced and 10% inhibition was the maximum recorded. No inter-specific variation in sensitivity was evident.

Cresylic acids

The 500 mg/l treatment completely prevented growth of all three species. Supression of growth was greatly reduced at lower concentrations and A. mellea was more sensitive than A. ostoyae and A. bulbosa.

In vitro assessment of protectant activity

Hexaconazole was the most effective fungicide against all three species: a minimum of 95% inhibition was recorded after a 500 mg/l treatment and the higher concentration treatments were compltely effective. Fenpropidin was also shown to have protectant activity. Comparison of the sensitivities of the three isolates to the different chemicals revealed similar patterns to those recorded in the agar tests. A. mellea proved the most resistant to the range of chemicals tested and A. bulbosa the most sensitive (particularly to the phenolic fungicides). However, A. bulbosa was the least sensitive of the isolates to fenpropidin treatment (as in agar tests). The cresylic acid mixture proved to be the least effective treatment.

After further incubation, inhibition by some of the fungicides was reduced but hexaconazole and fenpropidin treatments remained effective.

DISCUSSION

The results show that the EBI fungicides, hexaconazole, flutriafol and fenpropidin, showed activity against Armillaria at all concentrations tested. Ergosterol biosynthesis inhibitors have been shown to be successful in controlling many diseases at a range of concentrations (Buchenauer, 1987). These chemicals interfere with synthesis of ergosterol by inhibition of the C-14 demethylation step

(de Waard & Fuchs, 1982). They are capable of protectant, post-infectional and anti-sporulant activity (Schwabe et al, 1984). Differences in sensitivity to the EBI's, particularly to the piperidine (fenpropidin), was exhibited by the three species of Armillaria.

In contrast to this response to the triazoles, the guanide and the phenolic and cresylic acid mixture treatments showed very similar patterns of inhibition of the three species. The mode of action of the guanide is reported to be that of a cationic surfactant (Hassall, 1983) which attacks lipoprotein membranes. Membrane disruption is also a property of the phenolic fungicides which are multi-site inhibitors. The similar reactions of the three Armillaria species is consistent with the broad spectrum activity of these fungicides. The effects of the and phenolic fungicides were greatly reduced at lower concentrations, whilst the EBI's and the guanide were active at concentrations below 500 mg/l ai.

The wood block technique was used to simulate as far as possible the field situation and served to assess the protectant activity of the chemicals. Hexaconazole was the most effective treatment overall. It may be that the greater effect of this chemical compared to the agar tests was due to increased contact between the chemical and the fungus. Fenpropidin showed high protectant activity in addition to the eradicant fungicidal properties demonstrated in agar.

The next stage in the development of an Armillaria control measure is the treatment of infected trees with chemicals. Following tests for phytotoxity, trials have been established to evaluate the effectiveness in field conditions of those chemicals which show promise in the laboratory tests. First assessments have already been made.

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REFERENCES

Buchenauer, H. (1987) Mechanism of action of triazolyl fungicides and related compounds. In :Modern selective fungicides. Properties, applications, mechanisms of action. H. Lyr (Ed.) London. 205-231.

Cheo, P.C. (1968) Control of Armillaria with systemic chemicals. Plant disease reporter 52 639-641.

De Waard, M.A. ; Fuchs, A. (1982) Resistance to ergosterol-biosynthesis inhibitors II. Genetic and physiological aspects. In : Fungicide resistance in crop protection. J. Dekker and S.G Georgopoulos (Eds.). Wageningen. 87-100.

Hassall, K.A. (1983) 2nd Edn. The chemistry of pesticides. Their metabolism, mode of action and uses in crop protection. London.

Rahman, M.A. (1974) Studies on the effect of Armillatox, a proprietary fungicide, on the growth of and infection by Armillaria mellea. Msc. thesis. University of Oxford.

Rishbeth, J. (1970) The role of basidiospores in stump infection by A. mellea. In : Root disease and soil-borne pathogens. Toussoun, T.A.; Bega, R.V. and Nelson, P.E. California. 141-146.

Rishbeth, J. (1982) Species of Armillaria in southern England. Plant pathology 31 9-17.

Schwabe, W.F.S.; Jones, A.L.; and Jonker, J.P. (1984) Greenhouse evaluation of the curative and protective action of sterol-inhibiting fungicides against apple scab. Phytopathology 74 249-252

INTEGRATED CONTROL OF TWO-SPOTTED SPIDER MITE ON STRAWBERRY

M.A. EASTERBROOK

AFRC Institute of Horticultural Research, East Malling, Maidstone, Kent, ME19 6BJ.

ABSTRACT

The integration of biological control of two-spotted spider mite on unprotected strawberries with chemical control of other pests and diseases is desirable because of reduced availability of acaricides. Such a system was shown to be feasible. The non-native predator Phytoseiulus persimilis gave control of a high population of spider mite and spread rapidly from plants on which it was released. The native phytoseiid Typhlodromus pyri appears to be able to control spider mite under certain conditions but is unlikely to reduce high populations to non-damaging levels.

INTRODUCTION

The control of two-spotted spider mite (Tetranychus urticae) on strawberry has been achieved satisfactorily on most farms in recent years by the use of acaricides, chiefly compounds containing cyhexatin. The withdrawal of this chemical in 1987 meant that few acaricides remained that were approved for use on strawberry and mite populations on many farms were suspected of having resistance to these compounds. It is desirable, therefore, to try to reduce the need for acaricides and so delay the onset of resistance by maximising the action of natural enemies of spider mite in an integrated control system.

Three possible options for such a system are 1. to encourage naturally-occurring predators, 2. to introduce native predators from other sources, 3. to introduce non-native predators, e.g. Phytoseiulus persimilis. Research aimed at testing the potential of these options has begun at IHR, East Malling. There has previously been little research on the first two options on strawberry in Britain. P. persimilis has been used successfully on strawberries grown under plastic (Cross 1980; Port & Scopes 1981) but has not been tested on unprotected plants. Whichever option is used, other pests and diseases will have to be controlled with pesticides compatible with mite management.

MATERIALS AND METHODS

Use of naturally-occurring predators

Option 1 was tested in 1986-7 on a strawberry planting containing cvs. Hapil, Cambridge Favourite and Gorella on which the predatory phytoseiid Typhlodromus pyri was present. A treatment in which insecticides were chosen for compatibility with mite management (integrated control) was compared with a programme which included a pyrethroid insecticide (standard), each treatment being applied on two 50 m x 10 m plots. All plots received a standard fungicide programme of dichlofluanid, iprodione and bupirimate. Pesticides were applied by Hardi Mini mistblower at 300 litres/ha.

Release of native or non-native predators

Options 2 and 3 were tested in 1988 on a planting of cv. Rapella grown on polythene on raised beds. P. persimilis were introduced on 21 June by sprinkling a commercial preparation (Spidex, Koppert Ltd.) on every fourth plant (estimated 7 predators per release plant). On the same date, apple shoots containing the native predator T. pyri were placed on every second plant on other plots (estimated 6 predators per release plant). Other plots received no predators. There were three replicate plots of each treatment, each plot being 40 m of a 2-row bed.

In both trials mites were counted on samples of leaves (30-60/plot) under a stereomicroscope.

RESULTS

Use of naturally-occurring predators

Numbers of T. pyri were high (0.35-0.65/leaf) on all plots at the start of the trial (Fig. 1). As expected, pirimicarb had little effect on T. pyri numbers. On the standard plots chlorpyrifos appeared to cause some reduction but enough T. pyri survived to suggest that a proportion of the population, at least, was resistant to organophosphates. Cypermethrin, however, caused a severe reduction in numbers of T. pyri with a subsequent upsurge of spider mite to 18 active stages/leaf. In contrast, on the integrated control plots, spider mite numbers remained below 2/leaf.

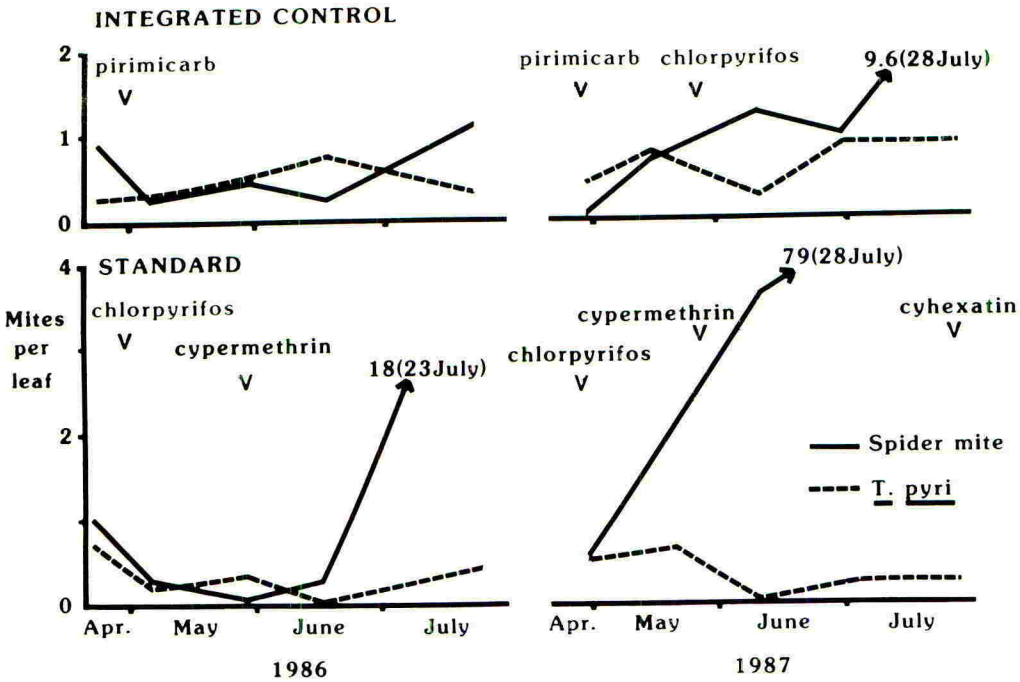

Fig. 1 Populations of spider mite, Tetranychus urticae, and predatory mite, Typhlodromus pyri under integrated control and standard spray programmes.

Populations followed a similar pattern in 1987. Chlorpyrifos was introduced into the integrated control programme and allowed sufficient survival of T. pyri to prevent an increase of spider mite such as followed the application of cypermethrin. Although spider mite numbers on the integrated control plots rose above the levels of 1986, and reached 14/leaf on one plot, they exceeded 70/leaf on the standard plots, requiring an acaricide treatment.

Release of native or non-native predators

TABLE 1

Mite numbers on predator-release trial

Treatment	Mites per leaf (active stages only)@								
	P. persimilis release			T. pyri release			No release		
	SM≠	PP	TP	SM	PP	TP	SM	PP	TP
20 June	3.1	0	0.01	2.9	0	0	4.6	0	0
Predator release 21 June									
5 July	9.6	0.4	0.03	15.2	0	0.11	11.9	0	0
Tetradifon 7 July									
18 July	9.4	0.7	0.03	26.8	0.03	0.16	20.9	0	0.01
2 August	11.5	1.6	0	30.6	0.25	0.11	13.7	0.17	0
24 August	9.5	2.3	0.03	106.5	0.27	0.02	60.5	4.6	0.01

@ samples from release plants only until 24/8 when all plants sampled
≠ SM, spider mite; PP, Phytoseiulus persimilis; TP, Typhlodromus pyri

Spider mites were building up very rapidly at the time of predator releases, with many eggs being laid, so tetradifon was applied two weeks later to try to reduce spider mite numbers in the period of predator establishment. P. persimilis established quickly and prevented spider mites from reaching very high numbers (Table 1). They also spread rapidly so that by late July they could be found on plants midway between release plants and by August had appeared on the other treatments.

The releases of T. pyri were much less successful, as this predator failed to build up to appreciable levels and was unable to control T. urticae.

DISCUSSION

The trial on the planting where T. pyri had colonised naturally suggested that this predator might be able to regulate T. urticae at non-damaging levels. However, in the trial where T. pyri was artificially introduced it did not increase sufficiently to prevent a build-up of spider mite. It may be more successful if released when spider mite numbers are lower, as it is known to have a poor numerical response and to dislike the webbing that T. urticae makes (Sabelis 1985). P. persimilis, on the other hand, is well adapted for predation on T. urticae and there are many

examples of successful biological control with this species, including a recent success on unprotected strawberries in New Zealand (Workman, 1986), under climatic conditions similar to those in the British Isles. P. persimilis would probably have achieved control earlier in the trial reported here if it had been released when spider mite numbers were lower. It remains to be seen whether P. persimilis is able to survive the winter regularly in the U.K., or whether it would have to be released each year. It is possible to devise a spray programme for most pests and diseases of strawberry that would allow either of these predator species to survive.

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REFERENCES

Cross, J.V. (1980) Red spider mite control using predators on protected strawberries. Technical Bulletin, Ministry of Agriculture, Fisheries & Food, pp. 2.

Port, C.M.; Scopes, N.E.A. (1981) Biological control by predatory mites (Phytoseiulus persimilis Athias-Henriot) of red spider mite (Tetranychus urticae Koch) infesting strawberries grown in 'walk in' plastic tunnels. Plant Pathology 30, 95-99.

Sabelis, M.W. (1985) Capacity for population increase. In: Spider mites: their biology, natural enemies and control, vol 1B, Helle, W. and Sabelis, M.W. (Eds), Amsterdam: Elsevier, 35-41.

Workman, P.J. (1986) Integrated control of two-spotted mite on strawberry runner beds. Proceedings 39th New Zealand Weed and Pest Control Conference, 162-165.

ICIA0001 : A NOVEL FUNGICIDE FOR USE AGAINST DISEASES ON VINES

S.P. HEANEY

ICI Agrochemicals, Jealott's Hill Research Station, Bracknell, Berks, RG12 6EY

J.C. ATGER, J.F. ROQUES

ICI SOPRA, Clamart, France

ABSTRACT

ICIA0001 is a new benzamide fungicide for the control of Plasmopara viticola and Phomopsis viticola on vines. In combination with protectant fungicides ICIA0001 gave excellent control of Plasmopara viticola even under severe disease pressure. ICIA0001 is effective against phenylamide resistant and phenylamide sensitive strains. It has excellent curative, penetrant and antisporulant properties and distributes systemically in the apoplast.

INTRODUCTION

ICIA0001 is a new benzamide fungicide with high levels of activity against vine downy mildew (Plasmopara viticola) and good levels of activity against cane and leaf spot (Phomopsis viticola). Both pathogens can seriously reduce yields in vines and are favoured by wet conditions when infective propagules can be splash dispersed to germinate on susceptible tissue.

Fungicides currently used to control Plasmopara viticola include a number of protectant molecules; copper, dithiocarbamates and phthalimides. More recently molecules have been discovered with systemic and/or curative action: the phenylamides, fosetyl-Al and cymoxanil. Their use has allowed a reduction in the number of fungicide treatments required during the growing season. However, resistance has been reported in several areas of France to the phenylamides (Clerjeau & Simone 1982).

Phomopsis viticola may infect vines at a very early stage in crop growth, attacking as the buds burst. A pre bud burst shoot treatment of sodium arsenite can be very effective, though this treatment has limited clearance in Europe and may only be used in the winter period. Protectant treatments covering the bud-burst and leaf unfolding stage can also be effected with dithiocarbamates and/or phthalimides.

ICIA0001 is a valuable addition to the group of Oomycete specific compounds with systemic and curative properties, and has additional activity against the non-Oomycete pathogen Phomopsis viticola. This paper describes glasshouse and field trials with ICIA0001 for the control of these pathogens. In field trials, ICIA0001 was used alone or in combination with protectant and/or systemic fungicides and compared to standard commercial treatments.

MATERIALS AND METHODS

Glasshouse studies

Plasmopara viticola

Glasshouse tests were carried out on young vine seedlings with 3-6 leaves under controlled environmental conditions. Chemicals (technical material) were dissolved in acetone and diluted appropriately in water before being applied to test plants as a foliar spray. Plants were inoculated with a sporangial suspension (*c*.10,000 spores/ml) 1, 2 or 3 days before treatment with test chemicals (curative schedule). After incubation for 6 days, level of disease was assessed as percentage area infected and sporulating on the leaf surface.

Field studies

Plasmopara viticola

Trials were laid down as randomised blocks, replicated 4 times, with 5 or 6 vines/plot. Vines were inoculated with sporangial suspensions of *Plasmopara viticola* before flowering. At sites with misting facilities only, 2 shoots on the central vine in the plot were inoculated. At sites with irrigation facilities only, 1 shoot/vine was inoculated. Inoculated shoots were tagged and excluded from disease assessments. Bunch infections resulted naturally from foliar contamination. In trials conducted by the Institut National de la Recherche Agronomique (INRA), bunches were inoculated directly. During dry periods, vines were misted or irrigated during the cooler parts of the day to maintain development of the epidemic; 10-15 mm of rainfall was simulated in such applications.

Fungicides were applied at 1000 to 1500 l/ha (most commonly 1000 l/ha) using conventional equipment. Application commenced at the first appearance of disease and continued at 10-14 day intervals. Under climatic conditions very favourable for disease development (frequent local thunderstorms) intervals were occasionally reduced to 7 days. Assessments of foliar and bunch disease were made throughout the season by assessing the number of leaves infected and percentage necrotic area from a random sample of 100 leaves/plot and all bunches on 5 vines/plot. The 2 oldest and 3 youngest leaves on each shoot were assessed during the latter part of the growing season, but were excluded from assessment at other stages. Data were subjected to analysis of variance and a Fisher protected t-test was used to detect significant differences (P=0.05).

Phomopsis viticola

Treatments were replicated 10 times with 2 vines/treatment. Chemicals were applied to run off, commencing when half of the vines were at stage D (first leaf unfolded). The second application was made when half of the vines were at stage E (2 to 3 leaves expanded). The percentage of first and second internode area infected was recorded.

RESULTS AND DISCUSSION

Glasshouse studies demonstrated that ICIA0001 gave excellent control of *Plasmopara viticola* when applied 1, 2 or 3 days after inoculation. In contrast to cymoxanil no decline in activity was measured as the curative period was increased from 1 to 3 days (Table 1). ICIA0001 has also demonstrated good intrinsic protectant activity against *Plasmopara viticola* (LC_{90}, 25 ppm), though persistence of effect was moderate, biological activity being halved every 3.4 days (Heaney *et al*. 1988).

Further glasshouse studies have revealed the ability of ICIA0001 to penetrate young vine plants through the leaf, stem or root, and to distribute systemically within the apoplast. Rapid penetration resulted in excellent rainfastness being achieved within 4 h. Cymoxanil demonstrated low biological activity with a similar drying period (Heaney *et al.* 1988).

These studies indicated that optimal use could be made of ICIA0001 by mixing it with a persistent protectant compound, thus providing both complementary action and reducing the risk of resistance developing to the molecule.

TABLE 1

Curative activity of ICIA0001 against vine downy mildew

Treatment	LC50 (mg a.i./l)*								
	1 Day curative**			2 Day curative			3 Day curative		
	mean	lower***	upper***	mean	lower	upper	mean	lower	upper
ICIA0001	1.8	0.6	5.1	2.2	0.5	10.2	1.4	1.4	4.6
Cymoxanil	1.3	0.7	2.6	14.1	8.8	22.4	65.0	51.0	82.1

* Values based on the mean of six tests after logit transformation of data
** Chemical applied one day after inoculation
*** Lower and upper 95% confidence limits about the mean, log transformed

The activity of ICIA0001 in the field was demonstrated on a relatively short interval of application with the initial spray accurately timed to utilise the curative properties of the molecule. Where phenylamide resistant strains dominated the population, ICIA0001 alone or in mixture with a protectant was superior to protectant and phenylamide standards and equivalent in activity to cymoxanil/protectant mixtures (Table 2).

TABLE 2

Control of vine downy mildew on nursery vines (France 1987)*

Treatment	Rate (g a.i./hl)	% Leaf area infected 10DAT2**
ICIA0001	9	6c***
ICIA0001 + mancozeb	9 + 140	7c
ICIA0001 + folpet	9 + 100	4c
Cymoxanil + mancozeb	12 + 140	6c
Oxadixyl + cymoxanil + mancozeb****	20 + 8 + 140	38b
Mancozeb	140	21b
Untreated	-	85a

* INRA trial inoculated with a phenylamide resistant strain
** 10DAT2 = 10 days after the second application
*** Treatments with common letters were not significantly different at $P = 0.05$
**** Applied every 14 days. All other treatments applied every 10 days

In combination with mancozeb or folpet, ICIA0001 consistently demonstrated levels of disease control on foliage and bunches equivalent to or better than commercial standards even under exceptional disease pressure (Tables 3 and 4).

An important feature of ICIA0001, which distinguishes it from commercial standards, is its ability to eradicate established lesions thus preventing sporulation. This was demonstrated when sporulating diseased tissue as opposed to necrotic area was assessed (Table 3).

TABLE 3

Control of vine downy mildew on leaves of mature vines (France 1987-88)

Treatment	Rate (g a.i./hl)	% Leaf area diseased 1987 I* 4DAT7	1987 II 7DAT8	1987 III** 11DAT5	1988 IV 8DAT5	1988 V*** 4DAT2
ICIA0001 + mancozeb	9 + 140	0bc	1b	4c	3d	0c
ICIA0001 + folpet	9 + 100	0c	1b	4c	3d	0c
Cymoxanil + mancozeb	12 + 140	1bc	2b	5c	8c	11b
Cymoxanil + folpet	12 + 100	2bc	2b	4c	13b	10b
Mancozeb	280	3b	3b	15b	-	-
Untreated	-	48a	50a	76a	58a	21a
Spray Interval (Days)		10-11	10	14	7-11	11

* I to V represent five different trials sites in France
** Trial conducted by Institut National de la Recherche Agronomique (INRA)
*** Sporulating diseased tissue only assessed

TABLE 4

Control of vine downy mildew on bunches (France 1987-88)

Treatment	Rate (g a.i./hl)	% Bunch area diseased 1987 I 4DAT7	1987 II 4DAT4	1987 III* 9DAT6	1988 IV 8DAT5
ICIA0001 + mancozeb	9 + 140	0b	1b	3b	16bc
ICIA0001 + folpet	9 + 100	1b	1b	1b	12c
Cymoxanil + mancozeb	12 + 140	1b	1b	4b	28b
Cymoxanil + folpet	12 + 100	0b	2b	2b	21bc
Mancozeb	280	0b	1b	5b	-
Untreated	-	8a	43a	94a	87a
Spray Interval (Days)		10-11	10	14	7-11

* Trial conducted by INRA

The value of ICIA0001 as a complementary partner to other systemic fungicides (phenylamides and fosetyl-Al) was also demonstrated. In a situation where phenylamide resistant strains were present, ICIA0001/ phenylamide mixtures were significantly more effective than cymoxanil/ phenylamide mixtures, with ICIA0001/fosetyl-Al mixtures showing particularly good control of vine downy mildew (Table 5).

TABLE 5

Control of downy mildew on nursery vines (France 1987)

Treatment*	Rate (g a.i./hl)	% Leaf area diseased 8DAT6
ICIA0001 + mancozeb	9 + 140	6d
Metalaxyl + folpet**	22 + 127.5	56b
ICIA0001 + metalaxyl + folpet	9 + 22.5 + 80	6de
Cymoxanil + oxadixyl + mancozeb	8 + 20 + 140	20c
ICIA0001 + fosetyl-Al + folpet	9 + 150 + 80	3e
Untreated	-	78a

* Application interval 10 days
** Phenylamide resistant strains detected in this trial

ICIA0001 alone or in mixtures has shown good activity against Phomopsis viticola, significantly reducing disease incidence under moderate disease pressure (Table 6).

TABLE 6

Control of cane and leaf spot on vines (France 1987)

Treatment*	Rate (g a.i./hl)	% Area infected 1st internode	% Area infected 2nd internode
ICIA0001	9	5b	0b
ICIA0001 + folpet	9 + 100	8b	1b
ICIA0001 + mancozeb	9 + 240	5b	0b
Mancozeb	140	4b	0b
Untreated	-	32a	10a

* Sprayed at bud burst and 14 days later

Crop Safety

ICIA0001 has been used on a wide variety of vine cultivars under a range of environmental conditions. Application rates which have shown high levels of disease control have normally provided a substantial margin for safety. Under environmental conditions where transpiration rates were likely to be exceptionally high a light and transient interveinal chlorosis has occasionally been recorded on a small proportion of the foliage. No phytotoxic symptoms have been recorded on bunches.

Residue and Fermentation Studies

Residues of ICIA0001 in grapes treated with recommended rates have been very low (<0.01 to 0.02 mg/kg). ICIA0001 does not affect the fermentation process.

CONCLUSIONS

ICIA0001 is a novel benzamide fungicide with high levels of activity against Plasmopara viticola and good levels of activity against Phomopsis viticola. ICIA0001 has a novel mode of action and is effective against phenylamide resistant and phenylamide sensitive strains. The molecule is able to penetrate leaf and stem tissue of vines and distribute systemically in the apoplast.

Mixtures of protectant multi-site partners with ICIA0001 complement its outstanding curative, antisporulant and distributive properties and should reduce the selection pressure for resistance development. In view of this it would seem unnecessary to restrict the number of applications per season. For the control of Plasmopara viticola, such mixtures should be employed on a schedule tailored to the climatic conditions, with an average interval of 10-12 days acting as a suitable guideline. ICIA0001 may also be utilised effectively in combination with other systemic fungicides. Treatments containing ICIA0001 should not be recommended on a curative schedule for vine downy mildew. However, it should be recognised that curative action and rapid penetration are important features of a robust treatment for this pathogen, where climatic conditions favourable for disease development can prevent chemical application or wash off recently applied material.

Mixtures of ICIA0001 with mancozeb should also provide control against black rot, whilst mixtures with folpet should contribute valuable added efficacy to standard programmes for control of Botrytis cinerea.

ICIA0001 mixture treatments thus provide a new and very flexible set of tools for the grower seeking to control these damaging wet diseases on vines.

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REFERENCES

Clerjeau, M.; Simone, Y. (1982) Apparition en France de souches de mildiou (Plasmopara viticola) résistantes aux fongicides de la famille des anilides (metalaxyl, milfurame). Le Progrès Agricole et Viticole 99, 59-61.

Heaney, S.P.; Shephard, M.C.; Crowley, P.J.; Shearing, S.J. (1988) ICIA0001 : A Novel Benzamide Fungicide. Proceedings 1988 British Crop Protection Conference - Pests and Diseases.

USE OF ACETATES TO INDUCE HOST RESISTANCE TO *XYLEBORUS FORNICATUS* (COLEOPTERA: SCOLYTIDAE) ATTACKING TEA.

M.A.S.K. RANASINGHE

Department of Agricultural Biology, University of Peradeniya, Sri Lanka.

R.L. WICKREMASINGHE

National Institute of Plantation Management, Athurugiriya, Sri Lanka.

ABSTRACT

The shot-hole borer, *Xyleborus fornicatus* Eichoff, (Coleoptera: Scolytidae) has been a serious pest for about one hundred years, on tea grown in Sri Lanka. There is a need for new approaches to control this pest because the currently recommended methods are either expensive or hazardous. A field trial was carried out to find whether incorporation of either potassium acetate or zinc acetate to the fertilizer mixtures could reduce the borer attack by inducing the host plant to make some of its sterols unavailable to the borer. Compared to the untreated control plots, the treated plots had an overall significant reduction of the beetle population. Up to 21 months after pruning, the treated plots had significantly lower numbers of pupae and adults of this beetle. In addition, the percent of the sampling units attacked by the borer was also lowered in the treated plots. There was no significant difference between potassium acetate and zinc acetate treated plots, with reference to the above criteria.

INTRODUCTION

For over a century, tea, *Camellia sinensis* L., has been grown as a commercial crop in Sri Lanka. Currently it is the major industry and the leading foreign exchange earner in this country.

The tea shot-hole borer, *Xyleborus fornicatus* Eichoff, has been a pest of tea for nearly a century. It is particularly serious in the mid-country (400-1000 m above m.s.l.) tea.

The biology and ecology of this pest have been described by a number of authors (Gadd 1941, Cranham 1966, Calnaido 1965). This is an ambrosia beetle whose larvae feed on *Monocrosporium ambrosium* in the galleries constructed by the female in the tea stem. The life cycle of the beetle is closely synchronized with the growth pattern of tea

(Sivapalan 1977) which is pruned every 3 - 4 years. During a three year pruning cycle the borer population begins to rise around the ninth month after pruning (MAP), reaches a peak by about the 18th MAP and declines rapidly after the 24th MAP (Calnaido 1965). The normal assessment of its population is counting the number of beetles in 25 randomly selected 10 cm long units of the stem (Judenko 1958).

The current method of borer management includes the use of resistant clones, adjustment in the pruning supplemented with chemical control where necessary (Sivapalan 1979). These practices though sound are expensive (cultural) and/or hazardous (chemical). It is thus desirable to have an alternate cost-effective method to control this pest.

Fundamental studies on the basis of host resistance to the borer have shown that, at a given location, the amount of available Δ-spinasterol in the stem is the principal determinant of the degree of infestation by this pest (Wickremasinghe et al. 1978). The importance of sterol was thought to be due to its conversion into moulting hormones by the beetle and use in sporulation by *X. ambrosium*.

The level of Δ-spinasterol in tea is determined by the level of saponins, theanine, arginine, chelabulagic acid and calcium. Saponin, in particular, could bind sterols and thus become a determinant of the host resistance to the borer. Sivapalan and Shivanandarajah (1977) reported significant lowering of brood emergence in *X. fornicatus* reared in an artificial diet containing tea saponins. Sivapalan (1977) also found an increase in borer population during the pruning cycle where there was accumulation of sterols in the tea stem.

Wickremasinghe and Thirugnanasuntharam (1980) subsequently found that the addition of potassium acetate to the fertilizer mixture increased the saponin activity of the tea stem resulting in a marked reduction in pupation of *X. fornicatus* larvae. Others also have reported inhibitory or toxic effects of saponins on insect larvae (Matolsy et al. 1974).

The objective of this experiment was to investigate the effect of broadcasting potassium acetate and zinc acetate, with the fertilizer rounds, on *X. fornicatus* in mature tea grown under commercial conditions.

MATERIALS AND METHODS

This field trial was carried out from September 1985 through August 1987 at Imboolpitiya Estate, a State-owned plantation located near Kawalapitiya in the Kandy district of Sri Lanka.

Field No. 9 in this estate was selected because it was representative in terrain of the mid-country tea fields, planted with a susceptible tea clone (TRI 2025) and was due for pruning.

A randomized complete block design with three replicates was used. Each plot was 13.5 x 13.5 m with a guard row of tea bushes around.

Pre-treatment assessment of the borer was done by collecting 25 randomly-selected, 10 cm long sampling units (Sivapalan 1975) from each plot. Subsequently the field was pruned and a bush count was taken to ensure that all the plots had comparable number of tea bushes.

In the experimental area, all the cultural practices except application of insecticides, were carried out as currently recommended by the estate management.

The treatments used in this experiment were: three levels (0.5 g, 1.0 g and 1.5 g per bush) each of potassium acetate and zinc acetate, and an untreated control. For ease of handling, the acetates were bulked with fine dry sand and applied three times (4, 8 and 12 MAP) to individual bushes to coincide with the fertilizer applications.

Beginning on the 10th MAP, 25 modified standard units (Sivapalan 1975) were collected from the primary branches of the tea bushes from each plot. In the laboratory each sampling unit was dissected and the number of each life stage of the borer was recorded. This was done bi-monthly until the 21st MAP.

The data were summarized and analyzed by ANOVA (percent of sampling units attacked) and chi-square (number of borers).

RESULTS AND DISCUSSION

Until 15 MAP, there was no significant difference among the percent of sampling units infested by the borer in the experimental plots. From 17 - 21 MAP, the percent of sampling units infested in the treated plots was significantly lower ($P < 0.05$) compared to that in the untreated control (Table 1). The lack of marked differences early in the pruning cycle may be due to the relatively low borer population. Wickremasinghe and Thirugnanasuntharan (1980) also observed low borer population until 19 MAP.

The difference between potassium acetate and zinc acetate treated plots was not consistent. This may indicate that the source of acetate was not very important.

TABLE 1

Percent[1] of borer-attacked sampling units at Imboolpitiya Estate, Sri Lanka - 1985/87.

Treatment	Months after pruning					
	10	13	15	17	19	21
Potassium Acetate						
0.5 g/bush	4.6	10.6	8.0	32.0	46.6	52.0
1.0 g/bush	2.6	6.6	24.0	24.0	46.6	56.0
1.5 g/bush	2.6	12.0	17.3	29.3	33.3	36.7
Zinc Acetate						
0.5 g/bush	1.3	2.6	21.3	45.3	54.6	54.7
1.0 g/bush	2.6	6.6	13.2	20.0	38.8	48.0
1.5 g/bush	4.0	4.0	25.3	26.6	49.3	41.3
Untreated						
Control	2.6	6.6	32.0	76.0	73.3	78.7

[1] Mean of three replicates each with 25 units.

Overall, the total borer population (all stages) found in the treated plots were significantly different (χ^2 = 165.37 with 30 df) from those in the untreated control (Table 2). But this trend was not shown consistently over the months. Thus the population of the pupae and adults (Table 3) were analyzed separately. Again there was an overall significant difference (χ^2 = 248.88 with 30 df) among the treated and untreated plots. Further analysis of the monthly counts indicated that the treated plots consistently had significantly lower pupal and adult population from 15 - 21 MAP. Wickremasinghe and Thirignanasuntharan (1980) observed a similar trend of pupal population up to 19 MAP. These observations are consistent with the view that acetates could reduce the shot-hole borer population by reducing the number of successful moults from larvae to pupae.

There was no significant difference in the number of pupae and adults between potassium acetate and zinc acetate treated plots. Neither were the differences among the different levels of acetates significantly different.

TABLE 2

Total number[1] of shot-hole borer (all life stages) at Imboolpitiya Estate, Nawalapitiya, 1985/87.

Months after pruning	Potassium acetate (g) 0.5	1.0	1.5	Zinc acetate (g) 0.5	1.0	1.5	Untreated control
10	00	19	10	10	00	03	02
13	19	15	05	03	06	14	05
15	07	23	27	44	04	52	45
17	20	26	24	34	29	14	140
19	37	42	16	59	28	71	88
21	73	71	48	64	53	55	117

[1]Total in 75 sampling units.

TABLE 3

Total number[a] of Xyleborus fornicatus pupae and adults at Imboolpitiya Estate, Nawalapitiya, 1985/87.

Months after pruning	Potassium acetate g/bush 0.5	1.0	1.5	Mean	Zinc acetate g/bush 0.5	1.0	1.5	Mean	Untreated control
10	00	05	02	2.33	05	00	03	2.67	02
13	07	08	03	6.00	02	03	05	3.33	02
15	04	10	14	9.33	21	04	19	14.67	25
17	18	18	20	18.67	32	20	11	21.00	105
19	17	19	14	16.67	51	17	32	33.33	42
21	24	27	16	22.33	30	31	21	27.33	43

[a]Number per 75 sampling units.

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REFERENCES

Calnaido, L. (1965). The flight and dispersal of shot-hole borer of tea (Xyleborus fornicatus Eichoff. Coleoptera: Scolytidae). Entomologia Experimentalis et Applicata 8: 249-262.

Cranham, J.E. (1966). Insect and mite pests of tea in Ceylon and their control. Monographs on Tea Production in Ceylon No. 6, Tea Research Institute, Talawakele. 122 p.

Gadd, C.H. (1941). The life history of shot-hole borer of tea. Tea Quarterly 14: 5-22.

Judenko, E. (1958). Trials with a method of assessment of infestations caused by shot-hole borer (Xyleborus fornicatus Eich.) on old tea. Tea Quarterly. 29: 51-59.

Matolosy, G.; Varjas, L.; Bordas, R. (1974). Assay of steroid inhibitors for insect anti-hormone activity. Acta Phytopathologica. Academy of Science, Hungary. 9: 161-166.

Sivapalan, P. (1977). Population dynamics of Xyleborus fornicatus Eichoff. (Coleoptera: Scolytidae) in relation to yield trends in tea. Bulletin of Entomological Research 67(2): 329-333.

Sivapalan, P. (1979). Integrated insect pest control: A Review. Proceedings of the Annual Sessions, Sri Lanka Association for the Advancement of Science. 35th Annual Sessions, Part II. 21-25.

Sivapalan, P.; Shivanandarajah, V. (1977). Inhibitory effects of extract from seeds and roots of tea, seeds of Sapindus emerginatus, Azasterols and nonsteroidal amines on the development of Xyleborus fornicatus in vitro. Entomologia Experimentalis et Applicata. 22: 274-279.

Wickremasinghe, R.L.; Perera, L.P.M.; Perera, K.P.W.C. (1978). α-spinasterol, temperature and moisture content as determining factors in the infestation of Camellia sinensis by Xyleborus fornicatus. Biochemical Systematics and Ecology. 4: 103-110.

Wickremasinghe, R.L.; Thirugnanasuntharam, K. (1980). Biochemical Approach to the control of Xyleborus fornicatus (Coleoptera: Scolytidae). Plant and Soil 55: 9-15.

A PRELIMINARY FORECASTING SYSTEM FOR CARROT FLY IN THE UK

R.H. COLLIER & S. FINCH

AFRC Institute of Horticultural Research, Wellesbourne, Warwick CV35 9EF

ABSTRACT

The times of peak carrot fly activity in the UK vary by as much as a month from region-to-region and year-to-year. A preliminary method for forecasting carrot fly attacks, based on accumulated temperatures, has been developed to improve the timing of mid-season insecticide treatments against this pest. The forecast is based on data from traps monitoring fly activity under field conditions and accumulated soil day-degrees. In 1988, forecast and observed dates of the peaks of first and second generation carrot fly activity at Wellesbourne were 16 May & 19 May and 23 August & 26 August, respectively.

INTRODUCTION

Most carrot crops in the UK are vulnerable to attack by the carrot fly (Psila rosae). Although it is possible to avoid at least one generation of the fly by sowing crops late or harvesting them early, most early-sown carrot crops can be protected against attack by the first generation in May only by applying an insecticide to the seed or to the soil at drilling (Anon., 1983). These treatments are likely to be sufficient for crops harvested before September but crops to be harvested later, and thus to be exposed to attack by the second generation of carrot fly in August/September are likely to require supplementary mid-season spray treatments. Accurate timing of these treatments is essential for them to be effective.

The timing of peak activity by the first and second generations of carrot fly may vary by several weeks from year-to-year and from region-to-region (Esbjerg et al, 1988) and therefore 'calendar spraying' can fail to protect some crops adequately.

Activity of the cabbage root fly (Delia radicum) has been related to weather data, particularly the temperature (Finch & Collier, 1986), enabling emergence and the onset of the pest's activity to be forecast accurately. A project commenced in 1987 to develop a similar system for forecasting accurately carrot fly activity throughout the UK and thus to achieve more efficient use of insecticides against the pest and reduce environmental hazards of insecticide usage on crops susceptible to this pest. A preliminary forecast system is described in this paper.

MATERIALS AND METHODS

Monitoring carrot fly activity

The activity of adult carrot flies on carrots at Wellesbourne was monitored in 1981, 1982, 1983, 1986 and 1987. Marigold yellow water traps (15 cm diameter, 6 cm high) (Finch & Skinner, 1974) were sited in crops

near to areas infested with carrot fly in the previous year and part-filled with a solution of 20 ml Teepol (R)/l water. The traps were emptied and the carrot flies counted and sexed three times each week. Results were based on the mean catch from 4-6 traps.

The activity of carrot flies in carrot crops in south-west Lancashire and the Fens of East Anglia was monitored in 1987 using three methods: traps were either metal cylinders covered with clear acetate sheet to which Tanglefoot (R) had been applied, Dutch 'windmills' consisting of 4 petri dishes coated with Tanglefoot (Den Ouden & Theunissen, 1988) or the standard water traps described above. All traps were painted Marigold yellow and the catches were examined at least weekly.

Recording accumulated temperatures

Most insects develop at rates related directly to the prevailing temperatures (Sharpe & DeMichelle, 1977) and require an almost constant number of thermal units, now commonly called day-degrees (D°) (Baker, 1980), to develop from the egg to the adult stage or from the peak of one generation to the peak of the next.

In 1980-1988, accumulated day-degrees above a base of $6^{\circ}C$ were measured continuously throughout the year at Wellesbourne using temperature integrators (Edale, Cambridge Ltd; IHR-Wellesbourne) (Finch & Collier, 1988) of which the probes were buried 6 cm beneath the soil surface, a depth consistent with that at which carrot fly larvae often feed and pupate. Accumulated day-degrees were recorded daily at 09.00 h GMT each year.

RESULTS

Carrot fly completed two generations at all sites monitored and occasionally there was a small third generation late in the autumn. Figure 1 shows the pattern of activity of the carrot fly population at Wellesbourne in 1987, the year when activity was monitored in all 3 regions. Peaks of activity occurred during May and August whilst few flies were caught before the beginning of May or during mid-June to mid-July.

The peak of carrot fly activity was taken as the time when 50% of the total flies in each generation had been captured. At Wellesbourne in 1987 the peak of first generation activity occurred on 15 May and the peak of second generation activity on 7 August. In the same year, the peak of first generation activity in the Fens was on 24 May and in Lancashire on 17 June. Peak second generation activity occurred on 15 August in the Fens and 22 September in Lancashire. In 1987, activity at Wellesbourne was about one week earlier than at the sites monitored in the Fens and more than four weeks earlier than at the Lancashire sites. The first and second generations in each locality were separated by approximately 3 months.

Over the 5 year's monitoring at Wellesbourne the peak of first generation activity occurred as early as 14 May and as late as 30 May and second generation activity peaked between 7-28 August.

Development of the preliminary forecast

Table 1 gives the times of peak first and second generation carrot fly activity at Wellesbourne from 1981-87 and the accumulated day-degrees (base 6°C) from 1 February each year to the peak of activity. Peak first generation activity occurred after a mean of 288±17 day-degrees and second generation activity after 1350±71 day-degrees. The start of carrot fly activity (approximately 10% of the total) was also estimated for each generation in each year and was approximately 170 and 1035 day-degrees for the first and second generations respectively.

TABLE 1

Date and number of soil day-degrees accumulated above 6°C for the two peaks of carrot fly activity at Wellesbourne during 5 years between 1981 and 1987.

Year	First generation peak		Second generation peak	
	Calendar date	Accumulated day-degrees from 1 Feb	Calendar date	Accumulated day-degrees from 1 Feb
1981	18 May	277	11 Aug	1236
1982	14 May	272	13 Aug	1395
1983	27 May	263	26 Aug	1527
1986	30 May	355	28 Aug	1451
1987	15 May	275	7 Aug	1141
Mean ± S.E.		288±17		1350±71

The mean numbers of accumulated day-degrees to the start and peak of activity from 1981-1987 were used to develop the provisional forecast for Wellesbourne shown in Figure 2 for 1988. The forecast shows accumulated day-degrees during 1988 (updated weekly as continuous line) compared to the 8-year average and the warmest and coolest years (dashed lines). Horizontal lines represent the mean thermal requirements for the start and peak of activity in each carrot fly generation (170 and 288 and 1035 and 1350 day-degrees respectively for the first and second generations). The point where the accumulated day-degree line intersects the horizontal lines indicates when a particular stage has been reached in the life-cycle of the fly in the current year. Several weeks before the start of activity, the slope of the line for the current year, relative to the mean line, gives advance warning of the time at which carrot fly activity is likely to occur.

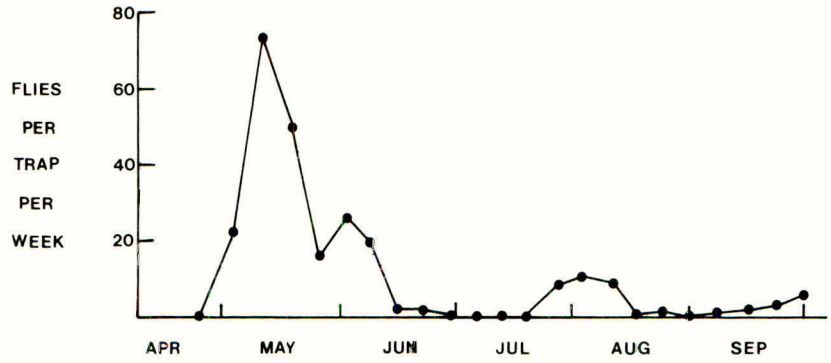

Fig. 1. The numbers of carrot flies trapped at Wellesbourne in 1987.

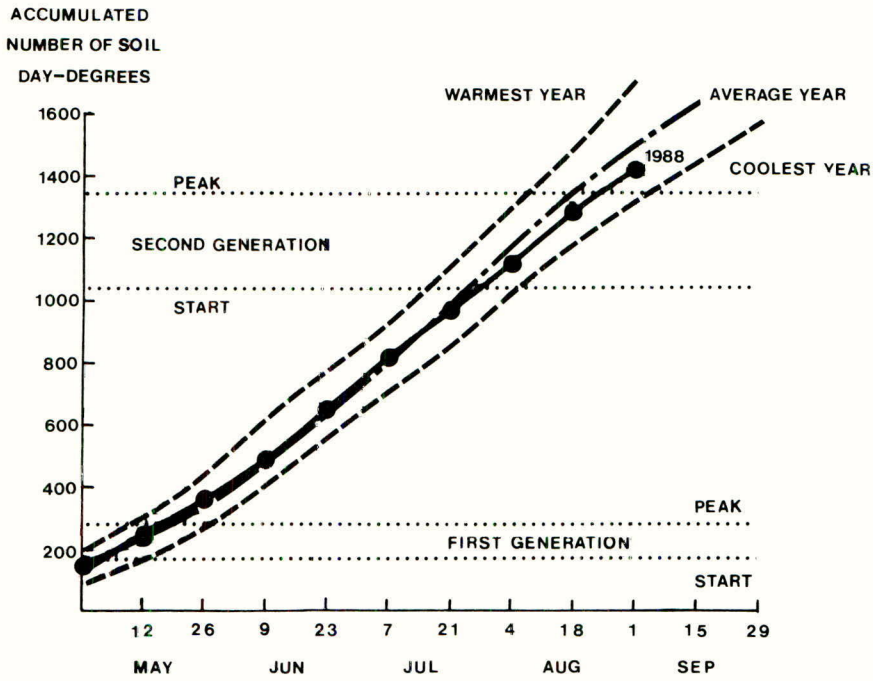

Fig. 2. Forecast of carrot fly activity at Wellesbourne in 1988.

DISCUSSION

The preliminary carrot fly forecast is based on the average thermal requirement for each generation estimated from 5 years' monitoring data. The variation about the mean, ±17 D^{o} for the first generation, ±71 for the second, represents a standard error of approximately 3 and 6 days respectively, the weather in May being generally cooler than in August. As the forecast is based on the activity of the flies in previous years, its accuracy can be checked only by testing how much the observed and predicted activity differ from one another in the current year. In 1988 the first generation peak occurred on 19 May and the second generation on 26 August; the predicted dates were 16 May and 23 August.

A base temperature of 6°C was used for day-degree accumulations in the preliminary forecast as this was the base used regularly for forecasting cabbage root fly activity (Finch & Collier, 1988). However, this base is probably too high for carrot fly as studies in North America indicate bases of 1 - 4°C for egg to pupal development in carrot fly (Stevenson, 1981a; McLeod *et al*, 1985). Work is currently in progress at Wellesbourne to determine the appropriate base temperature for day-degree accumulations for carrot fly in the UK.

Apart from temperature, factors including the pattern of post-winter emergence, aestivation during hot summers and the effect of daylength on diapause induction are also likely to influence the times of peak activity in any particular year and locality (Finch & Collier, 1988). On these occasions the rate of carrot fly development may no longer be directly proportional to temperature and a simple day-degree model may be inappropriate. In addition, there may be genetic differences in the rate of development of populations from different localities (Finch & Collier, 1983). Therefore it is essential to gather information on carrot flies from as many regions as possible. Studies are now under way to incorporate these factors into a more comprehensive forecasting model, produced independently of monitoring data. This model can then be tested against past records of carrot fly activity from as many sites as possible. A regionalised forecast of carrot fly activity would enable growers to time mid-season insecticide treatments on carrot crops more accurately and optimise insecticide performance. The forecast would also indicate those periods when sprays are unnecessary.

The initial forecast of the timing of carrot fly activity may lead to more sophisticated use of carrot fly monitoring to provide spraying thresholds for individual fields. Such thresholds have been used in Canada (Stevenson, 1981b) and Switzerland (Freuler *et al*., 1982) and are being developed in Denmark (Esbjerg *et al*., 1988) and the Netherlands (Den Ouden & Theunissen, 1988). The thresholds are determined by the efficiency of the trapping system as well as by the size of the insect population and decision to spray is based on the mean numbers of insects captured per trap. The economic thresholds used currently in Canada, Switzerland, Denmark and the Netherlands are based only on the presence or absence of flies; their refinement would further reduce the amounts of insecticides applied ineffectively to carrot crops.

ACKNOWLEDGEMENTS

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REFERENCES

Anon. (1983). Carrot fly. MAFF Leaflet 68. 12pp.

Baker, C.R.B. (1980). Some problems in using meteorological data to forecast the timing of insect life cycles. European Plant Protection Organisation Bulletin 10, 83-91.

Den Ouden, H. & Theunissen, J. (1988). Monitoring populations of the carrot rust fly, Psila rosae, for supervised control. Integrated Control in Field Vegetable Crops. IOBC/WPRS Bulletin/X1/1. pp. 26-32.

Esbjerg, P., Philipsen, H. & Percy-Smith, A. (1988). The significance of carrot fly (Psila rosae) monitoring in Denmark. Integrated Control in Field Vegetable Crops. IOBC/WPRS Bulletin/X1/1. pp. 14-25.

Finch, S. & Collier, R.H. (1983). Emergence of flies from overwintering populations of cabbage root fly pupae. Ecological Entomology, 8, 29-36.

Finch, S. & Collier, R.H. (1986). Forecasting the times of attack of the cabbage root fly (Delia radicum) on vegetable brassica. Aspects of Applied Biology 12 Crop Protection in Vegetables pp.37-46.

Finch, S. & Collier, R.H. (1988) Monitoring and forecasting atttacks of cabbage root fly and carrot fly in vegetable crops. Acta Horticulturae 219, 39-45.

Finch, S. & Skinner, G. (1974). Some factors affecting the efficiency of water traps for capturing cabbage root flies. Annals of Applied Biology 77, 213-226.

Freuler, J., Fischer, S. & Bertuchoz, P. (1982). La mouche de la carotte, Psila rosae Fab. (Diptera: Psilidae). II Mise au point d'un piege. Revue Suisse de Viticulture, Arboriculture and Horiculture 14, 137-142.

McLeod, D.G.R., Whistlecraft, J.W. & Harris, C.R. (1985). An improved rearing procedure for the carrot rust fly (Diptera: Psilidae) with observations on life history and conditions controlling diapause induction and termination. Canadian Entomologist 117, 1017-1024.

Sharpe, P.J.H. & DeMichelle, D.W. (1977). Reaction kinetics of poikilotherm development. Journal of Theoretical Biology 64, 649-670.

Stevenson, A.B. (1981a). Development of the carrot rust fly, Psila rosae (Diptera: Psilidae) relative to temperature in the laboratory. Canadian Entomologist 113, 569-574.

Stevenson, A.B. (1981b). Carrot rust fly: monitoring adults to determine whether to apply insecticides. Journal of Economic Entomology 74, 54-57.

NATURALLY-OCCURRING DETERRENTS TO CABBAGE ROOT FLY EGG-LAYING

S. FINCH and T.H. JONES*

AFRC Institute of Horticultural Research, Wellesbourne, Warwick, CV35 9EF.

ABSTRACT

The cabbage root fly, Delia radicum, was deterred from laying eggs alongside cauliflower plants by spraying the plants with suspensions of frass from caterpillars of the garden pebble moth, Evergestis forficalis. The deterrent chemical in the frass was isolated and identified as sinapic (3,5-dimethoxy-4-hydroxycinnamic) acid. D. radicum was also deterred from laying eggs on plants infested by the cabbage aphid, Brevicoryne brassicae. Physical disturbance of the fly by the aphid appeared to be the major factor responsible for this effect. D. radicum was deterred from laying eggs alongside cauliflower plants on which the diamond-back moth, Plutella xylostella, had laid eggs irrespective of whether or not the eggs remained on the plants while the flies laid their eggs.

INTRODUCTION

The presence of one pest insect species on a plant may influence whether another will select and successfully colonise that plant (Finch & Jones, 1987). Host-plant selection by the cabbage root fly, Delia radicum, is altered when plants are already colonised by some other insects (Finch, 1983). This paper identifies mechanisms by which D. radicum is deterred from laying eggs on brassica plants colonised by some other insect species.

MATERIAL AND METHODS

Plants

Cauliflower plants were grown from seed in 7.5 cm diam. pots containing John Innes compost. They were used for experiments 8 - 10 weeks after sowing.

Insects

The cabbage aphid, Brevicoryne brassicae, the garden pebble moth, Evergestis forficalis, the diamond back moth, Plutella xylostella and D. radicum were reared in the laboratory in rooms maintained at 20±1°C and 65±5% r.h. and illuminated by fluorescent tubes for 18 h/day.

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* Present address: Department of Pure and Applied Biology, Imperial College at Silwood Park, Ascot, Berkshire, SL5 7PY

Experiment procedures

The laboratory experiments used a test chamber consisting of three 65 cm x 65 cm x 45 cm high cages arranged one above the other (Ellis & Hardman, 1975). Female cabbage root flies were released into each cage and allowed to lay eggs for 1 day. The eggs on each plant were then recovered and counted. Each experiment was repeated three times and the variance of the transformed data ($\log_e$ numbers of eggs per plant) was analysed.

In the field experiments, cabbage root flies were released into 6 m x 3 m x 2 m high cages covered in Tygan (R) (10 mesh/cm) (Finch, 1971). Each experiment was repeated simultaneously in three cages. D. radicum eggs recovered from the soil around each plant two days after the flies were released were counted and these data were analysed statistically as described above.

Interactions between D. radicum and E. forficalis caterpillars

Caterpillar frass was collected by placing clean filter papers beneath foliage on which the caterpillars were feeding. Suspensions for spraying on test plants were made by stirring 1 g frass, or 1 g macerated leaf tissue, into 50 ml distilled water and then adding two drops of Savona (R), a wetting agent. Test plants in the laboratory experiments were sprayed with 4 ml distilled water ("check"), frass suspension, or macerated leaf material. In the field experiments, treatments comprised 8 ml applications.

The compound in the frass of E. forficalis caterpillars that deterred D. radicum from laying eggs was identified by combined gas chromatography/mass spectrometry, using an AEI MS 902 mass spectrometer, as sinapic (3,5-dimethoxy-4-hydroxycinnamic) acid (Jones, Cole & Finch, 1988). To determine whether the deterrent effect resulted from a chemical moiety or directly from the acidity of the sinapic acid solution, sinapic acid obtained from a commercial source (Fluorochem Ltd.) was buffered, in aqueous solution, to pH 7.2 with an equimolar solution of Na_2HPO_4/NaH_2PO_4. Concentrations of unbuffered and buffered acid solutions, ranging from 0.001 mM to 20 mM on a log-dilution scale, were tested for their effect on egg-laying by D. radicum.

Interactions between D. radicum and Brevicoryne brassicae populations

"Clean", aphid-free plants, plants infested with B. brassicae and plants from which living aphids were removed immediately prior to testing were compared for their effects on egg-laying by D. radicum.

To test whether aphid alarm pheromone was involved in the response of probing flies to the presence of aphids, a preparation of the trans-specific aphid alarm pheromone (44% (E)-B-farnesene, 26% (Z)-B-farnesene) (Edwards et al., 1973) was mixed with distilled water to produce test solutions containing 0.02 - 32 mg pheromone/ml. The numbers of D. radicum eggs eggs laid on cauliflower plants sprayed with 4 ml of one of the alarm pheromone solutions ("treated") or 4 ml distilled water ("check") were compared.

The behaviour of D. radicum was observed on six-leaved cauliflower plants on which three leaves had been enclosed in plastic bags while the

others were "inoculated" with B. brassicae adults. The plants were then left for one week, sufficient time for the aphids to colonise the infested leaves, before the plastic bags were removed, leaving each test plant with the same numbers of aphid-infested and 'clean' leaves. One gravid D. radicum that had not previously laid eggs was released into a small cage containing a test plant and the movements of the fly on the leaves were recorded until it left the plant. Forty flies were observed in this manner.

Interactions between D. radicum and P. xylostella

D. radicum females were offered "clean", uninfested plants or plants on which 30-40 P. xylostella eggs had been laid and remained or plants from which eggs had been removed.

RESULTS

Approximately three times as many D. radicum eggs were laid on the untreated "check" plants as on plants sprayed with suspensions of frass from caterpillars of E. forficalis (Table 1). The chemical responsible for this deterrent effect was isolated from the aqueous fraction of the frass and identified as sinapic acid. Spraying plants with a macerate of cauliflower leaves had the reverse effect, egg-laying by D. radicum being stimulated by this treatment.

TABLE 1

Egg-laying in laboratory and field experiments by D. radicum on cauliflower plants sprayed with 4 ml of macerated leaf tissue or suspension of frass from E. forficalis caterpillars. n = numbers of plants used for each treatment.

Site/treatment	Mean numbers of D. radicum eggs/plant	
	untreated "check"	treated
Laboratory (n = 10)		
Leaf macerate	50	142*
Frass suspension	123	38*
Field (n = 24)		
Frass suspension	33	10*

*Significantly different from 'check' (P = 0.05)

D. radicum egg-laying was reduced on cauliflower plants sprayed with an aqueous solution of 20 mM sinapic acid but not by lower concentrations. However, when the sinapic acid solutions were buffered, egg-laying was deterred by 0.1, 1.0 and 10 mM solutions (Table 2). Spraying cauliflower

plants in field cages with buffered 10 mM sinapic acid solutions deterred D. radicum egg-laying for 5 days compared to only 2 days with the frass suspension (Jones, Cole & Finch 1988 - in press).

TABLE 2

Egg-laying by D. radicum on cauliflower plants (n = 15) sprayed with (a) 4 ml sinapic acid solution or (b) a mixture of 2 ml sinapic acid + 2 ml phosphate buffer.

(a)

Acid concentration (mM)	Mean nos. eggs (±s.e.) recovered per plant: Water "check"	Acid "test"
0.002	83 (13)	106 (10)
0.02	85 (10)	65 (9)
0.2	54 (6)	46 (6)
2	73 (15)	68 (4)**
20	99 (16)	40 (7)

(b)

Acid concentration (mM)	Mean nos. eggs (±s.e.) recovered per plant: Water "check"	Acid "test"
0.001	94 (5)	99 (10)
0.01	82 (7)	96 (7)***
0.1	99 (7)	38 (3)***
1	130 (17)	46 (5)***
10	97 (7)	22 (4)

Significantly less than check ** ($P = 0.01$); *** ($P = 0.001$)

The numbers of eggs laid by D. radicum on cauliflower plants were reduced by c. 60% when each plant was infested with approximately 120 B. brassicae. Infestations of 30 aphids/plant did not affect egg-laying by the flies (Table 3). When the aphids were removed from cauliflower plants infested with 30 or 120 aphids and the flies were presented with the de-infested plants contaminated with honeydew and other aphid waste products, D. radicum laid more eggs than on the clean "check" plants.

TABLE 3

Mean numbers of D. radicum eggs laid on cauliflower plants a) infested with aphids or b) previously infested with aphids.

	No. D. radicum eggs laid/plant: 'check'	'treated' 30 aphids	'treated' 120 aphids
a) Aphids present	133	131	50*
b) Aphids removed	51	128*	144*

Significantly different from check *($P = 0.05$)

In experiments with the trans-specific alarm pheromone, only concentrations of 32 mg pheromone/plant deterred D. radicum from laying eggs.

D. radicum females spent approximately 10 times as long probing clean, aphid-free leaves than leaves infested with B. brassicae. Although initial leaf selection appeared to be at random, D. radicum females showed a marked tendency to fly from leaves infested with aphids. Only the females that completed their period of probing on clean, aphid-free leaves moved down the plant stem and laid eggs in the soil.

Fewer D. radicum eggs were recovered from cauliflower plants on which P. xylostella had already laid eggs, irrespective of whether the eggs were present throughout or were removed immediately prior to egg-laying (Table 4).

TABLE 4

Egg-laying by D. radicum on plants infested with 30-40 P. xylostella eggs

P. xylostella eggs	Mean nos. D. radicum eggs laid/plant	
	"Clean" plants	Infested plants
Present during experiment	97	56 *
Absent during experiment	99	59 *

Significantly different from check * (P = 0.05)

DISCUSSION

D. radicum females use their labellum and tarsal receptors to examine thoroughly the surface of the foliage of potential host plants before laying their eggs, generally in the soil next to the stem (De Wilde, 1947). The deterrent effect of sinapic acid, present in the frass of E. forficalis caterpillars after the metabolism of sinapoyl precursors in cruciferous foliage, is probably mediated through contact rather than olfactory receptors (Jones, Cole & Finch, 1988).

Although D. radicum was deterred from laying eggs on cauliflower plants infested with large colonies of B. brassicae, the flies were stimulated to lay more eggs on plants from which living aphids had been removed. The increased egg-laying may have been caused by chemicals in honeydew and other aphid waste products attracting more females to the plants or arresting and stimulating them to lay eggs for longer periods (Hagen et al. 1976).

Only the highest concentration of aphid alarm pheromone tested

elicited a deterrent response. As only very small quantities of alarm pheromone can be detected in the cornicle secretions of B. brassicae (< 0.01 ng per insect) (Dawson et al. 1982), it seems unlikely that alarm pheromone is responsible for deterring cabbage root fly from laying eggs on aphid-infested plants. Physical disturbance of the fly by the aphid appears to be the most plausible explanation. Factors responsible for the deterrent effects of P. xylostella eggs on D. radicum egg-laying have not yet been identified.

Naturally-occurring chemical deterrents that influence insect behaviour have considerable potential for broadening the scope of pest control in an acceptable manner. However, before such chemicals can be used in practice they will first have to undergo rigorous tests to ensure they are relatively safe and environmentally-acceptable.

REFERENCES

Dawson, G.W.; Griffiths, D.C.; Pickett, J.A.; Smith, M.A.; Woodcock, C.M. (1982) Improved preparation of (E)- -farnesene and its activity with economically important aphids. Journal of Chemical Ecology 8, 1111-1117.

De Wilde, J. (1947) De koolvlieg en zijn bestrigjding. Mededelingen van den Tunibouw Voorlich-tings Dienst 45, 1-70.

Edwards, L.J.; Sidall, J.B.; Dunham, L.L.; Uden, P.; Kislow, C.J. (1973) Trans- -farnesene, alarm pheromone of the green peach aphid, Myzus persicae (Sulzer). Nature 241, 126-127.

Ellis, P.R.; Hardman, J.A. (1975) Laboratory methods for studying non-preference resistance to cabbage root fly in cruciferous crops. Annals of Applied Biology 79, 253-264.

Finch, S. (1971) The fecundity of the cabbage root fly Erioischia brassicae under field conditions. Entomologia experimentalis et applicata 14, 147-160.

Finch, S. (1983) Cabbage root fly - effects of other insects on oviposition. Report of the National Vegetable Research Station for 1982, 35-36.

Finch, S.; Jones, T.H. (1987) Interspecific competition during host-plant selection by insect pets of cruciferous crops. In: Insect- Plants. Proceedings of the 6th International Symposium on Insect-Plant Relationships, V. Labeyrie, G. Fabres, D. Lachaise (Eds). Dr W Junk Publishers, 85-90.

Hagen, K.S.; Greany, P.; Sawall, E.F.Jr; Tassan, G.R.L. (1976) Tryptophan in artificial honeydews as a source of an attractant for adult Chrysopa carnea. Environmental Entomology 5, 458-468.

Jones, T.H.; Cole, R.A.; Finch, S. (1988) A cabbage root fly oviposition deterrent in the frass of garden pebble moth caterpillars. Entomologia experimentalis et applicata (in press).

AN EVALUATION OF SUPERVISED SYSTEMS FOR APPLYING INSECTICIDE TREATMENTS TO CONTROL APHID AND FOLIAGE CATERPILLAR PESTS OF CABBAGE

P.R. ELLIS, J.A. HARDMAN

AFRC Institute of Horticultural Research, Wellesbourne, Warwick, CV35 9EF

M. HOMMES

Federal Biological Research Centre, Institute for Plant Protection in Horticulture, Messeweg 11-12, D3300 Braunschweig, F.R. Germany

R. DUNNE

An Foras Taluntais, Kinsealy Research Centre, Dublin 4, Ireland

S. FISCHER, J. FREULER

Station Federale de Recherches Agronomiques de Changins, Route de Duillier, CH-1260, Nyon, Switzerland

A. KAHRER

Bundesanstalt fur Pflanzenschutz, A-1020 Vienna, Austria

C. TERRETAZ

Station Agricole pour la Protection des Plantes, Sion, Switzerland

ABSTRACT

Simple damage thresholds, based on the percentage of plants infested by aphids and caterpillars were evaluated on cabbage in five European countries in 1985 and 1986. Pest control, based on the tested threshold values, was as efficient and reduced the amount of insecticides by 50% and the numbers of sprays by 25% in comparison with a routine spray programme. A sequential sampling scheme evaluated at Wellesbourne in 1987 was as efficient and gave similar reductions in treatments to those obtained with threshold values in the previous two years but reduced the time taken to monitor the crop. In all experiments, supervised systems maintained crop quality.

'Supervised pest control' is the term applied to methods of determining the need for insecticide treatments based on densities of pest infestations and condition of the crop. To provide farmers with systems of economically viable supervised control which ensure that crop quality is maintained, simple rapid and reliable methods must be developed to monitor the densities of pest populations.

Brassica crops in western Europe are attacked by several important foliage pests incuding the cabbage aphid, Brevicoryne brassicae, cabbage moth, Mamestra brassicae, small white butterfly, Pieris rapae, diamond-back moth, Plutella xylostella and garden pebble moth, Evergestis forficalis. A

collaborative project was initiated by the International Organisation for Biological Control (IOBC) Working Group on Integrated Plant Protection in Field Vegetables to study these six species on brassica crops in five countries in W. Europe, using the methods of supervised control devised by Theunissen (1984). A preliminary report on this project was published by Hommes et al. (1988); this paper summarises the results obtained in the first two years of the collaborative project and results from a complementary experiment at Wellesbourne in 1987.

MATERIALS AND METHODS

In 1985 and 1986 simple thresholds for cabbage aphid and caterpillars were investigated using at least three 200 m^2 plots of commercially-important cultivars of white cabbage at six institutes. The damage thresholds for aphids were:

1985: 10% infested plants for first two samples
5% infested plants for further samples until harvest
1986: 30% infested plants with small colonies or
6% infested plants with colonies comprising more than 100 aphids

and for caterpillars were:

1985 and 1986: 10% infested plants for first two samples
5% infested plants for further samples until harvest

In 1985 and 1986, each treatment regime was assigned to one plot at each site. The treatments included: untreated 'check' plots; plots receiving a 'routine treatment' comprising a combined tank-mix application of 75 g pirimicarb/ha (50% a.i. SG; Aphox; Plant Protection Ltd) to protect the crops against aphids plus 5 g deltamethrin/ha (2.5% a.i. EC; Decis; Hoechst) against caterpillars, applied in 600 ml water/ha using a knapsack sprayer every two weeks from two weeks after transplanting until the plots were harvested; and plots receiving a 'threshold treatment' comprising a pirimicarb + deltamethrin treatment similar to that described previously but applied only when threshold densities (see above) for the pest species were attained. Every two weeks from 14 days after transplanting until harvest, 5 plants at each of 10 observation centres sited at random within each plot were examined. The numbers of infested plants were recorded. At harvest, pest damage on 20 plants from each of five centres within each plot was recorded, together with the marketability of the cabbage. The damage classes used with aphids were: 1) Clean; no aphids or damage on wrapper leaves or head; 2) Aphids or damage only on wrapper leaves; 3) Aphids or damage on head; plant unmarketable. A similar classification was used for caterpillars.

Similar treatments were applied in 1987 but a sequential sampling scheme (Theunissen, 1988) was used to assess the insect infestations. Sampling began on a plant in a position selected from a table of random rows and columns. After recording pests and damage on the first plant, the observer moved across one row and either up or down a row according to whether the first plant was infested or not. Sampling and recording continued until a threshold line was crossed. If the upper line was crossed the decision was made to spray; if the lower line was crossed no spray was necessary. If clear decisions to spray or not had been reached, sampling was repeated at 2 week intervals until harvest. If more than 44 plants were examined without the lines being crossed, sampling was repeated one week later.

RESULTS

Cabbage aphid

In 1985, infestation levels in the threshold plots were less than the tolerance values of 10 and 5% only at the beginning and end of the season. The proportions of marketable heads in the routine and threshold plots were similar and the mean numbers of spray treatments were reduced from 6.5 to 4.5 (Table 1). In Austria, there was no difference between the yields of marketable heads in the untreated and the two sprayed plots. However, because aphid attack reduced the average weight of heads by 50% (Table 1), the application of insecticides was justified.

TABLE 1

Results of the collaborative field experiments on supervised control of cabbage aphid on cabbage in 1985 and 1986.

Country/Treatment	1985			1986		
	A / B	W	S	A / B	W	S
Austria						
untreated	100/ 1	830	-	96/ 1	-	-
routine	99/ 1	1520	8	100/ 0	-	8
threshold	100/ 1	1530	5	99/ 0	-	4
England						
untreated	98/43	-	-	99/18	-	-
routine	100/ 1	-	7	100/ 0	-	7
threshold	100/ 1	-	4	100/ 1	-	4
F.R. Germany						
untreated	78/72	-	-	11/10	-	-
routine	97/ 4	-	6	68/32	-	4
threshold	98/ 7	-	3	60/39	-	4
Ireland						
untreated	99/27	-	-	64/21	1503	-
routine	100/ 0	-	6	93/ 7	1556	5
threshold	97/ 2	-	3	79/16	1513	3
Switzerland						
untreated	17/13	-	-	100/ 0	257	-
routine	72/19	-	6	98/ 0	535	8
threshold	67/23	-	6	99/0	513	2
Switzerland						
untreated	57/24	-	-	100/22	1343	-
routine	86/15	-	6	100/ 7	1314	6
threshold	94/16	-	6	100/ 1	1486	3
Means						
untreated	75/30		-	78/12		-
routine	93/ 7		6.5	93/ 7		6.3
threshold	92/ 8		4.5	89/ 9		3.3

A = nos. marketable cabbage heads without damage
B = nos. cabbage heads with only slight damage
W = mean head weight (g)
S = nos. pirimicarb sprays/crop

An additional spray application was saved in 1986 compared with 1985 by using the higher threshold (Table 1). Discrimination of plants infested with small or large colonies of aphids was not practical because the percentage of infested plants with aphids alone exceeded the tolerance level of 30% when large colonies were taken into consideration.

The use of the sequential sampling scheme at Wellesbourne in 1987 reduced recording time from 90 min. to 65 min. except when the level of infestation was very close to the threshold value; at this level, recording times were very similar for both schemes. At Wellesbourne the infestation of aphids was similar to the two previous years but the numbers of sprays were only reduced from 7 to 5 (Table 2).

TABLE 2

Results of the supervised control experiment at Wellesbourne in 1987.

Treatment	Cabbage aphid		Cabbage caterpillars		Mean weight of heads (g)
	A/B	Nos. sprays	A/B	Nos. sprays	
Untreated	100/0	0	71/29	0	1213
Routine	100/0	7	98/2	7	1520
Threshold	100/0	5	100/0	3	1408

A = Total nos. marketable cabbage heads
B = Nos. unmarketable heads

Cabbage caterpillars

In contrast to the aphid attack, caterpillar infestations were slight in the 5 countries. The highest value on threshold plots in 1985 was 38% in Austria and in 1986 was 50% in Germany. At Wellesbourne in 1987 the infestation was higher than in the previous two years. The thresholds tested in 1985 and 1986 proved suitable for different infestation levels. The sampling plan worked efficiently on all occasions except when infestations were close to threshold values. The numbers of deltamethrin sprays were reduced in the threshold plots without decreasing the efficiency of the control measures (Table 3). Insecticide usage was reduced on average by 54% in 1985, 48% in 1986 and, at Wellesbourne by 57% in 1987, compared with routine spraying. There was no significant difference between the proportion of marketable cabbage heads from the threshold and routine plots.

Comparison of all treatments in the different experiments showed that fewer sprays were applied when they were used against either the aphids or caterpillars singly than when they were applied as mixtures against both groups of insects. Combined sprays were used in 54% and 43% of applications in 1985 and 1986 respectively and on 3 out of 5 occasions in 1987 at Wellesbourne.

Results showed that the numbers of spray applications in the

collaborative experiments, when based on threshold values, were reduced by 28% in 1985, 26% in 1986 and 29% in 1987 at Wellesbourne compared with routine sprays. The efficacy of the control measures was found to be satisfactory under the wide range of environments prevailing at the different sites.

TABLE 3

Results of the collaborative field experiments on supervised control of caterpillar pests of cabbage in 1985 and 1986.

Country/Treatment	1985			1986		
	A / B	W	S	A / B	W	S
Austria						
untreated	42/42	830	-	91/25		-
routine	95/81	1520	8	100/ 1		8
threshold	97/40	1530	5	100/ 5		4
England						
untreated	80/40		-	72/68		-
routine	99/ 1		7	100/ 1		7
threshold	99/11		4	100/ 2		5
F.R. Germany						
untreated	38/31		-	23/20		-
routine	100/ 0		6	98/ 9		4
threshold	97/ 2		3	94/22		3
Ireland						
untreated	85/70		-	100/62	1503	-
routine	100/39		6	100/10	1556	5
threshold	100/47		0	100/21	1513	1
Switzerland						
untreated	82/33		-	62/50	257	-
routine	99/ 1		6	100/ 0	535	8
threshold	99/ 5		3	99/ 1	513	4
Switzerland						
untreated	47/23		-	98/97	1343	-
routine	100/ 6		6	100/17	1314	6
threshold	92/ 4		3	100/33	1486	3
Means for six sites						
untreated	63/40		-	75/54		-
routine	98/21		6.5	99/ 8		6.3
threshold	95/16		3.0	99/16		3.3

Legend: see Table 1

DISCUSSION

In the UK, where foliage pests rarely attain epidemic proportions, the numbers of sprays applied to individual cabbage crops rarely exceed six and there is little margin for reduction. However the results of the collaborative experiments have shown that, where cabbage aphid numbers are

low, marketable yields may not be reduced even when a high percentage of plants have infested wrapper leaves. In addition, it has been shown that similar reductions in the numbers of sprays may be made in light (5.3 to 2.3) as in heavy (7.0 down to 5.0) years of infestation (Theunissen & Den Ouden 1985).

In order that supervised schemes are used by the vegetable-growing industry they must not be too complicated, particularly as pest control is only one facet of a complex programme of crop production. Several constraints on the uptake of these schemes have been discussed by Theunissen & Den Ouden (1988). The sampling plan used in 1987 appears complicated on first examination but in practice is relatively simple to use.

The risk of obtaining unmarketable cabbage as a result of pest attack is higher for caterpillars than for aphids. This view is supported by the numbers of aphids at Wellesbourne in 1987 which showed that infestations rarely exceeded 100 insects/plant and at these levels marketability was not impaired (Table 2). Adjustments to the sampling plan are needed to reduce the numbers of treatments as even on untreated plots all cabbage plants were marketable in 1987.

It is essential that the examination of a crop for pests must not take too long. Theunissen (1988) has made comparisons of sampling times in brassica crops and found that the 1.06 man-hours for an operator to examine a cabbage crop using the sequential sampling scheme at Wellesbourne in 1987 was commercially-acceptable. In the USA, a variable-intensity sampling scheme has been devised (Hoy et al, 1983) which is reported to be more efficient than sequential sampling schemes which risk the operator missing isolated pockets of infestation.

REFERENCES

Hommes, M.; Dunne, R.; Ellis, P.R.; Fischer, S.; Freuler, J.; Kahrer, A.; Terretaz, C. (1988) Testing damage thresholds for caterpillars and aphids on cabbage in five European countries - report on a collaborative project done in 1985 and 1986. In: Integrated Control in Field Vegetable Crops. IOBC/WPRS Bulletin/X1/1, pp. 118-126.

Hoy, C.W.; Jennison, C.; Shelton, A.M.: Andaloro, J.T. (1983) Variable-intensity sampling: a new technique for decision making in cabbage pest management. Journal of Economic Entomology 76, 139-143.

Theunissen, J. (1984) Supervised pest control in cabbage crops: theory and practice. Mitteilungen aus der Biologischen Bundesantalt fur Land-und Forstwirtschaft 218, 76-84.

Theunissen, J. (1988) Sequential sampling of insect pests in Brussels sprouts. In: Integrated Control in Field Vegetable Crops. IOBC/WPRS Bulletin/X1/1, pp. 111-117.

Theunissen, J.; Den Ouden, H. (1985) Tolerance levels for supervised control of insect pests in Brussels sprouts and white cabbage. Zeitschrift fur Angewandte Entomologie 100, 84-87.

Theunissen, J.; Den Ouden, H. (1988) Implementation of supervised control in commercial cabbage growing. In: Integrated Control in Field Vegetable Crops. IOBC/WPRS Bulletin/X1/1, pp. 127-131.

COMPARISON OF FOUR ADJUVANTS ON TOXICITY, ABSORPTION AND RESIDUAL ACTIVITY OF DIFLUBENZURON TO *SPODOPTERA LITTORALIS* (BOISD.)

M.F. EL SAIDY, M. AUDA, D. DEGHEELE

Laboratory of Zoology, Faculty of Agricultural Sciences, State University of Ghent, Coupure links 653, B-9000 Ghent, Belgium

ABSTRACT

Laboratory and greenhouse experiments were conducted to determine the effect of three spray oil type adjuvants coded A411F, A417 and A419 and one spreader-wetter coded A206 (Imperial Chemical Industries PLC). Their influence on the insecticidal activity of diflubenzuron (DFB) against larvae of *Spodoptera littoralis* (Boisd.) was evaluated. In laboratory assays, addition of 0.1% adjuvant to DFB resulted in a high synergism for A411F and A417. However, DFB was synergized to a slightly lower level with A419. On the other hand, A206 showed an antagonistic effect, when combined with DFB against the 3rd instar of *S. littoralis*. The effect of 0.3% adjuvant on the absorption of ^{14}C-DFB was investigated in the 4th instar. The absorption rate was significantly higher with the adjuvants, A411F performing best.
In greenhouse assays, the residual toxicity of DFB sprayed alone or together with 0.1% adjuvant on castor bean plants (*Ricinus communis* L.), was evaluated against the 3rd instar up to 9 days after treatment. Three adjuvants appeared promising: A411F, A417 and A419. Residual toxicity of DFB alone was strongly decreased after simulated rain, whereas the combination of DFB and adjuvant was equally good to that obtained under dry conditions, except for A206, which performed poorly under both conditions. These results indicate a possible role for adjuvants in enhancing insecticidal activity and so might have practical implications for the control of *S. littoralis*.

INTRODUCTION

The effectiveness of pesticide applications may be enhanced by inclusion of suitable adjuvants. A spray adjuvant may function as a wetting agent of treated plant foliage or of the pest itself. Wolfenbarger (1964) and Wolfenbarger *et al.* (1967) studied the effectiveness of surfactants plus an insecticide in field assays against various crop pests including bollworm, tobacco budworm, and a pink bollworm. They reported that, Triton^{R} and Tween^{R} adjuvants have shown direct toxicity to some caterpillars. Matteson & Taft (1964) found that surfactants enhanced the systemic activity of Zectron^{R} when used against the boll weevil. Butler (1974) showed that mortality enhancement is progressively decreased with decreasing adjuvant concentrations. The use of an oil-surfactant mixture as adjuvant enhanced the efficacy of insecticides against *Spodoptera littoralis* (Boisd.)(Degheele *et al.*, 1986 and El Saidy *et al.*, 1986, 1987). Neumann *et al.* (1987) indicated that a decrease of 50% in the active ingredient of diflubenzuron giving the same efficacy, is achieved when it is combined with an optimized level of an oil-surfactant blend to control orchard pests.

The aim of this study is to determine the effect of four potential adjuvants on toxicity, absorption and residual effectiveness of diflubenzuron (DFB) against the larvae of S. *littoralis*.

MATERIALS AND METHODS

Chemicals

^{14}C-diflubenzuron (DFB) uniformally radiolabelled in the aniline ring with a specific activity of 15 mci/g and unlabelled DFB (25% WP) were provided by Duphar B.V., The Netherlands. Four potential adjuvants ('Atplus'-type, Imperial Chemical Industries PLC) are designated by a code number as follows: A411F (mixture of nonphytotoxic paraffinic mineral oil with 17% surfactant 'Atplus' 300 F), A417 (mixture of nonphytotoxic paraffinic mineral oil with 5% surfactant 'Atplus' 100), A419 (mixture of 'Atplus' 411 F with 10% silicone surfactant) and one spreader-wetter coded A206 (alkoxylated alcohols mixed with volatile silicone).

Insects

S. *littoralis* larvae were reared on castor bean leaves (*Ricinus communis*) as described by Auda & Degheele (1985). All stages were kept at 23°C, 65% r.h., and a 16 h photoperiod; 3rd and 4th instars were used in the assays.

Laboratory assays

Synergism studies were carried out with castor bean leaves dipped in a series of different concentrations of the insecticide given alone or in combination with 0.1% adjuvant. Third instar larvae were exposed to treated leaves and mortality was recorded after 24 h. Five replicates of twenty larvae each were used, mortality being corrected according to Abbott's formula (1925). Mortality regression lines were established according to Finney (1952). Synergism ratios (SR) were computed by dividing the LC_{50} value of the insecticide applied alone by the LC_{50} value of the insecticide applied together with an adjuvant.

In an absorption experiment, groups of 10 4th instar larvae were treated individually by topical application with 0.15 µg ^{14}C-DFB given alone or together with 0.3% adjuvant in 0.5 µl of acetone to the thoracic dorsum and were placed in glass petri-dishes. At various time intervals during the subsequent 24 h, individual groups of 10 larvae each were taken and rinsed 3 successive times with acetone (1 ml) to remove the nonabsorbed insecticide. The corresponding petri-dishes were also rinsed with acetone. Acetone from washing and rinsing was pooled and evaporated under vacuum. Whole bodies of each group of acetone-rinsed larvae were then oxidized in a BMO (Biological Material Oxydizer, Harvey Instr. Corp., U.S.A.) equiped with a CO_2 trapping device. The combusted gases produced were trapped in 10 ml carbomax. The trap was washed twice with the cocktail solution (1:3, toluene:methanol) and added to the carbomax solution. Radioactivity was measured with a liquid scintillation counter Kontron^R. The data reported for absorption are for radioactivity inside the larvae. Three replicates of this experiment were carried out.

Greenhouse assays

The four adjuvants were screened for their influence on the residual toxicity of 0.003% DFB against 3rd instar larvae with and without simulated rain in the greenhouse. The evaluation technique of El Saidy *et al.* (1987) was used. Five replicates of this experiment were done.

RESULTS

Laboratory assays

No toxicity was observed when leaves were treated with the adjuvants. Also when the surfactant or the mineral oil was applied separately with DFB, no noticeable increase in insecticidal activity was observed. Addition of 0.1% adjuvant to DFB resulted in a significantly reduced LC_{50} value for A411F, A417 and A419 and thus indicating a high synergism ratio of 2.41 and 2.16 for A411F and A417 respectively (Table 1). A206 showed an antagonistic effect.

TABLE 1

Synergism of diflubenzuron in combination with 0.1% adjuvant against 3rd-instar larvae of *S. littoralis*.

Compounds	Slope ± S.E.	LC_{50}, ppm (95% Fiducial limits)	Synergism ratio
Diflubenzuron(DFB)	3.60 ± 0.83	12.3(10.0-16.0)	-
DFB + A411F	2.52 ± 0.69	5.1(2.5-9.6)	2.41
DFB + A417	3.39 ± 0.87	5.7(3.5-9.3)	2.16
DFB + A419	3.92 ± 0.80	8.6(6.3-11.7)	1.43
DFB + A206	4.52 ± 1.41	15.1(12.5-18.3)	0.81

Each mortality curve consists of six concentrations. Data are averages of 5 replicates of 20 larvae each.

TABLE 2

Absorption of ^{14}C-DFB applied alone or together with 0.3% adjuvant in the 4th instar of *S. littoralis*

Time	% Absorption ^{14}C-DFB ± S.E.				
	DFB alone	DFB + 0.3%			
		A411F	A417	A419	A206
30 min	0.9±0.18	1.2±0.10	0.8±0.08	0.6±0.08	1.4±0.22
1 h	1.5±0.13	5.1±0.82	0.9±0.10	1.6±0.15	2.9±0.37
3 h	1.9±0.19	5.5±0.76	2.8±0.16	2.1±0.18	4.7±0.41
6 h	3.1±0.28	9.9±1.64	4.0±0.45	3.7±0.30	5.8±0.46
24 h	4.9±0.57	15.6±1.49	7.4±1.17	7.2±0.83	9.6±1.09

Data are averages of 3 replicates of 10 larvae each.

Table 2 gives the rate of ^{14}C-DFB absorption applied alone or together with 0.3% adjuvant in 4th-instar larvae of S. *littoralis* at various time intervals following topical application. In general, all adjuvants significantly increased the absorption of DFB; A411F being the best, followed by A206 and A417 and A419.

Greenhouse assays

The residual toxicity of DFB, sprayed alone or in combination with 0.1% adjuvant at different time intervals against the 3rd instar is given in Fig. 1. Three adjuvants (A411F, A417 and A419) significantly enhanced toxicity and extended the residual activity of DFB as well. The combination with A206 was less effective than DFB alone. An increased toxicity and persistance has been stated with mineral oil adjuvants and an organophosphorous compound (El Saidy *et al.*, 1988) and pyrethroids (Ishaaya *et al.*, 1986).

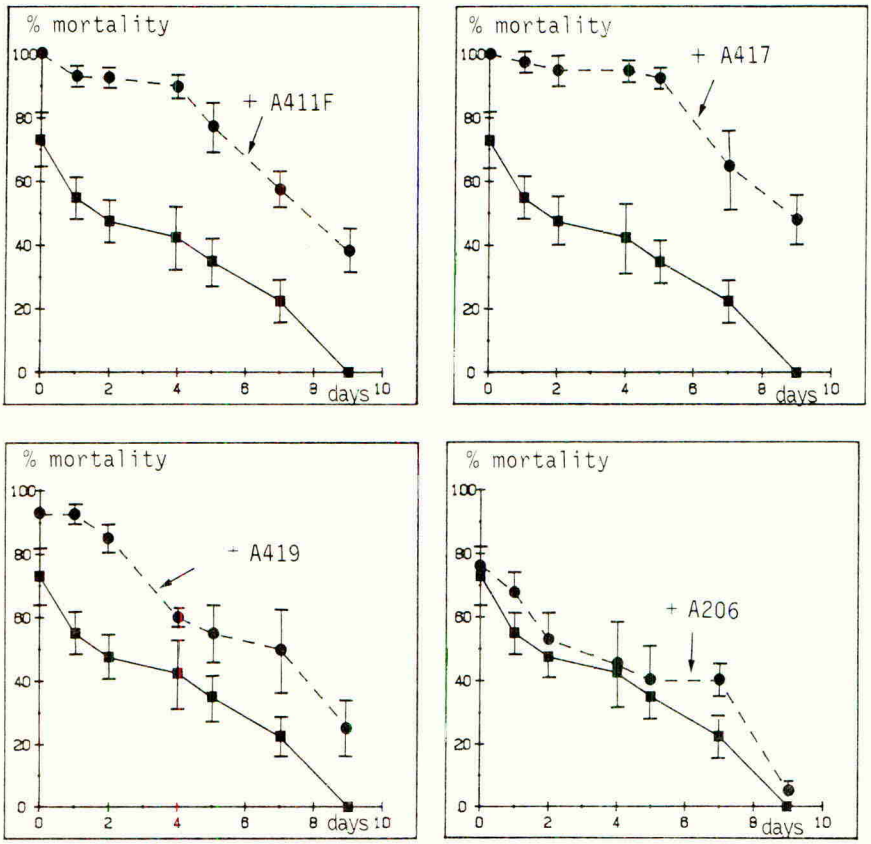

Fig. 1. Residual toxicity of 0.003% diflubenzuron applied alone (■——■) or together with 0.1% adjuvants (●- -●) at different intervals after spraying against 3rd-instar larvae of S. *littoralis*.

Simulated rain greatly reduced the toxicity and persistance of DFB to 3rd instar larvae (Fig. 2). Addition of 0.1% A411F, A417 and A419 to DFB spray tank solution significantly improved the rainfastness of the formulation and thereby, increased its toxicity and persistance against 3rd instar larvae of S. *littoralis*. On the other hand, A206 did not improve rainfastness nor persistance of DFB.

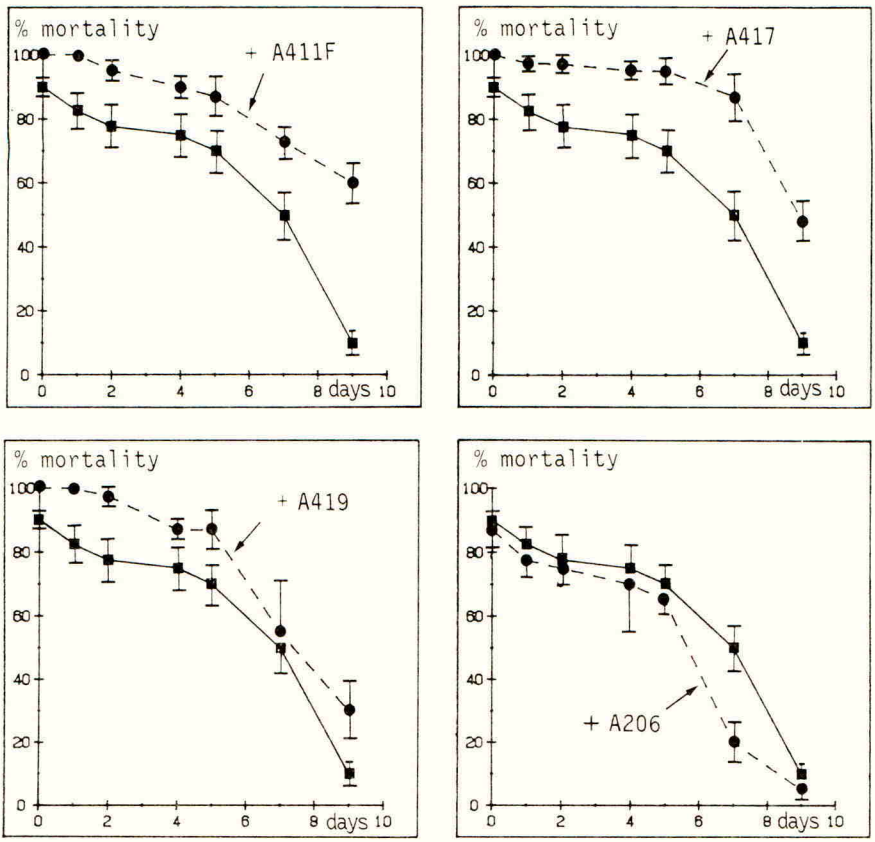

Fig. 2. Residual toxicity of 0.003% diflubenzuron applied alone (■——■) or together with 0.1% adjuvants (●- -●) at different intervals after simulated rain against 3rd-instar larvae of S. *littoralis*.

DISCUSSION

The results reported indicate that addition of adjuvants at optimized levels to DFB may have practical implications in controlling the Egyptian cotton leafworm S. *littoralis* and maybe other important agricultural pests. However these findings may not be transferred to other formulations and crops without additional field tests.

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REFERENCES

Abbott, W.S. (1925) A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18, 265-267.

Auda, M.; Degheele, D. (1985) Joint action of pyrethroids with chitin synthesis inhibitors, organophosphorous and carbamate insecticides on a suceptible and resistant strain of *Spodoptera littoralis*. Mededelingen Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent 50, 751-760.

Butler, L. (1974) Comparative study of adjuvants for increasing mortality of malathion-treated black carpet beetles. Journal of Economic Entomology 67, 571-573.

Degheele, D.; Auda, M.; El Saidy, M.F. (1986) Effect of some adjuvants on the toxicity of insecticides in L_3-larvae of a susceptible and resistant strain of *Spodoptera littoralis* (Boisd.). International Conference on Tropical Entomology, Nairobi, Abstract C89, 1p.

El Saidy, M.F.; Auda, M.; Degheele, D. (1986) Effectiveness of insecticide-adjuvant mixtures against susceptible and monocrotophos-resistant strains of *Spodoptera littoralis* in the laboratory. British Crop Protection Conference. Pests and Diseases 4, 639-644.

El Saidy, M.F.; Auda, M.; Degheele, D. (1987) Effects of adjuvants on penetration in and residual activity of monocrotophos and diflubenzuron on *Spodoptera littoralis* (Boisd.) larvae. Mededelingen Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent 52, 463-470.

El Saidy, M.F.; Auda, M.; Degheele, D. (1988) Laboratory and greenhouse bioassays of monocrotophos-adjuvant mixtures applied to larvae of *Spodoptera littoralis* (Boisd.). Mededelingen Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent 53, 759-764.

Finney, D.J. (1952) Probit Analysis. Cambridge University Press, Cambridge, 256 p.

Ishaaya, I.; Austerweil, M.; Frankel, H. (1986) Effect of the petroleum oil Virol on toxicity and chemical residue of fenpropathrin against adults of *Bemisia tabaci* (Homoptera: Aleyrodidae) as high- and low-volume sprays. Journal of Economic Entomology 75, 596-599.

Matteson, J.W.; Taft, H.M. (1964) The effect of various adjuvants on the systemic insecticidal activity of Phorate and Zectron. Journal of Economic Entomology 57, 325-326.

Neumann, G.L.; Sterk, G.; Paternotte, E. (1987) Use of oil-surfactant mixtures as adjuvants to diflubenzuron. Mededelingen Faculteit Landbouwwetenschappen, Rijksuniversiteit Gent 52, 471-475.

Wolfenbarger, D.A. (1964) The effect of insecticides, rates, intervals, between and number of applications and insecticide-oil and surfactant combinations for insect control of southernpeas. Journal of Economic Entomology 57, 766-769.

Wolfenbarger, D.A.; Lukefahr, M.J.; Lowry, W.L. (1967) Toxicity of surfactants and surfactant-insecticide combinations to the bollworm, tobacco budworm, and pink bollworm. Journal of Economic Entomology 60, 902-904.