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CONTRIBUTIONS TO THE MEETING AT
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'LUTTE INTEGREE EN CULTURES SOUS VERRE'

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PREFACE

The previous meeting of our working group in Budapest was only three years ago, and since then it has been a hectic time for those working on greenhouse biological control in western Europe. A number of new pest invasions have further complicated our lives: (a) *Frankliniella occidentalis* has definitely settled in Europe and is now causing very serious problems in cucumbers and ornamentals, (b) *Bemisia tabaci* seems to have become a permanent pest since 1987, and (c) *Liriomyza huidobrensis* arrived in 1989 and has given rise to critical situations in certain crops, particularly in lettuce. In addition, the efficacy of chemical control for the cotton aphid, *Aphis gossypii*, is decreasing and a biological control solution is therefore needed. This bulletin reflects very well the changes in the pest situation: many articles deal with biological control of *Frankliniella* and *Bemisia*, several report over improvements in the biological control of *Aphis gossypii* and *Myzys persicae*. The largest group of natural enemies under study is that against *Frankliniella*: predatory mites and insects, parasites, pathogens, coloured sticky traps and odour attractants.

It is regularly stated that the use of biological results in an upsurge of new pests, but this is not true for the greenhouse situation. Here, all the new pests are not specific for glasshouses under IPM, but also form problems in conventional chemical control programmes. Due to creative and enthusiastic research contributions by working group members, we have been able to continue use of earlier developed integrated control programmes. Furthermore, new natural enemies have been included in the classical programmes involving *Phytoseiulus* and *Encarsia*, and the area under biological control has significantly increased. Most impressive is the increase in use of the predator *Aphidoletes aphidimyza*. An unexpected development which has stimulated the application of biological control is the use of bumble bees for pollination, especially in tomatoes. It is satisfying to be able to conclude that the use of biological control in greenhouses has not come to a stand still, but, on the contrary, is showing many new areas for application. One of the developments that will strongly stimulate a further increase is the present change to environmentally safer pest control policies by several countries. As working group members we can provide the environmentally friendliest control agents!

At our conference in Budapest, held together with colleagues from the EPRS working group, it was concluded that preparation of a Bulletin containing the workshop contributions before the actual meeting is held was very effective. In this way the number of formal presentations could be reduced to a minimum, and most of the time at the workshop was used to discuss the already published material. Sufficient time remained for the development of cooperative research programmes and determine lines of research for the future. The result of this procedure is that you receive this Bulletin several weeks before we shall convene in Copenhagen.

I am very thankful to the management of the Research Centre for Plant Protection of the Danish Research Service for Plant and Soil Service, which allowed H. Brødsgaard, A. Enkegaard and J. Jakobsen to organize this meeting. Also, I would like to thank E.M. Bentsen who typed the articles. Our Danish colleagues have been very efficient in arranging the workshop and I am sure we will have a fruitful conference. Finally, I acknowledge the help of H. Brødsgaard and J. Bennison in editing the papers.

J.C. van Lenteren
convenor WPRS/IOBC Working Group
"Integrated Control in Glasshouses"
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EXPERIENCES WITH BIOLOGICAL CONTROL MEASURES IN GLASSHOUSES IN SOUTHWEST GERMANY

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Summary

In Baden-Württemberg about 33% of the glasshouse area with cucumbers, tomatoes, sweet peppers and aubergines are protected with beneficial organisms against noxious arthropods. The introduction of biological control methods into practice was supported by govermental fundings for the scientific supervision. The plant protection service and four advisors for biological control, who are employed by the grower's organisations since 1989 and partly financed by the government, cooperate in this field. Trials for the biological control in ornamentals started in poinsettias in 1987. More experiments, also in other cultures, were performed in 1988 and 1989 with partly very good results. In 1989 whitefly species (*Bemisia tabaci* and *Trialeurodes vaporariorum*) on poisettias were controlled on 3.4 ha in Baden-Württemberg. In 78% of the cultures the results were satisfactory to very good, in 22% sufficient to bad. The principles of biological control are up to now not completely understood by some poinsettia growers, i. e. early introduction of beneficials, monitoring of noxious animals and beneficials, hygienic measures and use of safe insecticides.

1. Introduction

Chemical control, especially in glasshouses with vegetables, has some disadvantages. Not only soil, water and air are endangered, but also the user and the consumer of the product. Pest species with a high level of resistance against pesticides, like *Frankliniella occidentalis, Bemisia tabaci* and *Trialeurodes vaporariorum*, are not easy to control chemically. The number of registered pesticides in the Federal Republic of Germany was reduced by more than 580 from 1988 to 1990 (Meinert, 1989). In this situation growers ask for alternative methods like biological control. Possibilities and limitations of biological control in Baden-Württemberg are discussed.

2. Biological pest control in vegetable cultures

Due to the activities of the plant protection service of Baden-Württemberg, the area on which beneficial arthropods are applied, has increased considerably over the last few years (fig. 1). In Baden-Württemberg cucumbers, tomatoes, sweet peppers, and aubergines are grown on 120 ha glasshouse area. Of this, more than 40 ha are protected with beneficial organisms. This is about 33%. The number of commercially available beneficial species has increased, too. Altogether, fourteen species are used in commercial and private glasshouses (tab.1). The *Aphidius* species and *Steinernema* species can be bought in Baden-Württemberg but their applicability for biocontrol is not yet known. Tab. 1 gives also an idea of the practical and experimental use of other antagonists in glasshouses but also in other agricultural cultures in Baden-Württemberg. In 95.6% of the cultures a satisfactory to very good control was achieved in 1988 (Albert et al., 1990). Since 1989 four advisors for biological control in glasshouses with vegetable cultures are employed, who are financed partly by the two grower's organisations and by the government. They should bring a further increase of the area with biocontrol in the future.

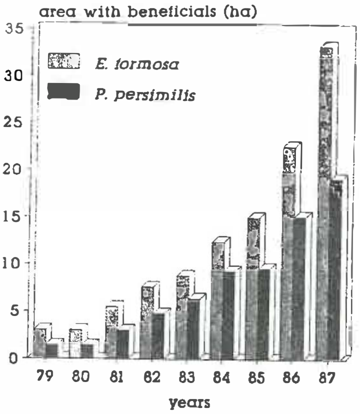

Fig. 1. Use of beneficial arthropods in Baden-Württemberg.

3. Biological pest control in ornamentals

Biological pest control in ornamentals is a field of growing interest (Sell, 1989). But up to now only a few students work in this field in Germany. Since 1987, several experiments were performed in ornamental plants in Baden-Württemberg. Because of problems with the chemical control of *B. tabaci* in poinsettias, we started experiments to control this species by introducing *E. formosa* in weekly intervals. Because of our experiences in cucumbers we introduced 5 *E. formosa* per m² at the beginning of the culture, later on 2.5 *E. formosa* per m2. In 1989, we found that an introduction rate on a per plant basis is easier to calculate and more convenient when the ratio has to be raised or lowered. As a common introduction rate we now suggest 1 *E. formosa* for five to ten plants. In our experiments *E. formosa* was not able to eliminate *B. tabaci* as can be the case with *T. vaporariorum*. But when *E. formosa* is introduced at weekly intervals, the number of infested plants can be kept at nearly the same level. If at the beginning of the culture in August about 15% of the cuttings were infested, we found nearly the same percentage of infested plants in December when the plants were sold (Albert und Schneller, 1989).

In 1989 one producer of beneficials sold *E. formosa* to 60 growers in West Germany, 36 of them living in Baden-Württemberg. These 60 growers were asked to fill in a questionnaire concerning their experiences with *E. formosa*. 37 growers answered the questionnaire. 78% qualified the result as very good to satisfactory. For 22% the results were just sufficient to bad.

Additional experiments were performed in other cultures (tab. 2). In most cultures the result of the biocontrol was good to very good, even with the control of *F. occidentalis*. But the results in Saintpaulia and Ageratum were not promising. Up to now, Saintpaulia is the ornamental plant with the highest loss because of *F. occidentalis* attack.

Tab. 1. Review of the methods of biological pest control with inundative release in Baden-Württemberg.
A: arable land, F: forest, FG: vegetables, G. vegetables in protected conditions, H: hobby, O: fruits, W: viniculture, Z: ornamentals in protected conditions.

Beneficials or pathogens	Noxious organisms
Methods in practical use	
Ichneumonid wasps:	
Trichogramma evanescens,	European corn borer A,G
T. dendrolimi	Tortricids O
Encarsia formosa	whiteflies G,Z,H
Diglyphus isaea, *Dacnusa sibirica*	leaf-miners Z,G
Predatory mites:	
Phytoseiulus persimilis	spider mites G,Z,H
Amblyseius cucumeris, Neoseiulus barkeri	*Thrips tabaci* G,Z *Frankliniella occidentalis* G
Gall midge:	
Aphidoletes aphidimyza	aphids G,H
Chrysopids:	
Chrysoperla carnea	aphids H
Nematod:	
Heterorhabditis spec.	*Otiorhynchus sulcatus* Z,H
Bacteria:	
Bacillus thuringiensis	diverse butterfly species F,G,O,Z,A,W,FG,H
Tested methods, not yet produced and/or registered	
Ichneumonid wasps:	
Trichogramma spec.	cabbage moth F
NGV (nuclear granulose virus)	Tortricidae O
Bacteria:	
Bacillus thuringiensis subsp. *tenebrionis*	Colorado beetle G,A
Insect pathogenic fungi:	
Verticillium lecanii	aphids, whiteflies, thrips, sciarid flies G
Metarhizium anisopliae (Bio 1020, Fa. Bayer AG)	*Otiorhynchus sulcatus* Z
Beauveria brongniartii	cockchafer species and other Scarabaeidae F,O,W
Methods in testing phase	
Ichneumonid wasps:*Aphidius spec.*	aphids (*Myzus persicae*) G,Z
Nematods:	
Steinernema spec.	Aegeriidae, Sciaridae O,G,Z
Other nematods	Tipulidae, Noctuidae FG,W,Z
Bacteria:	
Bacillus thuringiensis subsp. *israelensis*	Sciaridae Z,G
Eubacteria	root fungi FG,A
Antagonistic fungi:	
Verticillium lecanii	rust, aphids Z,A
Ampelomyzes quisqualis	powdery mildew G
Insect pathogenic fungi:	
Entomophthora spec.	aphids G,Z,FG
Aschersonia aleyrodis	whitefly species G,Z

Tab. 2. Experiments in biological plant protection in ornamental plants in Baden-Württemberg since 1989.
Control results: +++: very good, ++: good, +: satisfactory, -: insufficient, x: in use, ^{1}: higher dosage than the average

plant family	year 87	88	89	species of beneficials					supplementary methods yellow- cards	blue- cards	insec- ticidal soap
	number of cultures			*Amblyseius spp.*	*Encarsia formosa*	*Aphidoletes aphidimyza*	*Phytoseiulus persimilis*	*Verticillium lecanii*			
Euphorbia pulcherrima	1	4	8	++	+++			+	x	x	x
Fuchsia hybrids		2	4	+	+++	-			x	x	
Saintpaulia			1	-						x	
Brachycome			1	+	+++					x	
Geranium			1	+	-					x	
Dianthus			1	+			++			x	
Impatiens			1	++			++			x	
Lantana			1		+++					x	
Streptocarpus			1	++^{1}					x	x	
Ageratum			1	-	+				x	x	
Viola			1	+++^{1}						x	

4. Discussion

The use of biological control in vegetables is still increasing in Baden-Württemberg. Compared with Great Britain or the Netherlands the present application rate of 33% is still low. The employance of four ring advisors for biological pest control is thought to increase the acceptance of this method by the growers.

Biological control in ornamentals is a very promising field for research. As we have experienced in 1989, biological control is readily accepted by a number of ornamental growers, if not only strategies for the control of pest species are developed, but also for hygiene and pest monitoring as well as integration of chemical pesticides (Albert & Sautter 1989 and Albert & Schneller 1989). However, biological control is still new to most ornamental growers. Thus, some make mistakes with the integration of pesticides or do not completely understand the principles of biological control. These are an early introduction of beneficials, the regular monitoring of the beneficial and the noxious arthropod and a high standard of hygiene. Better education of growers could be an answer to this problem. Up to now biological pest control in ornamentals can be recommended only for poinsettias and fuchsias. But in this cultures the results with biocontrol can be better than pesticide use.

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MIRID BUGS - ANOTHER STRATEGY FOR IPM ON MEDITERRANEAN VEGETABLE CROPS?

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Summary

The use of classical natural enemies in Mediterranean protected vegetable crops has proved a useful beginning for IPM. Other entomophagous which may complement or even replace them should, however,be looked into. The purpose of this paper is to indicate how certain Mediterranean characteristics favour an alternative to classical IPM in greenhouse.

1. What features characterize the Spanish Mediterranean area?

a. Winter temperatures are mild and only very rarely fall bellow zero. This aids the survival of whitefly on different weeds, and crop contamination is easier and more frequent.

b. The cropping pattern in open field: fields are small (circa 1 Ha) and surrounded by weedy boundaries or are close to natural vegetation and other crops. Continuous cropping is carried out, with two crops per year. Several vegetable species are grown simultaneously - many of them are good whitefly (*Trialeurodes vaporariorum* (Westwood)) and/or leafminer (*Liriomyza* spp.) hosts: potato, tomato, french bean, courgette, eggplant and cucumber. As a result, pests are continually present, with carry-over and build-up taking place during the year.

c. Greenhouses: some of these vegetable crops are grown under plastic covers. The mediterranean greenhouse, however, is not isolated from the outside and, more significantly, affects it as well:

- Doors and side openings may not fit well. In order to avoid high temperature and humidity, they are normally opened daily. Thus, the spring crop is infected early by pests from weeds and/or surrounding crops. The greenhouse, in turn, serves as a very important focal point for whitefly and leafminers on summer crops if they are not controlled. On the other hand, the success of IPM in autumn protected crops is linked with control in open field during the summer. If this is not undertaken, the migration of whitefly into the greenhouse makes it impossible to control.
- Many plastic covers are permanent but in warmer regions of the Mediterranean they are frequently torn up before the crop finishes to aid ventilation. This extreme case clearly points to the difficulty of establishing limits between the greenhouse and outdoor crops.

2. What strategy has been used so far?

It can be seen from the above that any control strategy must consider both types of crops on an equal footing: (1) IPM in spring greenhouses using "classical" natural enemies like *Encarsia formosa* Gahan and *Diglyphus isaea* (Walker), to control pests and prevent their emigration to outdoor crops, and (2) IPM outdoors in order to reduce carry-over of pests between outdoor crops and crops in the greenhouse.

3. IPM in the greenhouse.

The use of "classical" natural enemies has proved a good beginning and the results have been positive (Gabarra et al. 1989). Three limitations need only be mentioned:

- If de-leafing unbalances the establishment of *Encarsia* in the north of Europe (Dunne 1987; Hansen 1987), its effects are even worse in the Mediterranean area, where natural enemies must be abundant in order to counter the sudden arrivals of whitefly adults. Commercial producers may not be able to economically supply all *Encarsia* needed. Would it not be better to employ mobile predators, which are not affected by this de-leafing practice?
- *Encarsia* does not respond rapidly to migrations from the outside. Would it not be better to use entomophagous insects with a better numerical response?
- Do the high temperatures and humidity rates in greenhouses in summer negatively affect *Encarsia*?.

4. What kind of control is there in outdoor crops? Are there effective natural enemies?

In tomato crops that are highly infested with whitefly, natural parasitism by *Encarsia tricolor* Förster is high, yet it appears incapable of controlling whitefly by itself. Nor has the release of *E. formosa* onto experimental plots proved effective. In addition, as soon as insecticide treatments stop, the activity of two predatory mirids that effectively control whitefly is possible (Gabarra et al., 1988), which hinders the activity of *Encarsia* spp.

Of the mirids encountered, the most abundant is *Dicyphus tamaninii* Wagner (Table 1). However, under certain conditions, *D. tamaninii* is also phytophagous, and damaged tomato fruit appears when it has controlled the whitefly populations. A decision-chart has been elaborated to keep a balance between both populations: if the mirid/whitefly ratio is too high, a chemical spray is used to reduce the population of this 'facultative predator' (*sensu* Wheeler, 1976). *Dicyphus errans* L. is uncommon, but it also attacks fruit (Malausa and Drescher, 1989). If it appears, it is included in the chart. The system has been applied with success by several growers for the last three years and has reduced the number of treatments by 75%.

Macrolophus caliginosus Wagner, which is not so abundant, is mostly a predator and does not appear to attack the fruit (Malausa and Drescher 1989). These mirids overwinter in field boundaries and in natural vegetation, where several plant species that harbour them have been found (Alomar and Goula, unpubl.). They can also be found on other crops together with few individuals of other mirids. The winter potato crop provides a refuge for up to 17 mirid species. These results indicate their possible importance on a regional level.

Table 1. Predator mirids found outdoors in the Mediterranean

	MC	DT	DE	CT
potato	+	+	+	+
tomato	+	+	+	+
eggplant	-	+	+	+
french bean	+	-	+	-
courgette	+	+	+	-
cumber	+	+	-	-

(MC: *M. caliginosus*; DT: *D. tamaninii*; DE: *D. errans*; CT: *Cyrtopeltis tenuis* Reuter; + found; -not found)

5. Can these entomophagous be used in the greenhouse?

Since the first tests carried out with *E. formosa*, the presence of these same mirids in IPM greenhouses in our area has been observed (Casadevall et al. 1979; Castañe et al. 1987). They have also been confirmed in greenhouses in other countries (Table 2). This is not surprising, given the continuity between greenhouse and outdoor crops mentioned earlier.

Table 2. Predatory mirids found in greenhouses in the Mediterranean.

	MC	DT	DE	CT
(1) Provence (France)	+	-	+	+
Catalonia (Spain)	+	+	+	-
(2) Sicily (Italy)	-	-	-	+
(3) Crete (Greece)	+	-	-	-

(1) Malausa and Drescher 1989; (2) Nucifora and Calabretta 1986; (3) Roditakis and Legakis 1989.
Abbreviations see above; + cited; - not cited

The ineffective predation outdoors logically indicates that they also form part of the control system inside the greenhouse. What remains to be determined is their exact role. Simultaneously, no damage has been observed in all these years. Additional advantages for their possible use are their polyphagy and mobility:

a. they control several pests, both in the laboratory and in the greenhouse (Fauvel et al., 1987; Malausa et al., 1987; Roditakis and Legakis 1989; Salamero et al., 1987).

b. being mobile, they are certainly not as affected by de-leafing and have a greater capacity of response to the sudden arrivals of pests. When the greenhouse crop ends, they can emigrate to fields, where their activity continues: the same greenhouse which before released whitefly, now releases entomophagous insects. *Encarsia* could also emigrate, but as has already been mentioned, the presence of the mirids does not permit its activity.

6. Conclusion.

The question here is not simply to discuss the functioning of *Encarsia sensu stricto*, but to see how an IPM programme in Mediterranean greenhouses aids pest control by favouring the activity of entomophagous insects from the exterior, such as *D.isaea* and these facultative predators. The same Mediterranean characteristics that favour the presence of pests, permit that of predators and parasitoids. If the arrival of beneficials is not predictable or insufficient, then they can be encouraged or introduced (thus, *D. isaea* is released in a few greenhouses despite the natural parasitism present in most).

7. Questions for discussion and future research:

- To what extent do mirids contribute to the control of whitefly in the greenhouse? Can they control whitefly on their own, without any need to introduce *Encarsia*?
- Are spontaneous colonizations enough? Can we have confidence in them? Or should beneficials be introduced from rearing units?
- Discuss the suitability and possibility of encouraging some of them selectively (for example, by favouring specific winter refuges).
- Does the proximity of weeds, natural vegetation and other crops play an important role in the colonization of the crop? Can entry be predicted? Can weeds be managed?
- Does the presence of prey stimulate entry and/or permanence in the crop?

- Do they have a greater numerical response than *E. formosa* to sudden entries of whitefly?
- Does phytophagy enable them to survive in conditions of very low prey density? How does it affect fertility?
- How are they affected by the high temperature in the greenhouse? Does it favour migration?

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INTEGRATED PEST MANAGEMENT IN THE NETHERLANDS IN SWEET PEPPERS FROM 1985 TO 1989

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Summary

After 1984, the development of IPM in sweet peppers has been accelerated, caused by the increasing export of sweet peppers to the U.S.A. Also the demand for residue free vegetables has increased. In spite of a low tolerance for thrips damage (cosmetical damage) and a large increase in the acreage, it was clear that IPM had good possibilities. Frequently new pests occur which threaten IPM, for instance: *Frankliniella occidentalis, Aphis gossypii, Liriomyza huidobrensis* and *Bemisia tabaci*. It has been proved that with a close co-operation between scientific research, field research and field application it was possible to achieve a rapid development of IPM in sweet peppers. This should be an example for further development of the IPM programme.

1. Introduction

Sweet pepper is a crop, in which integrated pest management has become a fact in the last few years. In this paper a review is given of the development of IPM in sweet peppers in the last 5 years.

Until 1985 IPM in sweet peppers was restricted to the application of *Phytoseiulus persimilis* against spider mites and *Bacillus thuringiensis* against caterpillars. Many other pests had to be controlled chemically. The coincidental appearance of natural enemies was often hindered by the application of broad spectrum insecticides with a long residual activity.
The ever increasing number of varieties of sweet peppers and the big increase in export, mainly to the U.S.A., asked for another approach. Residues of some fungicides and tetrachlorvinphos, used to control *Thrips tabaci*, were allowed in the Netherlands, but not accepted in the U.S.A. Especially in the field of thrips control, an alternative had to be found, without making concessions to the quality of the fruits. The development of a mass rearing system for *Amblyseius cucumeris* and the development of an integrated control programme for sweet peppers meant a break-through in biological thrips control (Ramakers, 1983). A unique co-operation between the growers organisations, the Central Bureau of Fruit and Vegetable Auctions, the Glass Crops Research Station, the Extension Services and the producer of natural enemies resulted in a project, in which in 1985 60 hectares of sweet pepper could be provided with *A. cucumeris* (de Klerk & Ramakers, 1986). It was possible to continue the export of sweet peppers to the U.S.A. because of this successful biological control programme. The economical importance of sweet peppers steadily increased. The acreage has been largely extended, while at the same time the percentage, on which IPM is applied, has increased to 98% (table 1).

2. Recent developments

2.1 Thrips

An early appearance of thrips (November, December, January) can be controlled with a dichlorvos programme (5 treatments every 4-5 days). Afterwards, the introduction of *A. cucumeris* can be started, as soon as sweet pepper pollen is present. The success of *A. cucumeris* partly depends on the fact that reproduction can take place in the field on the pollen of sweet pepper plants. This makes a preventive introduction possible. To achieve a good thrips control it is necessary that the incidence of predatory mites is high: 70-80% of the leaves needs to have one or more predatory mites and/or eggs before thrips occurs.

Table 1. The application of IPM on sweet peppers.

year	acreage sweet pepper *)	application of IPM	% IPM
1985	240 ha.	60 ha.	25%
1986	250 ha.	140 ha.	56%
1987	300 ha.	250 ha.	83%
1988	330 ha.	320 ha.	97%
1989	410 ha.	400 ha.	98%
1990**)	540 ha.	530 ha.	98%

*) planted in November, December, January, February and March.
**) expected.

This programme was first developed for *T. tabaci* and *T. fuscipennis*. In 1985 the Western Flower Thrips (*F. occidentalis*) appeared in sweet peppers. In the last few years this species is found in the larger part of the sweet pepper greenhouses (van de Homburg & Hubert, 1987).

A clean start can not always be achieved by the chemical programme. In some cases thrips are found very quickly after the last dichlorvos treatment. In the last two years, early commercial applications with the predatory mites are being done to see whether an early start (December) with *A.cucumeris* could be successful, instead of the use of dichlorvos. Through introduction on the rockwool pot a small rearing system of storage mites and predatory mites is maintained for several weeks. From this rearing the mites migrate into the plant. In this way, a period in which insufficient pollen is available, can be overcome. However there is a chance that predatory mites, introduced early, will enter into diapause. This problem is now studied at the University of Amsterdam, at the Department of Pure and Applied Ecology.

It has been proved that *F. occidentalis* can be controlled with *A.cucumeris* (van de Homburg & Hubert, 1987). Nevertheless there is a need for a selective control method for *F. occidentalis* in addition to the mites. In this respect, the fungus *Verticillium lecanii* is now studied and at the Institute for Plant Protection it is being researched to what extent *Orius* spp. can contribute. In 1989 naturally occuring *Orius* spp. were found in many sweet pepper crops, giving additional thrips control. The application of sticky traps is now restricted to monitoring thrips, but in the future a more effective sticky trap can contribute to the control of *F. occidentalis*

2.2. Aphids

It was initially assumed that pirimicarb could be used without any risk to control *Myzus persicae*. However it was proved that pirimicarb was harmful to *A.cucumeris* (Ramakers, 1989). Application of pirimicarb is undesirable if the population of *A. cucumeris* is building up or if the ratio thrips:predatory mites is critical. In the last few years *Aphis gossypii* is found more and more. This aphid is resistant to pirimicarb. As the application of broad spectrum insecticides decreases, there are more chances for natural enemies of aphids (parasitic wasps, gall-midges and lacewings). In 1989, field research indicated that *Aphidoletes aphidimyza* could be introduced successfully against some aphids, present in sweet pepper crops. In this project also the contribution of *Aphidius matricariae* to control aphids, became visible (van Schelt et al., 1990). In 1990 these predators and parasites will be introduced on a large scale in sweet peppers.

2.3 Leafminers

In sweet peppers leafminers can occur, but they are not a threat to biological control. In 1989, *Liriomyza huidobrensis* was discovered in sweet peppers. It was found that the parasitic wasps *Dacnusa sibirica* and *Diglyphus isaea* also parasitize *L. huidobrensis* (van der Linden, 1990).

2.4 Whiteflies

The greenhouse whitefly *Trialeurodes vaporariorum* is not a big problem in sweet peppers. It can be controlled by *Encarsia formosa*. This parasitic wasp is also effective against the sporadically occuring occurring whitefly *Bemisia tabaci*.

2.5 Other pests and diseases

Mirid bugs and broad mites appear incidentally and have to be controlled spotwise with chemicals. Mildew, grey mould and other fungal diseases can be controlled with selective fungicides, which are harmless to parasites and predators. Table 2 gives an impression of the most important pests within the IPM programme.

Table 2. Review of the development of IPM.

Pest	I.P.M. PROGRAMME OF THE MOST IMPORTANT PESTS		
	until 1984	in 1989	expected for 1990
Thrips T.tabaci T.fuscipennis F.occidentalis (after 1987)	dichlorvos, diazinon, tetrachlorvinphos, sulfotep	dichlorvos, A.cucumeris	A.cucumeris, Orius spp.*, sticky traps, V.lecanii *
Spider mites T.urticae	P.persimilis, fenbutatinoxide	P.persimilis, fenbutatinoxide	P.persimilis, hexythiazox, clofentezin
Aphids M.persicae A.gossypii	pirimicarb, dichlorvos|cyanide,	pirimicarb, A.matricariae heptenophos	A.aphidimyza,
Leafminers L.bryoniae L.trifolii L.huidobrensis (after 1989)	-	oxamyl (trickle irrigation), D.sibirica, D.isaea	D.sibirica, D.isaea
Caterpillars	B.thuringiensis, tetrachlorvinphos, diazinon	B.thuringiensis, teflubenzuron	B.thuringiensis
Whiteflies T.vaporariorum B.tabaci	-	E.formosa	E.formosa, V.lecanii *

* experimental

In spite of the fact that many pests have to be controlled in sweet peppers and that the tolerance is very low, IPM in sweet peppers can be considered to be successful on a large scale (table 3), created by an increasing range of predators and parasites.

Table 3. The duration of successful application of IPM in sweet peppers.

		percentage of successful control until the end of			
year	acreage	May	June	July	August
1985	60 ha	96%	94%	87%	63%
1986	140 ha		85%		70%
1987	250 ha				
1988	320 ha	99%	93%	85%	78%
1989	400 ha	91%	89%	87%	81%

The percentage indicates the percentage of area successfully biologically controlled. The growers who had to stop biological control because of very high infestations of thrips or other pests, had to change to chemical control, lethal to *A. cucumeris*.

3. Technical Backup

The technical backup plays an important role in IPM. About 30 full-time specialists in biological control are concerned with IPM, in tomatoes, cucumbers and sweet peppers. They are supervised by a team of advisors of producers of natural enemies.

4. Conclusion

The rapid development of biological control in sweet pepper is an example of a close co-operation between scientific research, field research and field application. This co-operation is necessary to guarantee further development of IPM.

IPM in the Netherlands has proven to be successful because of the fine-tuning of many institutes and companies:

- Glasshouse Crops Research Station in Naaldwijk
- University of Amsterdam (Department of Pure and Applied Ecology)
- University of Wageningen, Laboratory of Entomology
- Institute for Horticultural Plant Breeding in Wageningen
- Institute for Plant Protection in Wageningen
- Central Bureau of Fruit and Vegetable Auctions in The Hague
- Growers organisations
- Extension Services
- Producers of natural enemies

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A REVIEW OF THE BIOLOGICAL CHARACTERISTICS OF *ENCARSIA TRICOLOR* AND THEIR IMPLICATIONS FOR BIOLOGICAL CONTROL

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Summary

The results of the work carried out on *Encarsia tricolor* in the last three years are added to the information available on this species. The development of *Et* is well synchronized with the development of its hosts, allowing the establishment of the parasitoid in the crop following releases. The values of the Intrinsic Rate of Increase (r_m) at constant temperatures depend on the number and type of the secondary host present in the searching arena. When only *Et* and *Trialeurodes vaporariorum* coexist, r_m values are greater than those of *Tv*. The number of *Tv* nymphs killed through host feeding by virgin *Et* females can be very important (up to 14 per day). The use of *Et* in biological control presents some technical difficulties, mainly due to its way of development. The use of small populations of *Encarsia formosa* as secondary hosts to rear *Et* males may solve them, at least in part.

1. Introduction

At the meeting in Budapest in 1987, we submitted a review of current knowledge of the biological features of the facultative autoparasitoid *Encarsia tricolor* Foërster (*Et* from here onwards) and discussed its potential as an agent for control of the greenhouse whitefly *Trialeurodes vaporariorum* (Westwood) (*Tv* from here onwards), both in glasshouse and open air conditions (Artigues et al., 1987). We pointed then to the need for more research into certain topics, such as fecundity at low (< 14 °C) and high (> 24 °C) temperatures, and sex ratio determination. The results of the work carried out in the three years that have elapsed since then are added to the remaining information available on this species and presented here. The details of the experimental procedures and a more in-depth discussion of the results will be published later.

2. Potential use

The main fact underlying the use of *Et* in whitefly control in mediterranean conditions is that it can develop in the open air (Ferrière, 1965). Thus, if *Et* gave good control of *Tv* in the greenhouse, its populations could migrate from there to attack outdoor whitefly populations and complement the control exercised by predators such as Miridae (see Alomar et al. in this volume). One condition needed for this approach to be useful is that *Et* should be able to control *Tv* populations in glasshouses in an economic manner. We shall discuss this point following the guidelines proposed by van Lenteren (1986).

2.1 Internal synchronization with the host

Et females develop as primary parasitoids on several species of Aleyrodidae (e.g. *Aleyrodes spp.* and *Tv*) called "primary hosts" (PH). *Et* males develop as hyperparasitoids of their own or different species called "secondary hosts" (SH). Both sexes develop internally. The whole of our work was carried out using *Tv* as PH and *Et* and *Encarsia formosa* Gahan (*Ef*, from now onwards) as SH. Parasitism of all *Tv* instars from the sessile N1 to the pharate adult permits completion of the parasitoid female life cycle till adult emergence. As for the males, both young and mature *Et* larvae and *Ef* pupae are successfully parasitized (Avilla and

Copland, 1987). However, ovipositing *Et* females may prefer certain host stages to others. The preference of *Et* female for laying eggs in a particular instar of the whitefly was studied by offering single females an arena containing whitefly nymphs of various instars. The behaviour of the *Et* females was observed under the binocular microscope and X^2 tests were carried out. The most parasitized instars in the behavioural experiments were N3 and N4 nymphs (23 % of the nymphs of both types encountered were parasitized). When searching for hosts in an arena containing solely these two *Tv* instars, the *Et* females significantly preferred N4 for laying eggs. The development on different host instars may have other consequences, such as differential mortality and development rates. We have no quantitative data on the mortality of immature *Et* stages. As for the rate of development, female development is faster when the egg is laid on N3 and slower when it is laid on N1 (18 and 22 days from egg to adult, respectively); male development is faster when the egg is laid on mature larvae of *Ef* (15 days from egg to adult). The mean developmental time for males is always lower than that for females (Avilla and Copland, 1987). Therefore, we may conclude that, although all *Tv* instars may be successfully parasitised by *Et*, N3 and N4 whitefly nymphs are the most suitable instars for the development of the parasitoid females.

Another feature we have to consider in this section is the synchronization in time of host, female parasitoid and male parasitoid development. Female and male egg-to-adult development at constant temperatures ranged from 51 (14 °C) to 14 (28 °C) and from 33 (16 °C) to 12 (28 °C) days, respectively. Males developed faster than females. Predictions of the rates of development at variable temperatures were more accurate when made from 2nd and 3rd degree polynomials than from linear regressions (Avilla and Copland, 1988).

At the moment of the introduction of *Et* into a crop, mated searching females can only lay female eggs, because only PH are present in the crop. A few days later, depending on temperatures, females will be able to lay male eggs on their own developing daughters. Thus, the development of the males begins later than that of the females. The faster development of males at all temperatures permits the synchronous emergence of male and female adults.

As for the synchronization in development between host and parasitoid, *Et* females develop faster than *Tv* at temperatures above 15 °C. At the start of the growing season, when temperatures may be below this threshold, certain problems may arise. However, *Et* develops faster than *Ef* at temperatures below 22 °C (Avilla and Copland, 1988), and the good results from *Ef* at low temperature regimes (van Lenteren and Hulspas-Jordaan, 1983) lead us to suppose that the rate of development will not be a hindrance.

2.2 Climatic adaptation

In constant temperature experiments, females developed successsfully from 14 to 32 °C, but 100% pupal mortality was observed at 34 °C. Males developed succesfully from 16 to 28 °C, and the upper developmental threshold was not reached in this case. No experimental data on the lower developmental threshold (LDT) are available. The LDT extrapolated from linear regression were 8.9 and 9.6 for females and males respectively (Avilla & Copland, 1988). No problems caused by low temperatures are therefore to be expected. Air temperatures may reach values as high as 34 °C in the greenhouse, but only for a few hours, and their effect on *Et* survival will not be so severe. Besides, milder microclimates may exist in the canopy.

2.3 Absence of negative effects

Et being a facultative autoparasitoid, the coexistence in the same crop of *Ef* and *Et* populations will cause that immature stages of *Ef* to be parasitized and *Et* males to develop on them. In fact, we have observed that mature *Ef* larvae are much sought after by adult *Et* females for laying eggs in them (see 2.4). Proof of whether the simultaneous use of both species to control *Tv* would lead to higher mortality rates of the pest than with just one of them requires further experiments.

2.4 High host kill rate

The host kill rate is the sum of the number of PH killed through parasitization and the number killed by host feeding during the adult parasitoid lifetime. The number of hosts parasitized by *Et* females and the primary sex ratio of the offspring (number of PH parasitized : total number of hosts parasitized) were assessed under various experimental conditions. First, *Tv* nymphs (N3, N4 and pharate adults (PA)) were offered as hosts to singly kept *Et* females. This situation can be found by parasitoid females at the start of the colonization of a new crop. This experiment was carried out at 10, 14, 18, 24, 28 and 32 °C. Second, singly kept *Et* females were given access to N4 *Tv* nymphs and *Et* pupae as hosts. This situation can be found during the development of the crop. Third, singly kept *Et* females were exposed to N4 *Tv* nymphs and mature *Ef* larvae as hosts. This situation can be found when both parasitoid species coexist in the crop. In the two latter experiments, different ratios of PH : SH (from 48:0 to 6:42) were present in the searching arena. Finally, groups of one, two, four and eight female parasitoids were confined with nymphs of *Tv* (N4) and mature larvae of *Ef* as hosts, in order to test the effects of mutual interference. The last three experiments were carried out at 24 ± 1°C.

Table 1 shows the number of hosts parasitized by singly kept *Et* females, the duration of the development of the offspring and the intrinsic rate of increase (r_m) at constant temperatures when only PH were present in the searching arena. Table 1 also shows the r_m values for *Tv* and for *Ef* reported by van Lenteren and Hulpas-Jordaan (1983). The sex ratio of the offspring depended on the PH : SH ratio and the type of secondary hosts present in the arena. The presence of *Ef* led to a greater proportion of males in the offspring than the presence of *Et*. Table 2 shows the sex ratio of *Et* offspring in these situations and the values for r_m.

Table 1. No. of parasitized PH (PPH), developmental period (DP days), No. of days until 50 % of PPH (PPH50), Intrinsic rate of increase (r_m) of *Et* and r_m of *Ef* and *Tv* at constant temperatures (T, °C).

T	DP	PPH50	PPH	r_m	r_m - *Ef*	r_m - *Tv*
10	74	10	22	0.037	-	-
12	-	-	-	-	0.091-0.095	0.040
14	52	11	43	0.060	-	-
15	-	-	-	-	0.062-0.087	0.060
18	30	8	91	0.117	0.093-0.134	0.096
24	18	7	112	0.189	-	0.167
25	-	-	-	-	0.194-0.281	-
27	-	-	-	-	0.255	0.201
28	14	8	123	0.216	-	-
30	-	-	-	-	0.169-0.258	0.079

The r_m values of *Et* at constant temperatures when only PH were present in the arena were similar to those of *Ef* and greater than those of *Tv*. The presence in the arena of SH led to a decrease of r_m values. This decrease was very small when the SH were *Et* pupae and great when the SH were *Ef* larvae. The presence in the searching arena of more than one *Et* female led to a shift in the progeny sex ratio towards the male sex. This shift was apparent from a density of two females per arena and did not increase when female parasitoid density increased from two to eight per arena (progeny sex ratio was 51, 85, 86, 80 % males for a density of one, two, four and eight females per arena respectively).

Table 2. Primary sex ratio of the offspring (number of PH parasitized: total number of hosts parasitized, SR) and Intrinsic rate of increase (r_m) of *Et* at different PH : SH ratios present in the searching arena.

	SECONDARY HOST			
	Et		*Ef*	
PH : SH	SR	r_m	SR	r_m
48 : 0	1.00	0.189	1.00	0.189
42 : 6	0.98	0.188	0.80	0.180
36 : 12	0.96	0.187	-	-
24 : 24	0.93	0.186	0.57	0.166
12 : 36	0.81	0.180	-	-
6 : 42	0.64	0.171	0.07	0.082

The existence of host feeding by female *Et* was pointed out by Stübben (1949), although no studies of the quantitative aspects of the phenomenon have been carried out until now. We have studied the host feeding behaviour and number of hosts consumed by virgin females during their first three days of life and the existence of this behaviour in mated females during the period of maximum egg laying. Virgin females of the parasitoid fed on all the immature stages of the whitefly when exposed to N1-N2, N3-N4 or AF per arena. Pharate adults were accepted for host feeding in 11% of cases, whereas N1-N2 and N3-N4 were accepted in 43 % of cases. The number of host nymphs fed on per day ranged from 2 AF to 14 N3-N4 on average. Mated females also fed on *Tv* nymphs but not on mature *Ef* larvae. The percentage of nymphs fed on by mated females after attack was influenced by the presence of SH, reaching 36 % and 11% respectively with and without *Ef* in the arena. However, the number of nymphs fed on by mated females never reached the levels recorded for virgin females. A previously parasitized nymph can be fed on in a second encounter by the same, or different, female.

Finally, we shall consider host discrimination, as it is a phenomenon that leads to greater rates of increase. Host discrimination was studied in two ways. First, the distribution of the number of eggs per host was statistically compared via a Poisson distribution. The experiment was carried out at two host densities (5 and 25 N4 whitefly nymphs per 20 cm^2) and at different ages of the females. Second, the behaviour of searching *Et* females on an arena containing parasitized hosts was observed under the binocular microscope.

There were statistically significant differences between the observed distribution of the number of eggs per host and the theoretical Poisson distribution throughout the whole life of the female. In all the cases, the number of hosts observed receiving two or more eggs was lower than that expected and the number of hosts observed receiving one egg was higher than that expected. This is an indication that the female of *Et* was able to discriminate between previously parasitized and non-previously parasitized whitefly hosts. This result was confirmed by the behavioural studies. Most of the attacked whitefly hosts that were encountered a second time were rejected for oviposition sites when found by the same, or a different, female (less than 5 % were accepted). However, when attacked *Ef* larvae were encountered a second time, they were rejected for oviposition sites by the same female (8 % were accepted), but accepted in 39 % of cases by a different one. It would appear that discrimination takes place mainly after ovipositor insertion,

The elimination of supernumerary parasitoids was investigated by carrying out daily dissections of hosts. The presence of two or three eggs per host leads to the complete development of only one of them.

2.5 Good culture methods

We have not carried out systematic experiments on mass rearing of *Et*. We believe that as it is a species that overwinters in open air conditions in cold areas of the hinterland of Spain, storage at low temperatures may be more feasible than with *Ef*. The search for *Et* populations that might display diapause will be the object of future research.

The mass rearing of the two sexes, which have such different hosts requires careful consideration. The sex ratio of the releases will be strongly influenced by the technical aspects of culture methods, such as the number of days that the host population is exposed to adult parasitoids, parasitoid density in the rearing unit and others. The use of small populations of *Ef* as SH to rear *Et* males may help to solve these technical difficulties.

3. Conclusions

We may conclude that:

- The development of *Et* is well synchronized with the development of its hosts, what allows the stablishment of the parasitoid in the crop following the releases.
- *Et* shows a good host kill rate through parasitization and host feeding. . In particular, the number of *Tv* nymphs killed through host feeding by virgin females can be very important.
- No problems caused by low temperatures are to be expected. *Et* female pupae die at a constant temperature of 34 °C. This values may be reached in the glasshouse, but only for a few hours, and their effect on *Et* survival will not be so severe.
- Some technical difficulties may arise when trying to mass rear *Et*, due to its way of development. The use of another species as SH (e.g. *Ef*) may be envisaged as a solution.

We believe then, that *Et* is a good parasitoid for the control of *Tv* populations, but that there are some technical aspects that need further research.

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RECENT DEVELOPMENTS WITH INTEGRATED CONTROL OF THRIPS ON CUCUMBER IN THE UNITED KINGDOM

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Summary

Frankliniella occidentalis (western flower thrips) is now a major pest of cucumbers in the UK. The commercial integrated control programme for thrips on cucumbers was evaluated at five sites in the UK in 1989. *Amblyseius* spp. controlled western flower thrips ("WFT") below economically damaging levels at three sites, was considered to have contributed at a fourth, but failed to establish at a fifth site. At one of the successful sites, *Amblyseius* spp. introductions had been supplemented with applications of *Verticillium lecanii* and here the control of WFT appeared to be due to the combined effect of both organisms. Chemical control measures for WFT were resorted to only at the site where *Amblyseius* spp. failed to establish. In the light of information on *A. cucumeris* biology learned from Canada this season (Morewood & Gilkeson, personal communication), a different procedure for *Amblyseius* spp. introductions will be recommended in the UK in 1990. Further work is necessary to improve the IPM programme for thrips on cucumber, and future trials will include the evaluation of *Verticillium lecanii* and possibly Anthocorid bugs.

1. Introduction

WFT was first recorded on two commercial cucumber crops in the UK in 1987 and by the end of 1988, on twelve. The risk of a recurrence on infested nurseries and spread to adjacent nurseries was considered to be high at the beginning of 1989. Previous work in the UK in 1987 and 1988 had shown that WFT, unlike the onion thrips, *T. tabaci*, could not be controlled by Thripstick® alone. WFT could be controlled with dichlorvos or pyrazophos, but side effects in terms of damage to both plants and biological control organisms were unacceptable (Jacobson, 1988a).

Results with *Amblyseius* spp. on cucumebr in the UK have been variable. In 1987, in trials against *T. tabaci, A. cucumeris* establishment had been successful from either a single release of 250 per plant or three consecutive releases of 50 per plant every two weeks, starting at the first sign of thrips infestation (Bennison, 1988). In 1988, trials against WFT had indicated that *Amblyseius* spp. could suppress WFT increase, but they could not control an established population (Jacobson, 1988b). At the end of 1988 season, ADAS recommended procedures for cleaning up WFT infestations and preparing for the new 1989 crops to ensure nurseries were free from thrips at planting. Growers were then advised to introduce *Amblyseius* spp. preventively, at the rate recommended by the suppliers; 500,000 per hectare every two weeks, from planting.

This paper describes the monitoring of five nurseries using this programme. It was hoped to validate the commercial integrated control programme for thrips on cucumber.

2. Materials and methods

The trial was conducted at 5 sites:

	Location	Training system	Planting	Plot Size (Unreplicated)
1.	Nazeing, Essex	Archway	Feb '89	42 rows of 120 plants
2.	Roydon, Essex	Archway	July '89	40 rows of 93 plants
3.	Woodmansey, N. Humberside	Cordon	Dec '88	10 rows of 62 plants
4.	South Cave, N. Humberside	Cordon	Dec '88	6 rows of 104 plants
5.	Lymington, Hants	Cordon	Feb '89	12 rows of 70 plants

2.1 Treatments

Each glasshouse was treated with the commercial integrated pest management programme recommended on cucumbers:

Thrips:	Thripstick® was applied to the rockwool slabs and gutter area before planting and to the paths after planting, repeated every 6-8 weeks. *Amblyseius* spp. were introduced from planting, at 500,000 per hectare every two weeks; approximately 40 per plant per fortnight. *A. barkeri* were requested from the suppliers later in the season when aphicides were necessary, due to recent evidence to suggest that this species is more tolerant of some pesticides than *A. cucumeris* (van der Staay, 1989). At sites 3 and 4, the rate of *Amblyseius* spp. was doubled from April to June and in addition, at site 4, five sprays of an experimental formulation of *Verticillium lecanii* were applied during April and May. At site 5, the rate of *Amblyseius* was doubled during June and trebled during July and August.
Glasshouse whitefly:	*Encarsia formosa* and soft sope (Savona) if necessary.
Two-spotted spider mite:	*Phytoseiulus persimilis* and fenbutatin oxide (Torque) if necessary.
Aphis gossypii:	Nicotine if necessary.

3.2 Assessments

Assessments were done at ten or twenty sampling points per site, depending on the size of the glasshouse or area sampled. At each sampling point a top, middle and bottom leaf were taken for thrips and *Amblyseius* spp. counts every fortnight. At site 4, only upper leaves were sampled. At the same point every fortnight, a fresh yellow sticky trap was positioned at crop height and a yellow water trap with Teepol positioned under the crop canopy. At site 2 blue sticky traps were compared with yellow ones over a three week period. The following were recorded:

1. Numbers and species of thrips per water trap and sticky trap.
2. Numbers of thrips and *Amblyseius* spp. per leaf and percentage leaves infested.
3. Percentage leaf area damaged by thrips (this assessment was done only at sites 2 and 3, and at the end of the season, at site 4).
4. Numbers and species of *Amblyseius* spp. introduced (this assessment was not done at site 5).

3. Results

Results of assessments are shown in Figures 1-5, for sites 1-5 respectively.

Site 1: At this site in the Lea Valley, WFT were recorded in water traps and on sticky traps from 15 March, but not until 5 April from the leaves. By the end of the assessment period on 14 June, numbers of WFT had risen to 50 per leaf, with 100% leaves infested. *Amblyseius* spp. did not establish well; the highest number recorded were 0.06 per leaf, with 6.7% leaves infested. On many sampling occasions, no *Amblyseius* spp. were found. At the end of the assessment period, the grower decided to resort to chemical control of WFT as leaf and fruit damage had reached unacceptable levels.

Site 2: At this site in the Lea Valley, the crop was a second cucumber crop, the first having been pulled out and replanted after a severe WFT infestation. Both *Trips tabaci* and WFT were present through the trial period from 2 August until 3 October. *T. tabaci* predominated in August, with WFT predominating in September; it is thought that the frequent nicotine treatments used for *A. gossypii* control contributed to the decline of *T. tabaci*. Numbers of thrips reached a peak on 30 August at 10.6 per leaf and 96.7% leaves infested. Numbers of *Amblyseius* spp. remained very low, peaking at 0.3 per leaf and 15% leaves infested on 2 August. Leaf damage only reached 19% leaf area affected but the grower complained of excessive numbers of curly fruits, which were partly attributed to thrips damage. It is possible that *Amblyseius* spp. contributed to thrips control at this site, but as both WFT and *T. tabaci* were present, Thripstick® and nicotine will also have contributed. In addition the heavy leaf trimming adopted on the nursery removed many of the worst affected lower leaves.

Site 3: At this site in N. Humberside, WFT were detected on sticky traps and on the leaves from 22 March. Thrips numbers increased rapidly during May and June, peaking on 27 July with 95.8 WFT per leaf and 100% leaves infested. WFT numbers stabilised during July and August. *Amblyseius* spp. were recorded from the first assessment on 7 March but established slowly until June and July. Numbers then increased significantly, reaching 13.7 per leaf on 13 July and 92% leaves infested. Leaf damage was most severe in June and August but never exceeded 27% of the total leaf area. No fruit curling due to thrips feeding was recorded and, in the growers assessment, there was no significant loss of yield. Although WFT numbers were high and there was obvious damage to the foliage, the grower did not have to resort to the use of insecticides against thrips until September when he began his 'clean-up' treatments. Thus it is considered that *Amblyseius* spp. successfully controlled WFT at this site.

Site 4: At this site in N. Humberside, WFT were detected on sticky traps and on the leaves from early April. Most WFT were found in the original 'hot spot' of infestation in the centre of the monitored area. Numbers of WFT gradually declined between April and late June, from 12.4 per leaf and 100% leaves infested, to 0.5 per leaf and 20% leaves infested respectively. Leaf damage levels decreased accordingly, from 12% in April to 0.5% in late June. Low numbers of thrips and levels of damage were maintained for the remainder of the monitoring period, until late July. *Amblyseius* spp. established well, increasing from 0.20 per leaf and 20% leaves infested in April, to 5 per leaf and 95% leaves infested in late June. By mid-May, the percentage of leaves infested with *Amblyseius* spp. exceeded those infested with WFT, thus *Amblyseius* spp. were considered to be in control from that point on. Although there was no visible growth of *V. lecanii* on thrips or *Amblyseius* spp.found in the trial area, samples submitted to Koppert BV revealed 74% of WFT larvae and 23% *Amblyseius* spp. to be infected. Thus, *V. lecanii* may have contributed to thrips control at this site. Work at the Institute of Horticultural Research, Littlehampton has indicated that *V. lecanii* can give useful control of WFT (Gillespie, 1989).

Site 5: At this site in Hampshire, thrips were detected on the leaves from 10 March and on sticky traps from 17 March . Numbers of thrips remained below one per leaf until late July, when numbers began to increase. In September, there was a sharp increase to 95.2 thrips per leaf and 98% infested. The thrips population was a mixture of WFT and *T. tabaci*, with WFT predominating. *Amblyseius* spp. were detected in very low numbers from 22 February until 26 July. Establishment was slow, reaching only 0.5 per leaf and 28% leaves infested. No *Amblyseius* spp. were recorded during August and September. this was attributed to the adverse effects of two sprays of heptenophos applied for control of *A. gossypii*. Despite the low numbers of *Amblyseius* spp. recorded between February and July, they are considered to have controlled thrips at this site until the disruptive use of heptenophos.

4. Discussion and conclusions

4.1 Thrips control

It is generally considered that cucumbers can tolerate up to 30% loss of leaf area due to pest damage before yield is affected (Hussey & Barr, 1963). *Amblyseius* spp. are considered to have kept thrips infestations below economically damaging levels at sites 3, 4 and 5 and may have contributed to control at site 2. Site 1 was the only site where the grower resorted to chemical control. *V. lecanii* ("Mycotal") is thought to have contributed to thrips control at site 4.

4.2 *Amblyseius* spp. establishment

Amblyseius spp. were slow to establish at all sites during March and April. Establishment improved at sites 3, 4 and 5 during May, June and July and was particularly good at sites 3 and 4. Better establishment at sites 3, 4 and 5 could have been partly due to higher introduction rates used than at sites 1 and 2. Establishment of *Amblyseius* spp. remained very poor at site 1 and chemical control was used at this site from mid-June.

Recent information from Canada suggests that not all the *A. cucumeris* in a population lay eggs during days with less than 12 hours light, unless the minimum night temperature is above 21°C (Morewood & Gilkeson, personal communication). Under UK cucumber growing conditions, it is probable that 40-60% *A. cucumeris* females could enter this reproductive diapause between January and early March. When conditions become favourable, there is thought to be a further delay before full egg-laying is resumed. This could explain the slow establishment at all sites early in the season, but not the complete absence of any *Amblyseius* spp. on most sampling occasions at site 1.

Poorer *Amblyseius* spp. establishment at the two Essex sites than at the sites in Humberside and Hampshire could also be due to the growing system. At the two Essex sites, the archway system was used, which involves heavy leaf trimming. This could remove some *Amblyseius* spp. with the leaves and the more open canopy could also result in a less favourable environment. It is thought that *Amblyseius* spp. may prefer the more sheltered, humid environment afforded by the denser, untrimmed crop grown on the cordon system, as adopted at the Humberside and Hampshire sites.

4.3 *Amblyseius* species and numbers

The number of species of *Amblyseius* in the provided cultures were checked before introduction at all sites except site 5. Numbers were variable but this could have been due to the counting techniques used. The method used for checking quality of *Amblyseius* spp. supplies needs to be standardised.

The cultures provided as *A. cucumeris* were usually pure. However, those supplied as

A. barkeri always contained a mixture of the two species, often with *A. cucumeris* in the majority. The mid-season, *Amblyseius* spp. were collected from the crop at sites 3 and 4 and identified to species. Only *A. cucumeris* were recovered despite both species having been introduced.

4.4 **Effect of pesticides on *Amblyseius***

The following pesticides were used without any significant adverse effects on *Amblyseius* spp.: Torque (fenbutatin oxide); Nimrod (bupirimate); (propamocarb hydrochloride); Repulse (chlorothalonil); Ronilan (vinclozolin); Rubigan (fenarimol); Fungaflor (imazalil). All these observations are consistent with recent Dutch data on pesticide effects on *Amblyseius* spp. (van der Staay, 1989). Nicotine smokes are generally considered to be safe to *Amblyseius* spp. by commercial suppliers. However, there was evidence to suggest that they may be harmful near the point of combustion. Nicotine sprays may be less harmful, due to more even application and the option of localised sprays. Heptenophos (Hostaquick) was used for *A. gossypii* control at the end of the season at site 5 and appeared to eliminate the *Amblyseius* spp. This suggests that they were *A. cucumeris*, as *A. barkeri* is thought to be tolerant of heptenophos (van der Staay, 1989).

4.5 **Sticky traps and water traps**

Water traps were found to be ineffective at trapping WFT at sites 3 and 5 and were abandoned at these sites. However, water traps were equally effective as sticky traps at sites 1 and 2. Interestingly, more adult thrips were caught in water traps than larvae, suggesting adults were attracted to the yellow colour on the floor. The evaluation of Thripstick® on yellow polythene on the floor and over the slabs instead of white, would be worthwhile. As indicated in results from trials in 1988, yellow sticky traps generally caught thrips before they were evident on the crop (Jacobson, 1988a). Thus they can be used as early warning devices for thrips infestation.

A comparison between 10 blue and 10 yellow sticky traps at site 2 over a three week period showed that identical numbers of thrips were caught on both coloured traps; a mean of 107 thrips per trap were recorded on both colours. However, only dark blue traps were available in the UK in 1989 and only specific shades of blue are more attractive to WFT than yellow (Brødsgaard, 1989). Evaluation of different shades of blue sticky traps for thrips monitoring and control in the UK would be worthwhile.

4.6 **Sampling techniques**

Although thrips damage was patchy at all sites, with some areas of the glasshouse more severely infested than other, the leaf sampling technique adequately reflected the overall infestation and detected "hotspots". Leaf washing and microscopic examination techniques were compared for four assessment dates at site 3. Leaf washing was abandoned thereafter in favour of leaf examination. There seemed no consistent relationship between numbers of thrips per leaf and percentage of leaves infested in these trials. However, other workers have found a positive correlation (Steiner, personal communication).

4.7 **Recommendations for the future**

In the UK, *Amblyseius* introductions should be delayed until late March, when conditions are favourable for full egg-laying capacity. However, if WFT infest the crop before March, growers should start introductions earlier and consider raising minimum night temperatures to 21°C to favour *Amblyseius* establishment. Percentage leaf area damaged by thrips should be included in assessments, in order to estimate potential yield loss. Percentage leaves infested with thrips and *Amblyseius* may be a more relevant relationship than numbers of thrips and *Amblyseius* per leaf. Both assessments should be continued in order to correlate the two with leaf area damaged. *V. lecanii* (Mycotal) is now approved for use in the UK against glasshouse whitefly in glasshouse crops and should give some incidental control of thrips. Mycotal should be evaluated as part of the IPM programme for thrips in future work. *Amblyseius* spp. are the only commercially available predators for thrips control. However, Anthocorid bugs have shown good potential for WFT control on chrysanthemums in the UK (Wardlow, personal communication) and should be evaluated on cucumber. *Aphis gossypii* remains a major threat to IPM on cucumbers in the UK, owing to severe resistance to pirimicarb. Nicotine is effective and reputed to be safe to *Amblyseius* spp. but if used regularly, would disrupt the whole IPM programme. *Aphidoletes aphidimyza* failed to establish on cucumber in trials in the UK in 1988 (Bennison and Jacobson, unpublished data). An effective biological control agent for aphids is urgently needed for the future success of IPM on cucumber.

Acknowledgements

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Fig. 1. Site 1 - Thrips and Amblyseius assessments

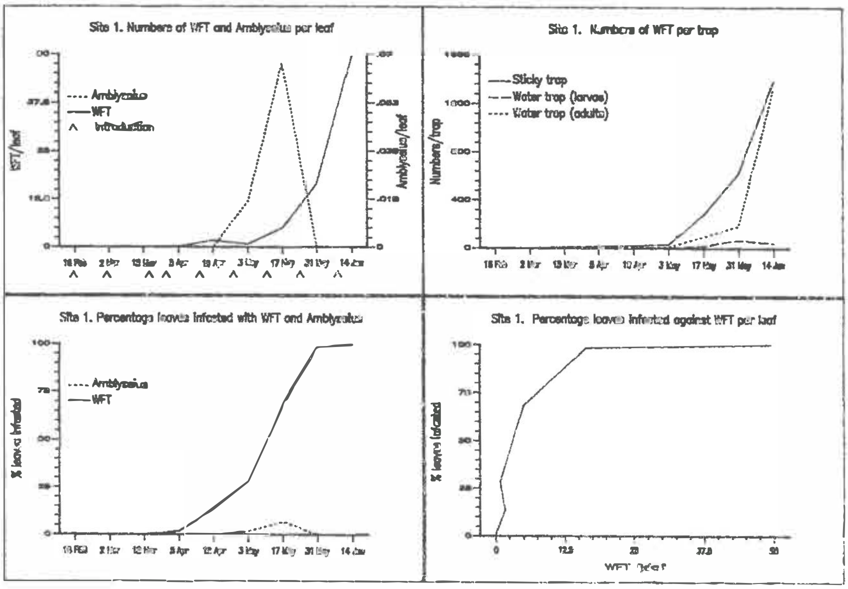
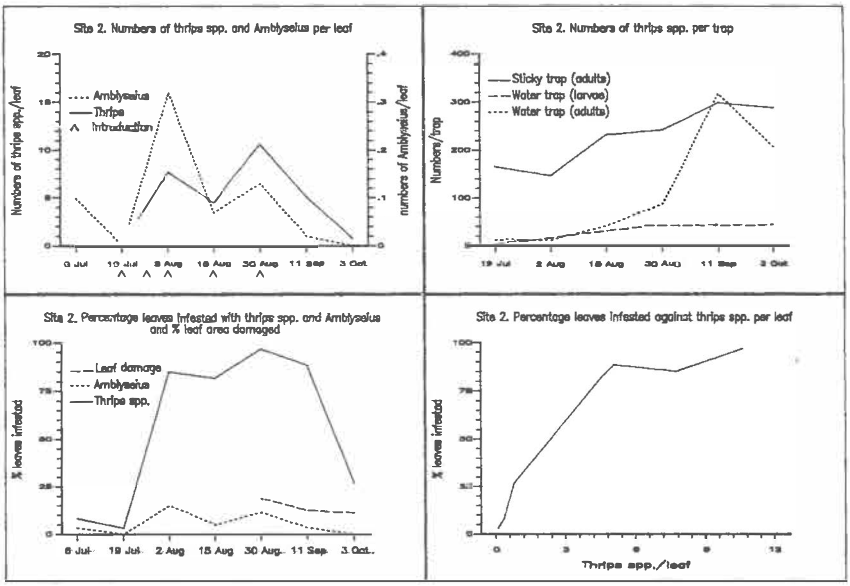


Fig 2. Site 2 - Thrips and Amblyseius assessments



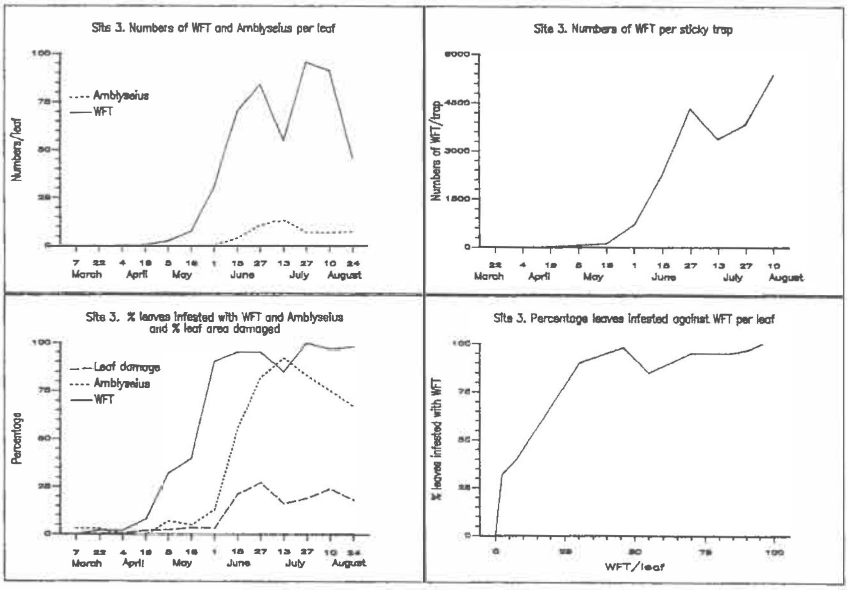
Site 2. Numbers of thrips spp. and Amblyseius per leaf

Site 2. Numbers of thrips spp. per trap

Site 2. Percentage leaves infested with thrips spp. and Amblyseius and % leaf area damaged

Site 2. Percentage leaves infested against thrips spp. per leaf

Fig. 3. Site 3 - Thrips and Amblyseius assessments



Site 3. Numbers of WFT and Amblyseius per leaf

Site 3. Numbers of WFT per sticky trap

Site 3. % leaves infested with WFT and Amblyseius and % leaf area damaged

Site 3. Percentage leaves infested against WFT per leaf

Fig. 4. Site 4 - Thrips and Amblyseius assessments

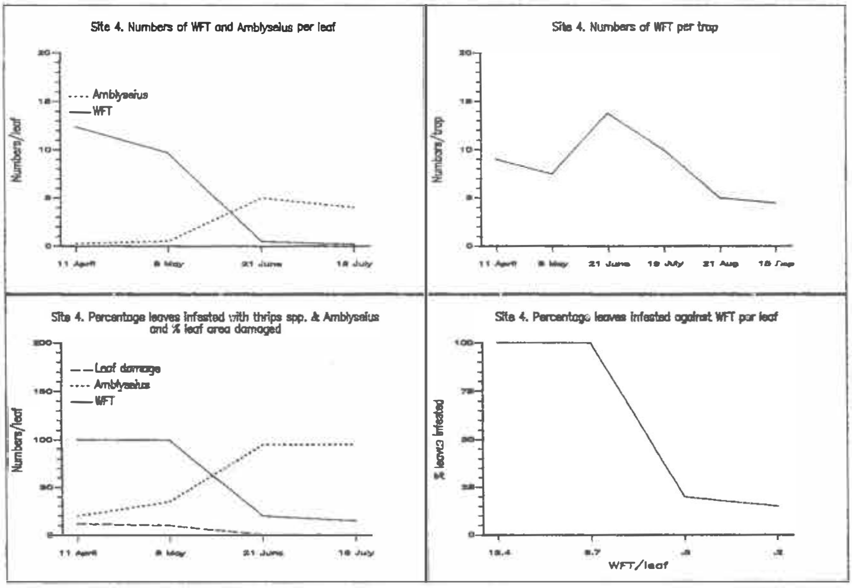
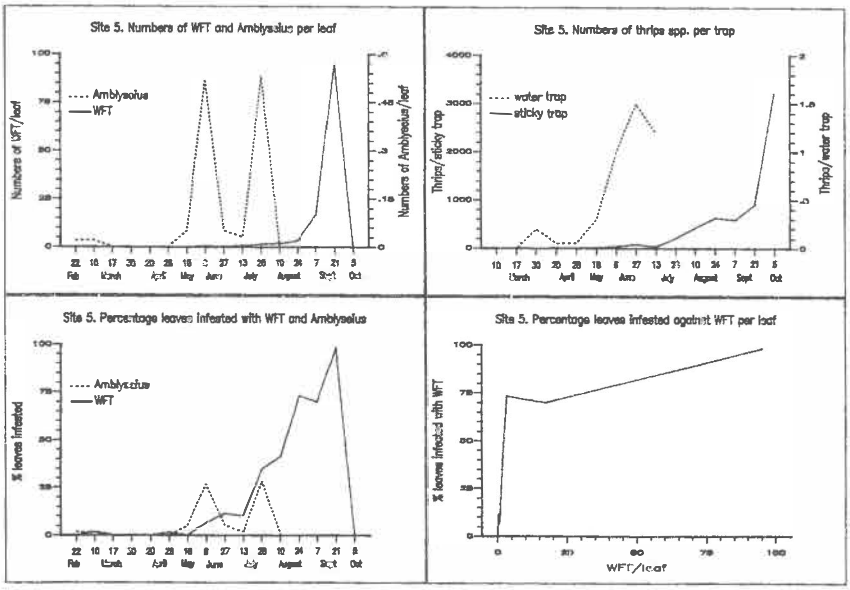


Fig. 5. Site 5 - Thrips and Amblyseius assessments



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BIOLOGICAL CONTROL OF *BEMISIA TABACI* (GENN.) AND *TRIALEURODES VAPORARIORUM* (WESTW.) BY *ENCARSIA FORMOSA* GAHAN ON POINSETTIA[1]

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Summary

The trials were conducted in 1988 and 1989 on potted poinsettia (*Euphorbia pulcherrima* Willd.) = in heated commercial glasshouses in northern Italy. *Encarsia formosa* Gahan, in 10 weekly releases each of 9.64 parasitized pupae per m² proved an effective biological control agent of *Trialeurodes vaporariorum* (Westw.) and *Bemisia tabaci* (Genn.). In 1989 the infestation of both species of whitefly adults was significantly higher in the chemical control glasshouse. In autumn 1988 and 1989, during the late crop cycle period, overall parasitization percentages of 55.1 and 60.3% for *B. tabaci* and 61.1 and 64.4% for *T. vaporariorum* were recorded from samples of labelled pupae. The *E. formosa* emergence rate was 81.9 and 66.1% from *B. tabaci* and 95.4 and 94.5% from *T. vaporariorum* pupae.

1. Introduction

The poinsettia (*Euphorbia pulcherrima* Willd.), which is grown potted in greenhouse, is an important cash crop in Italy. Two species of Aleurodidae, *Trialeurodes vaporariorum* (Westw.) and *B. tabaci* (Genn.), are harmful to it. The former infests many greenhouses and in warmer areas, open-field crops as well. The latter is typical of the world's warm temperate and tropical areas, and has become one of the main pests of cotton since the introduction and widespread use of synthetic organic insecticides in the 1950s (Greathead and Bennett, 1981). In Italy *Bemisia tabaci* has been known for some time (Silvestri, 1939), but only recently has severe damage to tomato by virus transmission been reported in Sicily (Credi et al., 1989). The Aphelinid parasitoid *Encarsia formosa* Gahan has been the subject of numerous studies, and is currently employed in the biological control of *T. vaporariorum* on greenhouse crops (Van Lenteren and Woets, 1988). However, although Gerling (1967) included *E. formosa* among the parasitoids of *B. tabaci*, this species is not to our knowledge currently released against *B. tabaci*. The present paper reports the results of trials employing *E. formosa* against these two pests. The findings are discussed in relation to the development of an effective biological control strategy.

2. Materials and methods

The two-year trials were carried out in 1988 and 1989 in heated commercial glasshouses in Cesena (northern Italy). Two adjacent glasshouses (1.5 m apart) were used each year: one for biological control with *E. formosa* and the other for chemical control with the insecticides routinely used by the grower on poinsettia (Tab. 1). Each glasshouse measured 450 m² and contained 2,500 potted plants of the cultivars 'Diva', 'Angelica' and 'Sup Ji-Bi'. The plants were set on benches in early July 1988 and in late July 1989. Because these plants were supplied from commercial nurseries unrelated to the trial farm, it was impossible to ascertain with certainty which pesticides had been used before the test began.

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E. formosa was released in parasitized *T. vaporariorum* pupae glued to commercial card supplied by Koppert B.V. There were 10 weekly releases each year, from 25 August in 1988 and from 27 July in 1989 in the stated factory-supplied amount: 4.4 pupae per m^2 per release. Each release was accompanied by laboratory quality control of the number of supplied parasitoids, i.e. 50% of the same commercial shipment was checked. It was found that the probable number of parasitized pupae per release was 9.64 ± 0.53 (X±SE) per m^2 (96.4 total) with an adult *E. formosa* emergence percentage of 71.87±7.21 (X±SE). Weekly samplings were taken from 25 August in 1988 and 11 August in 1989. The infestations of the two species were estimated by counting the number of adults on 100 randomly selected plants in each glasshouse. In the biological control glasshouse the number of whitefly pupae (also including the last instar larvae) of both species was counted on 500 mature leaves in both years. The pre-imaginal instars of the two species in 1989 were distinguished on the plants using a x 10 lens Evident parasitization was also recorded in this way. From 6 October to 1 December 1988 and from 7 September to 30 November 1989 several apparently non-parasitized pre-imaginal instars were individually tagged weekly (40-90 total per week for both species). Different-coloured threads were tied to leaves and a small circle was made with a ballpoint pen around the instar to monitor its fate. The activity of *E. formosa* against the two whitefly species was checked by monitoring for several weeks the colour taken on by the pupae and the form of the emergence hole.

The statistical analysis of the data was by the Students's t-test for heterogeneous variances.

Table 1. Pesticides used during the experimental trials.

	BIOLOGICAL CONTROL GLASSHOUSE		CHEMICAL CONTROL GLASSHOUSE	
	Active Ingredient		Active ingredient	
Date	1988	*	1988	*
15/7	Furalaxyl	SD	Furalaxyl	SD
28/9			Fenpropathrin	HVS
5/10			Aldicarb	G
11/10	Furalaxyl	SD	Furalaxyl	SD
2/12	Fosetyl-Aluminium	SD	Fosetyl-Aluminium	SD
	1989		1989	
27/7	Furalaxyl	SD	Furalaxyl	SD
30/8			Aldicarb	G
28/9	Furalaxyl	SD	Furalaxyl	SD
4/10	Propamocarb	SD	Propamocarb	SD
8/10			Fenpropathrin	HVS
9/10			Sulfotep	S
12/10	Metalaxyl + Benomyl	SD	Metalaxyl + Benomyl	SD
16/10			Methomyl + Endosulfan	HVS
16/11	Metalaxyl	SD	Metalaxyl	SD
17/11			Sulfotep	S

Plants also received 5 Chlormequat sprays (Plant Growth Regulator) during the 1988 and 4 sprays during the 1989 crop cycle.

*: SD=Soil Drench: HVS=High Volume Spray; G=Granules; S=Smoke

3. Results and discussion

E. formosa was found to have parasitized both the species of Aleurodidae. However, while the parasitization of *T. vaporariorum* is clearly evident because the pupae become black, *E. formosa* larvae do not cause melanization of *B. tabaci* pupae. Several days after parasitization the *B. tabaci* pupae take on a light brownish colour. The form of the *E. formosa* emergence hole was similar in the two hosts' pupae.

The biological control of the two species was found to be very effective (Fig. 1). In 1988 the infestation trend of whitefly adults in the biological control house was not significantly different ($p > 0.05$) from that in the chemical control glasshouse; in 1989 this trend was significantly higher d($p < 0.01$) in the chemical control glasshouse, despite the strong reliance on different insecticides (Tab. 1)

The number of whitefly pupae per leaf in the biological control glasshouse progressively increased from August to December 1989 (Fig. 1), yet without reaching harmful levels. No significant differences were found in the pupae infestation trends of the two species (Fig. 2), but in analyzing the last 7 samples (From 3 weeks after the last *E. formosa* release) *B. tabaci* showed a significantly higher infestation compared to *T. vaporariorum*. ($p < 0.01$).

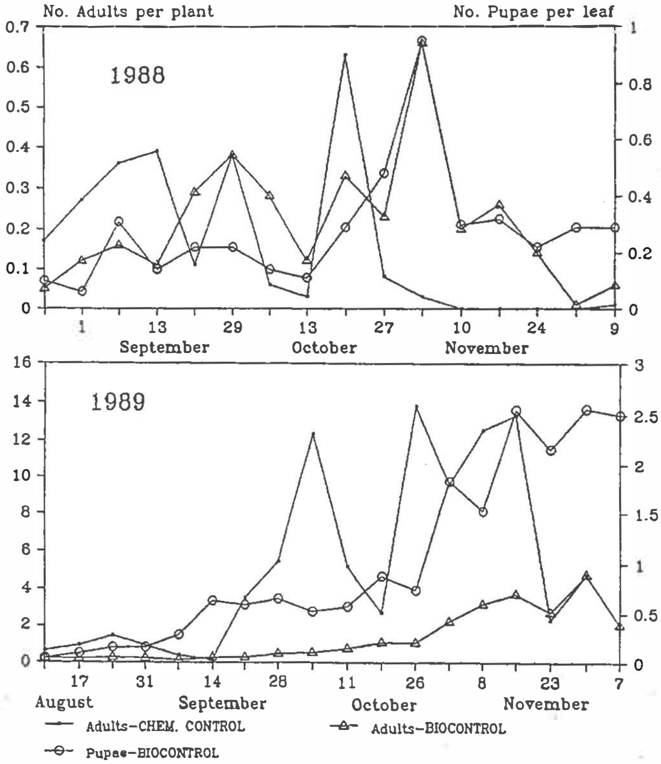

Fig. 1. Infestation trends of both adult whitefly species in the biological control and chemical control glasshouses and of pupae infestation in the biological control glasshouse in 1988 and 1989.

Nor were significant differences found in the trends of the two parasitization percentages monitored by the weekly sampling of 500 leaves (Fig. 3). Noteworthy is that the less evident colour change can lead, in this kind of field samplings, to an underestimate of parasitization as compared to *T. vaporariorum*'s.

The data related to the fate of the individually labelled pupae show that in the examined period the total parasitization by *E. formosa* was: 55.1 and 50.3% for *B. tabaci* and 61.1 and 64.4% for *T. vaporariorum* (Fig. 4). Here again no significant differences between the two hosts were found. Fig. 4 also shows the relatively high percentage of dead pupae for which it was impossible to determine the cause of death. This was also evident for *B. tabaci* (25.6% in 1988 and 14.8% 1989). The eventual killing of this species by *E. formosa* host-feeding or other reasons should be investigated in another type of experiment.

E. formosa emergence from parasitized pupae, which was monitored after labelling over several weeks, registered high percentages for both whitefly species (Fig. 5) and, again without significant differences between them.

These two-year trials show that *E. formosa* is effective in the biological control of both *B. tabaci* and *T. vaporariorum* on poinsettia. There are in all likelihood differences in the parasitoid's activity with respect to these two species, but an in-depth investigation of this aspect requires a different experimental approach.

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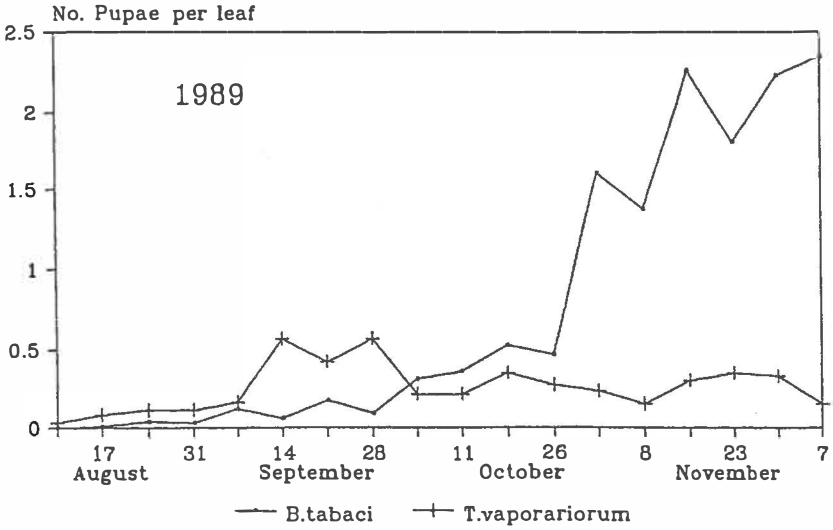

Fig. 2 Pupal infestation trends of *Bemisia tabaci* and *Trialeurodes vaporariorum* in the biological control glasshouse in 1989.

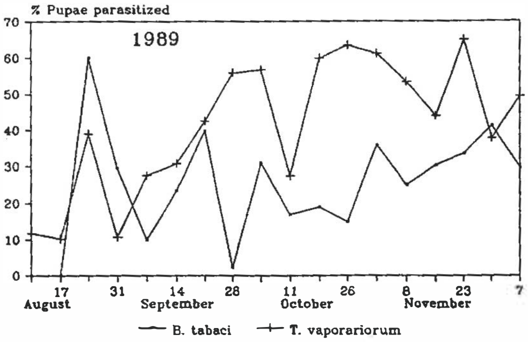

Fig. 3. Trends of *Encarsia formosa* parasitization of *Bemisia tabaci* and *Trialeurodes vaporariorum* found by visual monitoring of 500 leaves weekly in the biological control glasshouse in 1989.

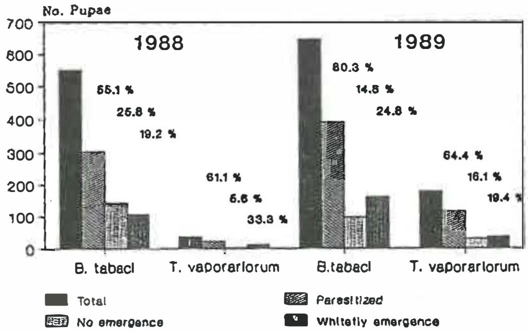

Fig. 4. total *Encarsia formosa* parasitization of *Bemisia tabaci* and *Trialeurodes vaporariorum* recorded by labelling the pre-imaginal instars.

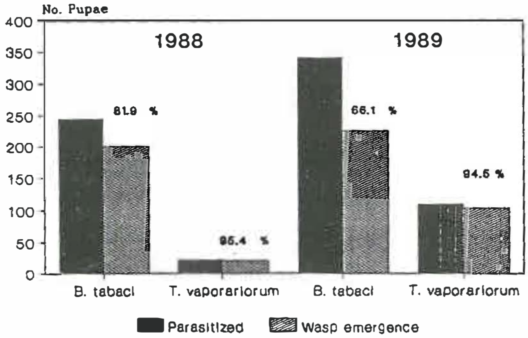

Fig. 5. Total *Encarsia formosa* emergence form *Bemisia tabaci* and *Trialeurodes vaporariorum* pupae recorded by labelling the pre-imaginal instars.

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CAN *BEMISIA TABACI* BE CONTROLLED WITH *ENCARSIA FORMOSA*?

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Summary

Management problems associated with the recent introduction of *Bemisia tabaci* in Western Europe have given incentives to look for natural enemies to control this new greenhouse pest. The parasitization behaviour and development of *Encarsia formosa* was studied for *Bemisia tabaci* in comparison with *Trialeurodes vaporariorum*. *T. vaporariorum* is the better host: immature mortality of *E. formosa* is considerably lower and quality of emerging parasites is much better than when *E. formosa* develops on *B. tabaci*. The host acceptance behaviour of *E. formosa* is apparently adapted to this situation: more eggs are laid in *T. vaporariorum* especially when both host species are offered simultaneously. Based on this information we think *E. formosa* cannot be used as a self perpetuating control system when the crop is infested exclusively with *B. tabaci*. Control might be obtained through regular (2-weekly) introductions of *E. formosa* during the cropping season.

1. Introduction

Until recently *Bemisia tabaci* was not a serious problem in greenhouses in Europe (van Lenteren & Woets, 1988). In 1987, *B. tabaci* was accidentally imported on poinsettia from the United States. It is particularly difficult to control due to its resistance to many pesticides. Its introduction is considered as a threat to successful biological control already implemented against a number of other greenhouse pests. Consequently, there were incentives to find a natural enemy for *B. tabaci*.

As a first step, we investigated whether *Encarsia formosa* could be used for controlling *B. tabaci*. As most of the available information on preference and performance of *E. formosa* was rather empirical and very few results had been published, we decided to start with a detailed observation of the parasitization behaviour in order to be able to interpret some of the empirical data. For reviews on *B. tabaci* and its natural enemies, we refer to Cock (1986), Gerling (1990) and Lopez Avila (1988).

The following aspects were studied:

1. The parasitization behaviour of *E. formosa* on *B. tabaci*,
2. The encounter probability of *B. tabaci* and *T. vaporariorum* with *E. formosa*,
3. The acceptance for oviposition of *B. tabaci* by *E. formosa*, and
4. The development of *E. formosa* in *B. tabaci*, and the quality of the parasite offspring.

2. Material and methods

Most of the experiments consisted of direct observations of the searching and oviposition behaviour of *E. formosa* as described in detail in earlier papers of our group (van Lenteren et al., 1976, 1980). Recording of behaviour was made with the help of the event recording program "The Observer" (Noldus, 1989), a software package especially developed for behavioural research. Naive female wasps were observed for a period of one hour in a climate room (20°C, 65% RH). The hosts offered to the wasps were always in superabundance, a condition which is essential in host choice experiments.

In some of the experiments either *T. vaporariorum* or *B. tabaci* were offered to *E. formosa*. In other experiments both types of hosts were offered simultaneously. To answer the question on development and quality of *E. formosa* when reared on *B. tabaci*, a large number of *B. tabaci* in a preferred stage were offered to *E. formosa*. The development was followed in detail. From the emerging parasites we measured size, number of ovarioles, oviposition frequency and lifespan.

3. Results

3.1. The parasitization behaviour of *E. formosa* on *B. tabaci*

The oviposition sequence of *E. formosa* on *B. tabaci* is the same as on *T. vaporariorum*. Once a host has been accepted for oviposition there are no obvious differences in parasitization behaviour. In several tests, oviposition in *B. tabaci* took significantly more time than in *T. vaporariorum*.

3.2. The encounter probability of *B. tabaci* and *T. vaporariorum* with *E. formosa*

The number of *B. tabaci* larvae encountered by *E. formosa* during the hour of observation was about 50% lower than that of *T. vaporariorum* when these hosts were offered separately. In experiments where both hosts were offered simultaneously at similar densities, 72% of the encounters were with *T. vaporariorum* and only 28% with *B. tabaci* (table 1). Van Lenteren et al. (1976, 1980, 1990) stated that the encounter probability of whiteflies depends on (a) the outline of whitefly larvae, (b) the walking speed and amount of turning of the parasite, and (c) the hairiness of the plant. In the present experiments only factor (a) could be different. The outline of *B. tabaci* larvae offered was, however, not smaller than that of *T. vaporariorum*. It seems therefore that *E. formosa* rejects *B. tabaci* larvae readily from a distance, but more research is necessary to prove this. Lower numbers of ovipositions on *B. tabaci* during the hour were also recorded in consequence of lower number of *B. tabaci* encountered and inspected. Furthermore, we found that pure patches of *B. tabaci* are left earlier and more often than pure *T. vaporariorum* patches (in 40% and 12% of all observations respectively). A much larger proportion of *T. vaporariorum* patches was parasitized than of *B. tabaci* patches.

3.3. The acceptance for oviposition of *B. tabaci* by *E. formosa*

Once encountered, *T. vaporariorum* and *B. tabaci* are equally accepted if offered separately. Approximately 45% of all encounters with unparasitized hosts in the third or fourth larval stage result in oviposition (table 1). Most rejections occur after the first antennal drumming phase. However, when *T. vaporariorum* and *B. tabaci* are offered simultaneously (choice situation) a drastic change in acceptance of *B. tabaci* occurred: 76% of the encountered *B. tabaci* were rejected. Acceptance of *T. vaporariorum* was about the same in the choice situation (circa 47%, see table 1). Earlier we have determined which host stage of *T. vaporariorum* is preferred for oviposition (van Lenteren et al., 1980). We have recently studied host stage preference of *E. formosa* for *B. tabaci* in detail (table 2). The experiment confirmed

Table 1. Number of encounters with and percentage acceptance of greenhouse (T.v.) and sweetpotato whitefly (B.t.) by *E. formosa*.

Host offered	Number tested	Total no. of encounters	Encounters with		% Acceptance of	
			T.v.	B.t.	T.v.	B.t.
T.v.	22	199	199		42	
B.t.	15	107		108		51
T.v. & B.t.	19	197	142	55	47	24

Table 2. Percentage acceptance of different larval stages of *T. vaporariorum* and *B. tabaci* by *E. formosa*.

host stage	% Acceptance of *T. vaporariorum*		*B. tabaci*
first instar larva	8		not tested
second instar larva	13		31
third instar larva	35		45
fourth instar larva	45		50
prepupa	35	prepupa + pupa	52
pupa	15		

observations summarized in table 1: 45-52% of the older larval stages and pupae are accepted for oviposition. Second instar larvae are rejected relatively often.

According to Gerling (1990) *Encarsia deserti* and *E. lutea* prefer the IVth instar stage of *B. tabaci* for oviposition, but parasites will also oviposit in instar stages II and III. Lopez Avila (1988) observed parasitization of four parasites - *E. formosa*, *E. cibcensis*, *E. adrianae* and *E. deserti* - in all five developmental stages of *B. tabaci* (LI - pupa). Parasites were able to complete their life cycle, independent of which host stage was parasitized. Developmental time of parasites was longer when young host stages were parasitized.

3.4. The development of E. formosa in *B. tabaci*, and the quality of the parasite offspring

An important question is what happens when *E. formosa* develops in *B. tabaci*. Is the quality of the emerging parasites as good as those emerged from *T. vaporariorum*? In The Netherlands *E. formosa* is introduced early in the growing season and later the offspring of the introduced parasites has to control new pest generations. Therefore, we need to know whether parasites reared from *B. tabaci* are able to control the next whitefly generations as well. The above results all relate to *E. formosa* reared on *T. vaporariorum* from Koppert BV. We started a culture on *B. tabaci*. Drastic changes in behaviour and performance occurred already after one generation on *B. tabaci*; the changes can be summarized as follows:

- Time spent drumming on a host and time spent with the ovipositor in the host's body (oviposition) was much shorter. The parasites stand still more often and longer.
- They left whitefly patches much earlier and more often.
- They encountered fewer hosts per unit of time (they walk slower).
- The number of hosts accepted for oviposition (be it *T. vaporariorum* or *B. tabaci*) is twice as low.
- Parasite mortality during development in *B. tabaci* was very high (80%) when compared with development in *T. vaporariorum* (< 10%).
- If *E. formosa* succeeds to develop in *B. tabaci* and does not die prematurely, the development is largely comparable to that in *T. vaporariorum*. Adults emerge from *B. tabaci* pupae only, not from younger stages. *B. tabaci* does not turn black after parasitism.
- Females are smaller, have fewer ovarioles (and have thus fewer mature eggs present), and lay fewer eggs per day (own observations and Lopez Avila, 1988).

4. Discussion and conclusions

When plants are infected with both *T. vaporariorum* and *B. tabaci*, *T. vaporariorum* is found and accepted more often, and will be eliminated first. If *B. tabaci* occurs alone it is accepted easier for oviposition, leading to a faster reduction than when occurring in mixed patches. The host acceptance behaviour of *E. formosa* is well adapted to the relative quality of the two hosts: parasitization occurs more frequently in qualitatively good hosts (*T. vaporariorum*) than in qualitatively poor hosts (*B. tabaci*) when offered simultaneously. With high enough *E. formosa* numbers and sufficiently frequent introductions, *B. tabaci* can be controlled by *E. formosa* even when it occurs together with *T. vaporariorum*. *E. formosa* reared from *B. tabaci* are less effective parasites: the overall percentage parasitism which can be realized by *B. tabaci* reared parasites will be much lower than that of *T. vaporariorum* reared parasites. Therefore, we do not expect that a few introductions of *E. formosa* will be sufficient for season long control of *B. tabaci*. Contrary to the situation with greenhouse whitefly, regular parasite introductions will be necessary. However, we expect *B. tabaci* problems to be limited because of a low rate of population growth in comparison with greenhouse whitefly (see Fransen, this volume). This is true as long as no important *B. tabaci* transmitted viruses are imported into Europe. We suppose that *B. tabaci* can be controlled on several important crops by relatively frequent introductions of *E. formosa*.

Further research results and statistical details will be published later (Boisclair & van Lenteren, 1990).

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THE EFFECT OF ANISALDEHYDE AS A SCENT ATTRACTANT FOR *FRANKLINIELLA OCCIDENTALIS* (THYSANOPTERA: THRIPIDAE) AND THE RESPONSE MECHANISM INVOLVED

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Summary

Anisaldehyde (4-methoxybenzaldehyde) was tested with a view to elucidating the possibilities of applying the scent for improving the catch of *Frankliniella occidentalis* on sticky traps in glasshouses. The odorous substance was used in combination with window traps and blue sticky traps. The results showed that anisaldehyde does not increase catches of *F. occidentalis* on scented window traps compared to unscented window traps, but that anisaldehyde in combination with blue sticky traps does increase catches significantly by a factor of 1.7 compared to unscented blue sticky traps. These results suggest that the response mechanism of *F. occidentalis* to flower scents is in fact an odour-induced visual response rather than pure anemotaxis.

1. Introduction

Thrips problems in glasshouses in temperate regions have become more and more severe during the 1980's because of the rapid spread of the western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) to a wide range of ornamental and vegetable crops (Brødsgaard 1989a). Due to the small size of *F. occidentalis* and its secluded way of living in flowers and buds, detection and monitoring of this thrips are very difficult. Therefore, experiments have been carried out to develop a monitoring tool.

Brødsgaard (1989b) found that *F. occidentalis* is attracted to colours and discerns clearly between different colours and hues. It was found that the greatest number of this flower thrips were caught on traps of a specific hue of blue.

Since fragrant flowers seem to attract more flower thrips than non-scented flowers it is likely that flower thrips orientate towards the scent of flowers (Annand 1926). Catches of thrips by means of different scents have been investigated by several researchers (e.g. Howlett 1914, Morgan & Crump 1928). The scents giving the largest catches of flower dwelling thrips have mainly been aromatic aldehydes found in flower oils (Attaway et al. 1966, Loper 1972). Penman et al. (1982) however, found that a non-flower scent, ethyl nicotinate, was highly attractive to *Thrips obscuratus* (Crawford).

Kirk (1985) tested four scents in combination with white water traps. The results showed that anisaldehyde (4-methoxybenzaldehyde) gave the greatest improvement of outdoor catches for the four species of flower thrips, compared to unscented white traps. He found no difference in catches of grass thrips between scented and unscented traps.

To investigate whether anisaldehyde in combination with blue sticky traps can increase the attractiveness and thus the effectiveness of blue sticky traps as a monitoring tool, experiments were carried out to find the preference of *F. occidentalis* for scented vs. unscented blue sticky traps. Furthermore, to investigate the response mechanism of *F. occidentalis* to anisaldehyde, these results were compared with the preference of the thrips for scented vs. unscented window traps.

2. Materials and methods

When a source of anisaldehyde is precent in a glasshouse, e.g. from a scented trap, the scent is detectable over a very large area and will thus affect the behaviour of thrips over this large area. This will interfere with the catches on 'unscented' control traps in this area (H.F. Brødsgaard, unpub. data).

The ability of *F. occidentalis* to orientate towards a scent source in glasshouses, where air movement is slow, was tested in an experiment conducted in a 30 m² glasshouse. Four window traps made of 5 x 10 cm clear acrylic plates glued on both sides with Tangletrap® were suspended vertically in a square pattern (2 m apart) over a crop of *Saintpaulia ionantha* Wendl. heavily infested with *F. occidentalis*. Two of the four traps were scented with a 2 cm long cotton string soaked with undiluted anisaldehyde (Merck art. No. 822314 A) attached to the insect glue. The other two traps were unscented controls. The traps were counted, replaced and re-randomised daily for 17 days.

Another experiment was conducted in a 30 m² glasshouse with anisaldehyde in combination with blue sticky traps (Riacryl 257, Brødsgaard (1989b)) to test whether a general anisaldehyde source can affect the efficacy of blue sticky traps,. Five potted sweet pepper plants (*Capsicum annuum* L. cv. 'California Wonder') heavily infested with *F. occidentalis* were placed in the NE corner of the glasshouse. Three blue sticky traps (7 x 20 cm) were suspended vertically 2½ m apart at a distance of 4 m from the plants in the WSW, SW and SSW directions. A general anisaldehyde source was made of a glass vial containing undiluted 4-methoxybenzaldehyde and closed with a PVC lid. A small hole (0.1 mm) was made in the lid so that a small amount of anisaldehyde would diffuse at a constant rate when the vial was exposed in the glasshouse. The vial was placed in the centre of the glasshouse every other day. The experiment lasted 36 days, i.e. 18 days with scent and 18 days with unscented controls.

The air temperature in the glasshouse was 26 ±4°C and the house was ventilated by means of roof vents which opened at 28°C.

3. Results

The results from experiment 1 show that *F. occidentalis* is caught in equal numbers by scented and unscented window traps 2 m apart. Experiment 2 shows that *F. occidentalis* has a significant preference for scented blue traps compared to unscented blue traps (Table 1).

Table 1. Mean ln-transformed number of *F. occidentalis* ± S.E. caught on sticky traps with and without anisaldehyde.

Exp. No.	Trap type	N	$\bar{x}$ ± S.E. scented	$\bar{x}$ ± S.E. unscented
1	window	34	1.4 ± 0.2	1.5 ± 0.2
2	blue	54	1.2 ± 0.1*	0.7 ± 0.1*

*) Significantly different ($P<0.1$) according to a T-test

4. Discussion

The results of these two investigations show that *F. occidentalis* does not orientate directly towards an anisaldehyde source, but that such a scent source in combination with a coloured trap can increase catch compared to an unscented coloured trap. This may suggest that anisaldehyde acts by stimulating a visual response in *F. occidentalis*. This means that when

F. occidentalis smells the scent it will seek towards the colour preferred. The improvement in catch was significant in experiment 2 but only by a factor of 1.7. This improvement in catch coincides well with the improvement of outdoor catches observed by Kirk (1987) for *Thrips imaginis* Bagnall in white traps in combination with anisaldehyde. He found an improvement by a factor of 3.3 for traps with an area of 23.8 cm^2. The coloured traps described in this experiment (2) have an area of 120 cm^2. Kirk (1987) stated that a strong visual appearance of traps reduces the effect of scent on flower thrips. Thus, the effect of anisaldehyde may well be more pronounced than in this experiment (2) if smaller traps or a sub-optimal trap colour is used, as the colour hue used in this experiment was the optimal of a wide range of hues tested (Brødsgaard, 1989b).

5. Conclusion

The western flower thrips (*F. occidentalis*) responds positively to anisaldehyde in combination with blue sticky traps in glasshouses. This could well be used in ecological studies. However, the use of anisaldehyde as an improvement of blue sticky traps as a monitoring tool in applied entomology is not relevant, as the catch improvement compared to unscented traps of optimal hue, size and shape is too small compared with the inconveniences associated with the use of scents (e.g. undiluted 4-methoxybenzaldehyde must be handled with caution in order to prevent ingestion and skin contact, the scent has to be replaced once in a while and the odour in the glasshouse is strong).

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RECENT DEVELOPMENTS IN INTEGRATED PEST CONTROL IN PROTECTED CROPS IN AUSTRIA

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Summary

The use of beneficials in protected crops in Austria is studied since 1985. *Encarsia formosa* and *Phytoseiulus persimilis* were successfully used in tomatoes and cucumber. Promising results were also achieved with IPM in bouvardia and roses. A project for large scale production of beneficials has been started in 1988.

1. Introduction

After several more or less unsuccessful attempts to massproduce and use beneficials for pest control in protected crops in Austria, a new initiative was started in 1988. The main reasons for this decision were the increasing problems with pesticide resistance and a general sensivitiy of producers and consumers towards the use of chemicals in agricultural production.

2. Production and use of beneficials

The three year project to build up and to establish a large scale production of the most used beneficials in glasshouses is mainly financed by the Federal Ministery of Agriculture and Forestry and is worked out in cooperation with the Federal Institute of Plant Protection, as well as with the Austrian Horticultural Growers Association (GLE). The latter institutions contribute the know-how, advisory services and the contact to the growers.

In 1989 the production started with an output for 7,5 ha which should grow to 25 ha in 1990, and to 50 ha or more in 1991. During the first year only *Phytoseiulus persimilis* Athias-Henriot on bean leaves and *Encarsia formosa* Gahan on tobacco leaves were offered. In 1990 also *Aphidoletes aphidimyza* and on a small scale basis Ammblyseius sp. will be produced (Austrian producer: Dr. M. Gross, Attemsgasse 44, A - 1020 Wien/Austria).

For other beneficials interested growers are referred to foreign producers.

In Austria beneficials were used in 1989 only on 2,5% of the total protected crops area of 540 ha. Details about the different cultures and various beneficials introduced into greenhouses can been seen in fig. 1 - 2.

3. Experimental experiences

Several trials were carried out since 1985 with *Encarsia formosa* against *Trialeurodes vaporariorum* (Westw.) in tomatoes, cucumber, eggplant and bouvardia, with *Phytoseiulus persimilis* against *Tetranychus urticae* (Koch) in cucumber and roses, and with Amblyseius sp. against Thrips sp. in cucumber and chrysanthemum.

3.1. Vegetables

3.1.1. *Trialeurodes vaporariorum*

In 1988 the control of whitefly by *Encarsia formosa* (E.f.) was studied in a commercial tomato greenhouse (300m², 800 plants) and a commercial cucumber greenhouse (216m², 300 plants). An introduction of 1,8 E.f. per plant in tomato and 3,4 E.f. per plant in cucumber resulted in respectively 89% and 74% parasitism, which was regarded a commercial success by the growers. All experiments to control greenhouse whitefly by the use of *Encarsia formosa* on vegetables pointed out the importance of yellow sticky traps for the monitoring of adult whiteflies, as well as for a certain degree of mass trapping (fig. 3a, 4a). Up to now this

Fig.: 1 PROTECTED CROPS CROWN IN AUSTRIA (1988/1989)

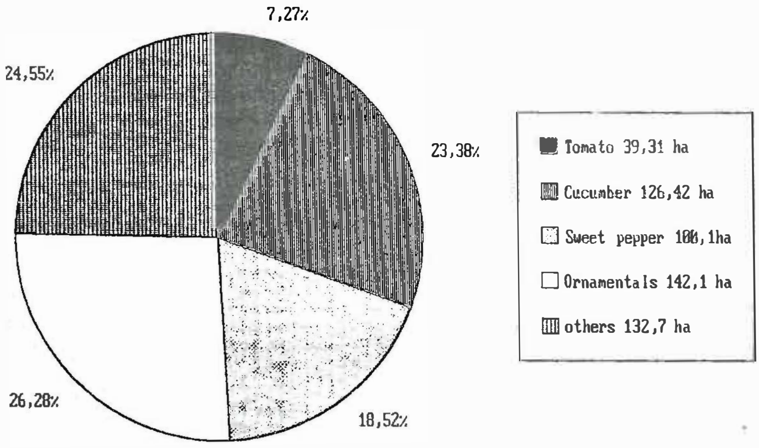
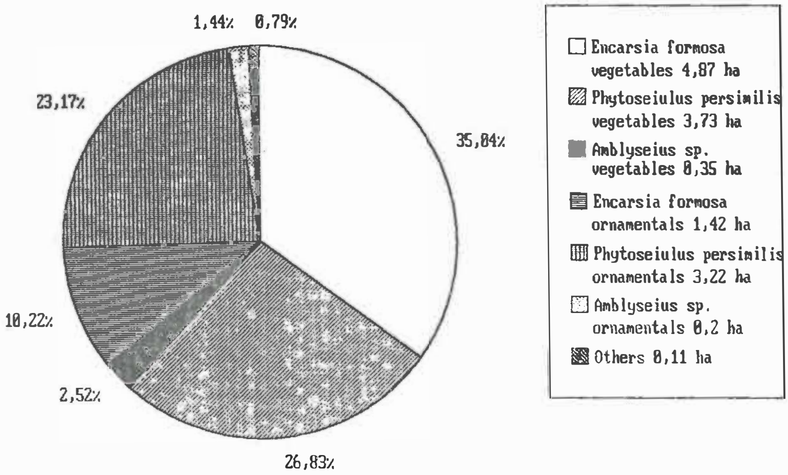


Fig.: 2 USE OF BENEFICIALS IN PROTECTED CROPS IN AUSTRIA (1988/1989)



biotechnical means of pest control has been well accepted by the growers. The comparison between the two methods to introduce the parasitic wasp proved both to be successful (fig. 3b, 4b). Although the banker-plant-system (Stacey, 1977) seemed to be more safe for "difficult" crops like cucumber or eggplant, than the use of detached leaves with *Encarsia formosa*, the transport and distribution problem still remains unsolved.

ig.: 3a Average trapping rate per yellow sticky trap (n = 32) in greenhouse tomatoes

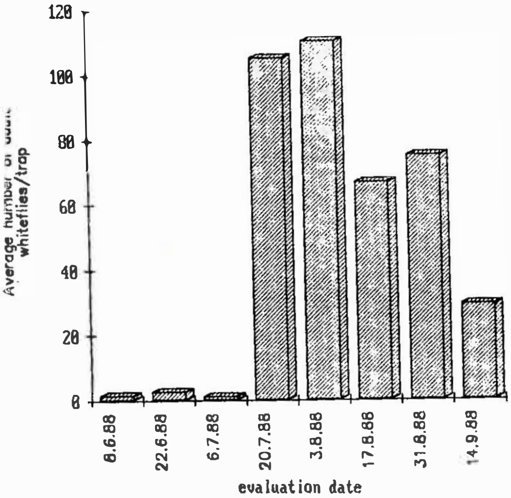


Fig.: 3b Development of Trialeurodes vaporariorum and parasitism by Encarsia formosa on greenhouse tomato

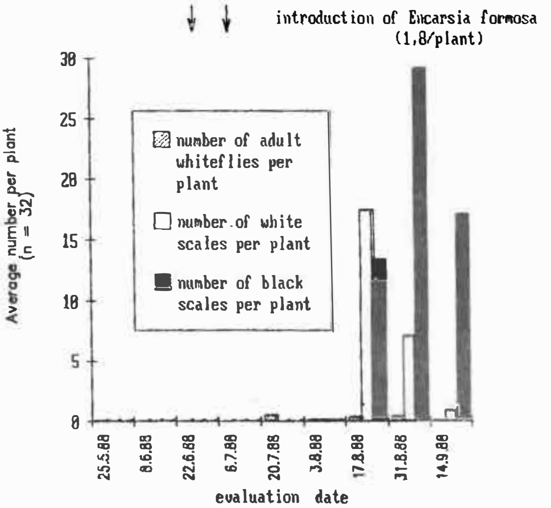


Fig.: 4a Average trapping rate per yellow sticky trap (n = 32) in greenhouse cucumber

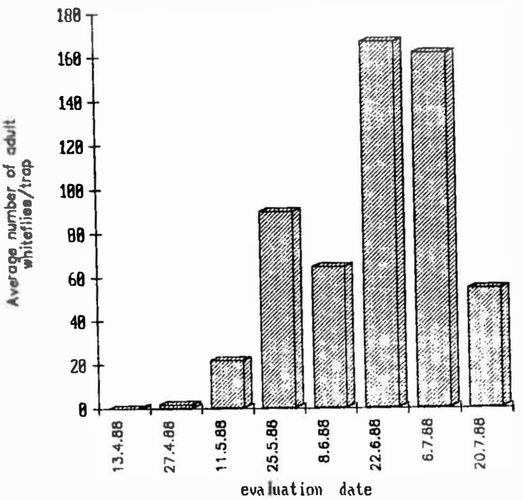
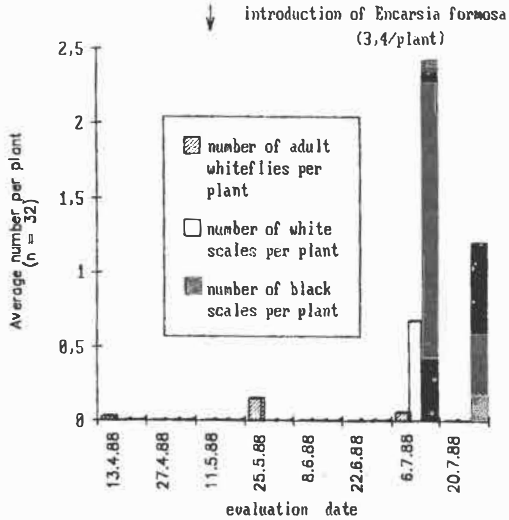


Fig.: 4b Development of Trialeurodes vaporariorum and parasitism by Encarsia formosa on greenhouse cucumber



Out of eight experiments to control *Trialeurodes vaporariorum* by the use of *Encarsia formosa* in vegetables only in one experiment with eggplants the parasitic wasp failured to give sufficient control.

In most of the trials other pests or diseases were treated with selective pesticides. After two years of integrated control measures an increase of natural occurring beneficials like

Chrysopidae, Coccinellidae, Anthocoridae and other species could be observed in the greenhouses, which mainly led to a suppression of aphid populations.

3.1.2. *Tetranychus urticae*

Phytoseiulus persimilis effectively controlled two-spotted spider mites on cucumber when introduced on bean leaves three weeks after planting. 1 -2 predatory mites together with 5-10 spider mites were placed on every 6th (Stenseth, 1980) of 360 cucumber plants. Additionally *Phytoseiulus persimilis* were brouhgt in ten weeks after the first introduction. In total 2,2 predatory mites per plant were applied.

3.1.3. *Thrips* sp.

The trial to control *Thrips* sp. on cucumber by the use of *Amblyseius* sp. could not be completed after initial promising progress, because of immigration of numerous Orius sp. Furthermore problems with the control of aphids forced the grower to apply non-selective insecticides.

3.2. Ornamentals

3.2.1. *Trialeurodes vaporariorum* in bouvardia

Greenhouse whitefly was successfully controlled in bouvardia by the combined use of *Encarsia formosa*, yellow sticky traps and buprofezin (4000 bouvardia plants in a greenhouse of 540m^2). At the start of the season 1,9 adult whiteflies were present per plant. 29 E.f. were released per m^2 . A first treatment with the selective insecticide was advised because of heavy spot-infestations in a quarter of the greenhouse and a second one because of the immigration of whiteflies from a neighbourhood cucumber glasshouse after the cucumber culture was finished.

3.2.2. *Tetranychus urticae* in roses

To evaluate the effect of *Phytoseiulus persimilis* against two spotted spider mite on roses in contrast to the treatments with acaricides 50 leaves from the lower part of different plants per greenhouse were examined for living or dead eggs, larvae and adults of *Tetranychus urticae* and the predator each week with the binocular. Furthermore the percentage of plants with infestation of spider mite or symptoms of spider mite damage out of 50 roses for sale were checked at weekly intervals.

The development of spider mite population at the different treatments is shown in Fig. 5. Differences could be observed in the infestation level and in the population development of *Tetranychus urticae* in the two glasshouses. The lower infestation level at the beginning of the season in greenhouse A may be due to the use of *Phytoseiulus persimilis* in this glasshouse in the year before the trial. It is known that most of the spider mites which cannot be effectively controlled by chemical treatment stay on the lower part of the plants, where the predators find good conditions and can therefore reduce the number of overwintering spider mites for the next growing season. The quality of roses for sale was slightly better in the glasshouse where the predators were used then in the greenhouse with acaricide treatment. For the mildew-sensitive rose variety "Only Love" twice as much fungicide treatment against powdery mildew was necessary in greenhouse A than in greenhouse B. For details see Blümel, 1990.

3.2.3. Thrips in chrysanthemum

During a trial to control *Thrips* sp. on chrysanthemum by the use of *Amblyseius* sp. in combination with coloured sticky traps, a comparison between different sticky traps for trapping of thrips was carried out. Blue sticky traps (Maasmond ®), white sticky traps

(Rebell®) and yellow sticky traps (Federal Institute of Plant Protection, Vienna) were weekly controlled for the presence of thrips. The best capture rate showed the blue sticky traps followed by white sticky traps. The yellow sticky traps captured almost no thrips.

On the blue sticky traps also a big number of adult syrphids was detected. A possible negative influence on the control of aphids was not checked.

Table 1. Experimental plot for the control of *Tetranychus urticae* on non-year-round-roses

criteria	greenhouse A	greenhouse B
rose variety	Sonja 3 rows Only Love 5 rows	Sonja 3 rows Little Silver 2 rows Frisco 3 rows
greenhouse area	680m^2	630m^2
number of plants	4000	4000
treatment against:		
spider mite	*Phytoseiulus persimilis* 6x 26/m^2 = 5/plant	acaricides 10x 2x Cyhexatin 5x Avermectin 1x Hexythiazox 1x Clofentizine 1x Bromopropylate 1x Fenpropathrin
aphids	7x insecticide	7x insecticide
thrips	5x insecticide	5x insecticide
powdery mildew	15x fungicide	7x fungicide

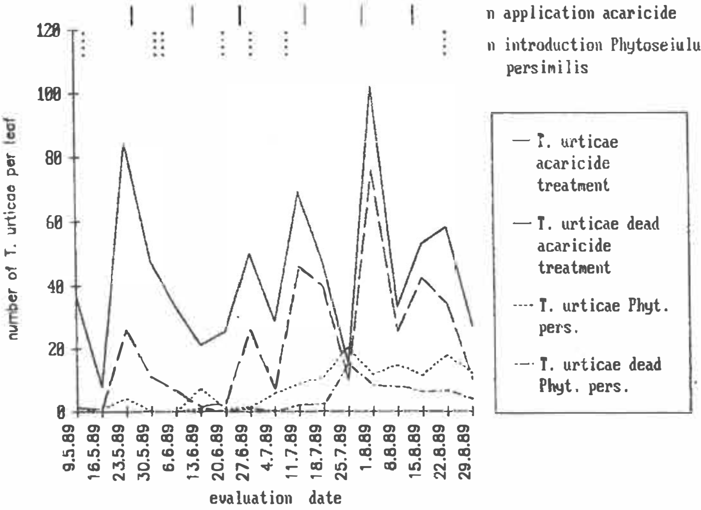
4. Information service

Growers are informed about production of beneficials and possibilities for their use on special meetings, in publications and by demonstrating them the production and commercial greenhouses where beneficials were introduced. Furthermore information about the possible combined application of pesticides are distributed for different crops. During the growing season there is advisory service from the Federal Institute of Plant Protection and other advisory boards.

Experiments for testing side effects of pesticides on beneficials have only been started 1988. All these informations are also available for horticultural schools.

Due to the great public interest in Austria TV-spots and films were produced.

Fig.: 5 Average number of developmental stages of Tetranychus urticae per leaf (n = 50)
on non-year-round roses (protected crop)
comparison of different control means



5. Prospects to the future

Techniques for the mass production of the beneficials will be improved constantly. The next trials will be carried out to test the open rearing system (Hansen, 1983) for *Aphidoletes aphidimyza* and *Aphidius matricariae* with grain aphids in vegetables as well as in ornamentals. Special experiments are planned for the control of whitefly on gerbera and pointsettsia.

Another topic may be the control of thrips with *Amblyseius* sp.

Like in many other countries the progress of integrated and biological pest control in protected crops can be endangered by newly occurring pests like *Frankliniella occidentalis* or *Bemisia tabaci.*

6. Acknowledgements

I would like to thank P. Ramakers for his kind provision of information and material for breeding *Amblyseius barkeri.*

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SROP/WPRS Bull. XIII/5 (1990), 45-50

AN INTEGRATED PEST MANAGEMENT PROGRAMME FOR PEPPERS; THREE YEARS TRIALS EXPERIENCE

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Summary

Extensive trials at several sites in the UK have shown that predatory mites (*Amblyseius* spp.) establish well on sweet peppers even in the absence of thrips. *Amblyseius* mites feed readily on pepper pollen (Klerk and Ramakers, 1986) and therefore a substantial population of the mites was sustained on the crop even when prey levels were low. Control of *Tetranychus urticae* by *Phytoseiulus persimilis* was generally good, providing predators were introduced evenly at the first sign of damage. Aphids (usually *Myzus persicae*) are a serious problem on peppers, and the control given by the predatory midge *Aphidoletes aphidimyza* was variable. Parasitic wasps (*Aphidius matricariae*) appeared naturally in most years, or were introduced, and helped to control the aphid population, but at most sites, sprays of pirimicarb were needed. This insecticide had little effect on *Amblyseius* populations. Caterpillars (*Mamestra brassicae* and/or *Laconobia olearacea*) were an occasional pest, but were controlled by *Bacillus thuringiensis* high volume sprays. It is concluded that the IPM programme is suitable for commercial use, but further work is needed to improve the effectiveness of *Aphidoletes*, and to investigate the effect of *Trichogramma* parasites against caterpillar pests of peppers. In addition, the suitability of Mycotal (*Verticillium lecanii*) as a control for whitefly, thrips and aphids should be investigated.

1. Introduction

Sweet peppers were traditionally grown as a short-season crop in the UK, in unheated glasshouses. However increased demand has led to peppers being grown as a long season heated crop, generally in rockwool. In this environment, a range of pests, including aphids (*Myzus persicae* and less commonly *Aphis gossypii*), thrips (*Thrips tabaci* and *Frankliniella occidentalis*), spider mites (*Tetranychus urticae*) and caterpillars (various species) commonly attack the crop. Chemical control of some of these pests, in particular *F. occidentalis*, would necessitate frequent sprays, and increasing concern about the possibility of pesticide residues on the fruit led ADAS to investigate an IPM programme for the pest complex attacking peppers. The aim of ADAS trials was to develop a robust IPM programme, which could be readily taken up by growers.

2. Methods and materials

Trial sites were either in commercial pepper crops, or in small experimental glasshouses. All the crops were long season heated crops grown in rockwool substrate. The trials were not replicated, but subsamples of leaves and flowers were taken from the trial area at each assessment. The trials in 1987 were designed to find the most effective rates of use for *Phytoseiulus persimilis*, but in addition *Amblyseius* spp. predatory mites were released on one site, against *T. tabaci*. Trials in 1988 investigated a full scale IPM programme using routine introductions of *Amblyseius, Phytoseiulus, Encarsia formosa,* and *Aphidoletes aphidimyza*. The programme was further tested on three sites in 1989, with the addition that *Aphidius matricariae* parasites were introduced at one site as well as *Aphidoletes* midges. Assessments were normally made "in situ" by checking leaves from the bottom middle, and top of the plant for numbers of pests and natural enemies. Pesticides were only applied when absolutely necessary: at most sites applications of pirimicarb (Pirimor) were needed for control of *Myzus persicae*.

3. Results

3.1 1987 trials

Table 1 shows the results of a trial in Worcestershire. Counts are the mean of 100 leaves per treatment. Predators were introduced at the first sign of spider mite damage.

Table 1.

Treatment	Sampling date	Number of *T. urticae*	Number of *Phytoseiulus*
1. 5 Predators per plant	23.07	2.9	0.1
	06.09	9.3	0.5
	20.08	0.2	0.3
	27.08	0.0	0.1
2. 2 Predators per plant	23.07	1.1	0.1
	06.08	5.0	0.2
	20.08	1.3	0.6
	27.08	0	0.2
3. Tetradifon + Dicofol on 17.07 and 03.08	23.07	2.0	-
	06.08	1.7	-
	20.08	1.1	-
	27.08	0.2	-

P. persimilis at 2 per plant appeared to work equally as well as at 5 per plant; and both rates gave better control than two sprays of acaricide.

Table 2. shows the results of a trial in Kent. Counts are the mean of 50 leaves per treatment. Predators were introduced at the first sign of spider mite or thrips damage.

Table 2

		Mean Number of			
Treatment	Sampling	*T. urticae*	*Phytoseiulus*	*Thrips*	**Amblyseius*
5 predators per plant	17.07.87	1.5	0	0	0
	16.08	0	0.11	0.41	0.21
	05.09	0.02	+	1,15	0.34
	28.09	0	0	0.77	0.35
2 predators per plant	17.07	0.7	0	0	0
	17.08	0.1	0.09	0.07	0.8
	05.09	0		0.37	0.15
	28.09	0	0	0.27	0.64

* Introduced at 8 per plant at the first sign of thrips.

At this site, *Phytoseiulus* gave good control of spider mite at rates of 5 per plant and 2 per plant. *Amblyseius* mites established well on the crop after one introduction, and appeared to suppress *Thrips tabaci* numbers.

3.2. 1988 trials

Table 3 shows the result of a trial in Yorkshire. Counts are the means of 192 leaves per assessment. *Aphidoletes* midges were introduced in 04/88 and 05/88, at 2 per plant. *Amblyseius* mites were introduced on 12/2 and 26/2/88 at 6 per plant. *Thrips tabaci* was recorded at very low levels during the trial.

Table 3.

Date	Mean number per 10 leaves				
	Amblyseius	Thrips	% leaf damaged by thrips	*Aphidoletes* larvae	Aphids
26.02.88	0.8	0	0	0	0
24.03	3.6	0	0	0	0
22.04	2.1	0.1	0.05	0	0
24.05	3.8	0.2	0.5	0	0
23.06	1.2	0.5	0.2	0.2	0
07.07	0.8	0.2	0.1	0	26
27.07	1.4	0.4	1	0.5	46
05.08	0.1	0	2.9	0.3	1.7

Aphidoletes did not establish on the crop from the first two introductions in April and May, but following the third introduction in June, larvae were found on the crop. Aphid control was poor, however, and sprays of pirimicarb were needed to reduce the population of *M. persicae*. However, *Amblyseius* mites established very well right from the start of the trial, even though no thrips were found at this time. Thrips numbers did not increase above 1 per 20 leaves sampled at any assessment, and crop damage was minimal. Again, sprays of pirimicarb had little adverse effects on numbers of *Amblyseius* mites.

Table 4 shows the results of a trial in Kent. Counts are the mean of 64 leaves per assessment. *Amblyseius* was introduced on 22/03/88 at 6 per plant.

Table 4.

Date	Mean number per 10 leaves	
	Amblyseius	*Thrips tabaci*
03.04.88*	9.5	37
14.05	0.1	0.5
25.05	4.5	0.3
09.07	8.0	0.7
01.07**	0	4.0
18.07	1.4	0.8
27.07	4.1	1.3

* Heptenophos sprayed on 15.04 and 30.04.88. *Amblyseius* re-introduced on 14.05

** Heptenophos sprayed on 28.06, and *Amblyseius* re-introduced on 11.07.

At this site, *Amblyseius* was introduced when levels of *T. tabaci* were high, and the applications of heptenophos in April had a very deleterious effect on the *Amblyseius* populations. However, numbers of the predator quickly rose following a re-introduction. Heptenophos was sprayed again in July, and again reduced numbers of *Amblyseius* to a very low level. Because heptenophos has little or no persistence, it was possible to re-introduce the predatory mites shortly after spraying.

3.3 1989 trials

Trials were carried out at three sites: *T. tabaci* was present at two of the sites, and *F. occidentalis* at the third. The full IPM programme used is shown in Table 5.

Table 5.

Beneficial	Rate used
Amblyseius sp.	25 per plant at start of flowering and 3 weeks later
Aphidoletes	1-5 per m² every week from planting
Aphidius	0.15 - 1 per m² every week from planting
Phytoseiulus	2 per plant at first sign of damage by spider mites
Encarsia formosa	0.7 per m² every week from planting

Table 6 shows the results of a trial in Yorkshire. Counts are the mean of 100 leaves per assessment. *Aphidoletes* was only introduced once at this site, but *Aphidius* was introduced every week as shown.

Table 6.

Date	Mean number per leaf		
	Amblyseius	*T. tabaci*	*Myzus persicae*
23.02.89	0.09	0.01	0
21.03	0.47	0.01	0
21.04*	0.64	0	0.15
17.05	0.29	0	3.14
13.06**	0.96	0	1.31
12.07	1.2	0	0
09.08	0.7	0	1.21

* pirimicarb applied 24.04
** pirimicarb applied 16.06, 23.06 and 09.08

In this trial, *Amblyseius* again established very well, and was present on most leaves throughout the trial period. *Aphidius* had little effect on the aphid population, and sprays of pirimicarb were needed at frequent intervals. In this case, however, the quality of the parasite was suspect, as many wasps had emerged on arrival. The results indicate further that pirimicarb has little effect on *Amblyseius* mites in practice.

Table 7 shows the results of a trial in Berkshire where Western flower thrips was present. *Amblyseius* mites were introduced at 25 per plant (mainly *A. cucumeris*, but some *A. barkeri*) one, 24 and 66 days after planting. In a separate compartment, thrips were controlled by spraying Dichlorvos.

Table 7.

Date	Mean numbers of Western flower thrips per flower	
	IPM Programme	Chemical Control Programme
30.06	0.13	2.27
07.07	0.09	3.59
18.07	0.30	17.18
24.07	0.31	17.74
31.07	0.99	8.32

In this trial, *Amblyseius* was allowed to establish on the crop for several weeks before Western flower thrips was introduced. The established population of predators was adequate to prevent Western flower thrips numbers increasing to economic injury levels. By contrast, sprays of dichlorvos in the chemical control programme did not prevent numbers of thrips increasing, and thrips damage was obvious in these plots.

4. Discussion

Because *Amblyseius* mites establish so readily on peppers they should be introduced routinely to the crop as soon as the first flowers open, or earlier if thrips damage is seen. At the rates used in the 1989 trials (25/plant for two introductions) control of both *T. tabaci* and *F. occidentalis* can be expected providing that thrips numbers are low at the start of introduction.

Amblyseius mites in particular *A. cucumeris* are sensitive to pesticides (Van der Staay, 1989) but several trials suggested that pirimicarb has little effect upon an established population. In the UK, Western flower thrips has become a widespread and serious pest on many nurseries. For this reason it is recommended that *Amblyseius* spp. predatory mites are introduced routinely to all pepper crops following the IPM programme.

Control of *T. urticae* presents no major problems: the rate of 2 *P. persimilis* per plant worked very well in two years trial work.

The weak links in the IPM programme at present are aphid (*M. persicae*) and caterpillar control. The predatory midge *A. aphidimyza* can give very good results against aphids (Markkula et al., 1979), but in these trials it was unreliable. Because pepper crops are normally grown in rockwool, with plastic sheeting on the floor there are no suitable pupation sites for the *Aphidoletes* larvae, and control of aphids must rely on continuous releases of midges every week into the greenhouse. This is likely to be very expensive in the UK. *A. matricariae* may be a better alternative, as they are cheaper and can give good control of *M. persicae* in practice. Further work is needed with this parasite. Another possibility is the pathogenic fungus *V. lecanii*. The strain available in the UK at present (trade name Mycotal) is effective against whitefly, with some effect on thrips and aphids. When used commercially against whitefly, good control of *M. persicae* has been seen (Wardlow, in publ.) on ornamental plants.

Much further development work remains with Mycotal, especially to investigate its effect on Western flower thrips. Release methods for *Aphidoletes* may be improved, leading to higher numbers of larvae on the plants. Another possibility is the use of 'banker' plants, infested with aphids such as *Sitobion avenae* to maintain a population of *Aphidoletes* in the glasshouse.

Control of cabbage moth (*Mamestra brassicae*) with *Bacillus thuringiensis* is not always very reliable. Alternatives which should be investigated are: diflubenzuron, and the use of *Trichogramma* sp. egg parasites.

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THE USE OF *APHIDOLETES APHIDIMYZA* FOR APHID CONTROL UNDER GLASS

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Summary

Experiments were conducted to assess the release rate of *Aphidoletes aphidimyza* required for control of *Aphis gossypii* on bed-grown chrysanthemums. The predator:prey ratio required for the control of *A. gossypii* on individual chrysanthemum stems was also evaluated. An assessment was made of the effect on midge diapause of the light-transmitting thermal screens, LS7 and LS11. The problems of using *A. aphidimyza* in integrated control in chrysanthemums and other crops are discussed.

1. Introduction

The aphidophagous midge, *Aphidoletes aphidimyza* (Rondani) is currently being evaluated as a possible alternative to chemicals or as a supplement or substitute for the pathogen *Verticillium lecanii* (Zimmermann) Viégas. The midge is well researched (reviews by Nijveldt (1988) and Kulp et al. (1989)), the first recorded commercial production and sale being in Finland in 1978 (Markkula and Tiittanen, 1985). In the UK, *A. aphidimyza* is available from several commercial sources and is sold as cocoons in peat, vermiculite or other media. Uptake of the midge by growers has been slow however, possibly due to a combination of relatively high cost and uncertainties over ways of applying the predator and integrating it with control methods for other pests and diseases.

The present paper describes research on methods of using the midge for aphid control, primarily in chrysanthemums. In all-year-round (AYR) chrysanthemums aphid problems can be commonplace, resistance to insecticides is well established, and the use of *V. lecanii* at the lower humidities present under modern growing conditions requires a succession of sprays to obtain satisfactory control (Helyer and Wardlow, 1987). The use of the midge in other crops is also briefly considered here.

Trials were therefore undertaken using weekly releases of cocoons into AYR chrysanthemum beds from the time of planting out until approximately three weeks before the crop was due to be cut. The initial trial was intended to establish whether *A. aphidimyza* could obtain control of *Aphis gossypii* Glover (the species with the highest increase rate on chrysanthemums), and the second trial assessed effective release rates. Small scale tests were conducted to establish the ratio of aphids:eggs likely to result in control. Experiments were also conducted to minimise the extend of diapause under blackouts by assessing the effect of the light-transmitting thermal screens, LS7 and LS11.

2. Releases into chrysanthemum beds

Tests with the midge involved the release of cocoons into beds of AYR chrysanthemums. Initial trials were at a high release rate of 30 cocoons per m^2 of bed in two glasshouse chambers in which a succession of beds were planted at monthly intervals, 3 beds per chamber. Plants were infested with *A. gossypii* from laboratory stocks at a rate of one aphid per nine plants. Two further chambers were retained as 'controls' i.e. aphids were present but midges were not released. Midge cocoons were introduced to each bed from the time of planting out and at weekly intervals thereafter. Four varieties were planted in each bed, each in two blocks, making a total of eight blocks. Varieties were chosen for reputed differences in resistance to attack by *Myzus persicae* (Sulzer) (no information being available for *A. gossypii*): Yellow Westland (partially resistant), Pink Gin, Hurricane, and Snowdon (susceptible).

Aphids in the control chambers reached damaging levels whereas in treated (midges released) chambers, *A. gossypii* increased no higher than a mean of 5 aphids per plant before being controlled by the midge larvae. The aphids were prevented from increasing again and a saleable crops resulted. Colonies eaten by midge larvae were evident in the growing points and buds, but the dead aphids did not remain on the plant for long. No honeydew damage was evident in the treated crops. No difference in the level of aphid attack by *A. gossypii* nor in the degree of control afforded by the midge was evident between varieties.

In a second series of trials, midges were introduced to the same four glasshouse chambers at four different rates. In the analysis of the first run, control was good at approximately 10 cocoons per m^2, but not at approximately 5 per m^2. In the chambers with two higher rates of introduction, aphid numbers appeared to be suppressed substantially, although the possibility that aphids did not establish satisfactorily cannot be discounted at present.

3. Establishing effective aphid:egg ratios

Individual potted chrysanthemum plants in vegetative growth were infested at the growing point with *A. gossypii* of mixed instars from stock cultures. After the aphids had settled, the plants were placed for a 24 h period only into cages containing male and female *A. aphidimyza*. Aphids and midge eggs were then counted on each plant and placed in a greenhouse chamber maintained at 15°C minimum. The development of the predator-prey interaction was followed by daily counts of aphids, eggs and predatory larvae.

With an initial ratio of 3 or less aphids per egg, substantial reductions in aphid density or elimination of aphids from the plant occurred. In the zone of 5 to 8 aphids per egg, control was followed by a resurgence after the predatory larvae had left the plant to form cocoons. With more than 15 aphids per egg, continued aphid increase was certain, albeit with some slowing of the rate of increase due to predation. Initial examination of similar data for *A. gossypii* on cucumbers at 20°C minimum suggests the ratios will not be markedly different.

Bouchard et al. (1988) found broadly similar ratios effective in a study of *A. aphidimyza* attacking aphids on apple. These ratios are for eggs laid within a 24 h period which differs from commercial practice where oviposition could, ideally, continue after predation in the colony has already started. The ratios may serve as a guide to the progress of control within individual colonies in crops where *A. aphidimyza* has been released, but have yet to be confirmed by counts in a commercial house.

4. Trials with screens LS7 & LS11 and with low-intensity light

The practice of 'blacking out' to initiate flowering can cause *A. aphidimyza* larvae enter diapause (hibernation) after they descend to the soil to form cocoons. It is the last larval instar that is sensitive to photoperiod, entering a diapausing condition if the daylenght is shorter than approximately 15.5 hours (Havelka, 1980). Initial observations with larvae from chrysanthemums allowed to pupate into pots of damp sand placed under black plastic blackouts showed 95% of the larvae entering diapause.

Tests were conducted with midge larvae under the lightselective thermal screens LS7 and LS11 which are in use in some AYR chrysanthemum nurseries as 'blackouts' (Lawson, 1987). The screens are used together in a double layer, LS11 consisting of reflective strips and LS7 green plastic strips, both in a woven matrix. Together they permit approximately 0.3% of the incident light to pass through, selectively filtering out the red wavelengths, the absence of which initiate flowering. Fortunately, low light intensities are known to avert diapause in *A. aphidimyza* (Gilkeson and Hill, 1986). Therefore, groups of potted chrysanthemums bearing *A. aphidimyza* larvae were placed under the screens and subjected to short-day conditions by 'blacking out'. Over the first three tests, 24% of the larvae entered diapause under the screens as against 14% with no blacking out at all, and 83% under the standard plastic blackout. This suggests that emergence from cocoons could be higher if light-selective thermal screens are in use and that some saving in the number of cocoons released may prove possible.

Low-intensity blue or green filtered incandescent lamps were suspended over chrysanthemum plants bearing *A. aphidimyza* larvae. Blacking out was by standard black plastic sheeting and the lamps were switched on from the time of blacking out to extend the photoperiod for the midge larvae. Over the first four tests, 42% and 49% of the cocoons entered diapause under green and blue light respectively, compared to 99% under full blackouts and 26% in long-day controls. The use of low-intensity lamps might therefore avert some diapause and permit continued reproduction, but the cost of lamp installation needs to be balanced against the pest control benefits. Bud formation under blue light was in advance of the plants under green light. This suggests there was sufficient red light in the spectrum from the green lamps to delay bud initiation and that further work should concentrate on blue or shorter wavelength light. The spectral sensitivity of diapause initiation in *A. aphidimyza* is unknown. In crops that are not photosensitive, the use of white light from a suspended bulb can be used to extend the seasonal period in which *A. aphidimyza* will reproduce normally (Gilkeson and Hill, 1986).

5. **Cucumber trial**

A preliminary trial for control of *A. gossypii* was conducted on cucumber. Surplus stocks of cocoons were released weekly into a house of cucumbers in rock-wool on a plastic-covered floor, after a low initial infestation of aphids had been found. Aphid increase was successfully suppressed, with larvae and many dead aphid colonies evident on the undersides of the leaves. No estimate of aphid densities was made. Aphids were not eliminated however, as two to three weeks after cocoon introductions had ceased, developing aphid colonies were again seen on the undersides of leaves. At the higher temperatures at which cucumbers are grown, *A. gossypii* increases very rapidly. It is evident that only regular releases of cocoons will prevent aphid resurgence in commercial crops.

6. **Discussion**

Further work is needed to establish a rate of introduction that will give reliable control in chrysanthemums, peppers and cucumbers. Present results for chrysanthemums indicate 10 cocoons per m^2, but this is high in relation to the cost of the midge (currently £15 - £25 per 1000 cocoons) and is not acceptable to the grower if successive introductions are necessary. While competition between rearing companies may help to lower the price somewhat, reducing the cost of mass production is of paramount importance for the wider use of *A. aphidimyza*.

The habit of cocoon formation beneath the plant may pose some problems for maximising the impact of *A. aphidimyza* and for integrating it with the control of other pests. It is not known how long the hibernating larva might remain in the soil below chrysanthemum crops. If the adults do not emerge before the crop is cut, subsequent soil rotavation or sterilization would be expected to cause mortality. Where the midge was used to protect pot chrysanthemums on slatted benching, it would be expected some would pass through the ground below to emerge successfully later.

In peppers or cucumbers, diapause would not be a problem, but floors covered with plastic could cause high mortality especially if 'Thripstick' is used for thrips control. These anticipated difficulties, together with the slower intrinsic rate of increase of this predator compared to many aphid species suggest that *A. aphidimyza* could not be used fully inoculatively in all cropping circumstances. Regular inundative releases may have to be made with emergence from the cocoons of earlier generations adding to the populations of adult midges in the house.

Early release while aphids are low in number or have yet to arrive appears important as eggs must be laid into small aphid colonies where the aphid:egg ratio can be kept low- this is essential for continuous effective control.

Tests on the side effects of fungicides, insecticides and acaricides on *A. aphidimyza* have been conducted and will be reported shortly (Helyer, in prep).

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AGE-SPECIFIC FECUNDITY AND ADULT LONGEVITY OF THE COTTON WHITEFLY, *BEMISIA TABACI* (GENN.) (HOMOPTERA: ALEYRODIDAE) ON POINSETTIA (*EUPHORBIA PULCHERRIMA*) AT DIFFERENT TEMPERATURES.

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Summary

Bemisia tabaci is a new pest in Denmark infesting glasshouse ornamentals, especially Poinsettia. The age-specific fecundity and adult longevity of *B.tabaci* on Poinsettia was investigated in the laboratory at five different temperatures. Temperature influenced longevity of *B.tabaci* females - at 16°C the adult females lived for 30 days, at 22°C for 22 days and at 28°C only for 15 days. Age-specific fecundity followed a general pattern at temperatures above 19°C. Daily eggproduction increased rapidly when whiteflies were young, reached a maximum and then declined and leveled off as the whiteflies got older. With increasing temperature the daily eggproduction was enhanced and the fertile period reduced. The maximum number of eggs were 2.5 eggs/day (16°C), 5.8 eggs/day (19°C), 6.6 eggs/day (22°C), 6.5 eggs/day (25°C) and 7.1 eggs/day (28°C) reached at the age of 14 days, 12 days, 10 days, 8 days and 5 days, respectively. The preoviposition period of *B.tabaci* at 16°C was 3.7 days which was significantly different from the preoviposition periods of 2-2.5 days obtained at 19°C, 22°C, 25°C and 28°C.

1. Introduction

For many years the cotton whitefly, *Bemisia tabaci* (GENN.) has been a serious pest of various crops in tropical and subtropical areas. During the last decades the importance of *B.tabaci* as a pest has increased, and many reports on the appearance of the species in new areas of the world have been made during the late 1980's (Price et al, 1987; Sanderson, 1987; de Guistina et al. 1989). In 1987 *B.tabaci* was introduced into Denmark for the first time. The introduction took place by means of imported plants. Since this first recording, *B.tabaci* has been found regularily as infestations of Danish glasshouse ornamentals, primarily Poinsettia (Scheel, pers. comm.).

As an important subtropical and tropical pest *B.tabaci* has been intensively studied and knowledge on the biology of the whitefly in crops like cotton and tomato, has accumulated (e.g. Horowitz et al., 1984, Butler et al., 1983, Azab et al., 1971, Gerling et al., 1980, Sharaf et al., 1985). Little is known, however, of the biology of *B.tabaci* under conditions prevailing in the glasshouse production of ornamentals in temperate regions. To provide basic information on biological characteristics of *B.tabaci* under these conditions experiments on reproductive capacity, developmental time and mortality have been undertaken.

In this paper results of experiments on age-specific fecundity and adult longevity of *B.tabaci* on Poinsettia at five different temperatures are presented.

2. Materials and methods

B.tabaci, originating from a culture at Pflanzenschutzberatung, Radolfzell, West Germany, were kept as a stock culture. The whiteflies were reared on tobacco (*Nicotiana tabacum*) in cages in an insectary, as well as in a glasshouse. The experiments were conducted on young Poinsettia plants (*Euphorbia pulcherrima*, cultivar *Angelica*) with 10-15 leaves. All studies were made in climate chambers over a period of 4 months at constant temperatures of 16°C, 19°C, 22°C, 25°C and 28°C, covering the range of temperatures encountered in

Poinsettia crops. The relative humidity varied between 60-90%. The photoperiod was 16:8 hr (l:d). Plants were infested with newly hatced (max. 24 hr old) *B.tabaci* females from the stock culture. The whiteflies were sexed under stereomicroscope without anesthetization. The females were kept individually in small clip-on-cages, 0.5 cm in diameter, placed on the youngest leaves giving the animal access to the underside of the leaf.

2.1. Age-specific fecundity

To obtain the daily fecundity rate 6 plants per temperature were infested each with 5 *B.tabaci* females. Every day the position of the cages were marked and cages plus females moved to a new spot either on the same or on a different leaf. Moving of the cages took place at normal room temperature without anesthetization. The numbers of eggs laid per female per day were counted under a stereomicroscope before egg hatching, i.e. every 4th-7th day depending on temperature.

For each temperature an additional plant was infested with approximately 400 newly emerged *B.tabaci* females. This plant served as a pool of females of similiar age as those used to initialise the experiment. From this pool females were drawn to substitute females that died in the clip-on-cages. The plant was enclosed with a fine mesh to prevent the whiteflies from escaping. The experiment was stopped when no females were left on the additional plant (3-7 weeks depending on temperature).

2.2 Longevity

To obtain longevity the same 6 plants used for the oviposition experiment were infested each with an additional 10 *B.tabaci* females in clip-on-cages. Every day dead and living whiteflies were counted. The cages were not moved and the inspection was conducted with as little disturbances as possible. The experiment ended when all whiteflies had died.

2.3 Statistical analysis

Longevity. Longevity at the different temperatures were compared by means of the t-test (SAS GLM procedure).

Agespecific fecundity. The mean daily number of eggs per female per temperature was calculated. Eggs laid by females that died during the 24 hr-periods were disregarded in the analysis. Age-specific fecundity has not yet been analysed, except for comparison of the mean maximum number of eggs/day/♀ at the five temperatures (t-test). The curve of age-specific fecundity versus age was fitted by eye to the model of Bieri et al. (1983).
Preoviposition period at the different temperatures were compared by means of the t-test (SAS GLM procedure).

3. Results

3.1 Longevity and survival rates

The average adult longevity of *B.tabaci* females on Poinsettia in relation to temperature is shown in table 1.

The lifespan of the whiteflies was influenced by temperature - the lower the temperature, the longer the females lived. Thus, at 16°C the longevity was 30 days, at 28°C only half this value. Significant differences in longevity were obtained between low temperatures (16°and 19°), medium temperatures (22°+25°) and high temperatures (28°). As temperature increased the standard deviation decreased implying that the range in lifespan narrowed.

Table 1. Longevity of *B.tabaci* females on Poinsettia at different temperatures. Values followed by different letters are significantly different at the 5% level (t-test).

°C	mean longevity (days)	S.E of mean	St.Dev.	Range
16	30.1 a	2.26	16.1	3-58
19	31.1 a	2.05	13.0	7-50
22	22.4 b	1.73	11.4	3-40
25	22.6 b	1.62	8.6	2-32
28	15.4 c	2.0	8.5	3-29

3.2 Preoviposition period

Table 2 shows the average preoviposition period of *B.tabaci* at the five different temperatures.

Table 2. Preoviposition period of *B.tabaci* females on Poinsettia at different temperatures. Values followed by different letters are significantly different at the 5% level (t-test)

°C	pre-oviposition period (days)	S.E of mean	St.Dev	Maximum (days)
16	3.7 a	0.39	1.9	9
19	2.6 b	0.19	1.0	6
22	2.4 b	0.12	0.7	4
25	2.5 b	0.16	0.9	5
28	2.1 b	0.07	0.4	3

B.tabaci females kept at 16°C had a preoviposition period of 3.7 days, which was significantly different from the preoviposition periods (2-2½ days) found at the other temperatures. At 19°C, 22°C, 25°C and 28°C the preoviposition periods were not significantly different.

3.3 Oviposition and age-specific fecundity.

The egglaying of *B.tabaci* varied with temperature. The daily number of eggs laid per female was in general lowest at 16°C and highest at 28°C. At 16°C the maximum number of eggs obtained from a single female during the 24 hr periods was 8 at the age of 14 days. At 28°C the maximum was 23 at the age of 9 days. The average age-specific fecundity rates (FR) in relation to temperature are shown in Fig. 1. At 19°C, 22°C, 25°C and 28°C the curves were of similiar shape: daily egglaying increased rapidly when females were young, reached a maximum relatively early and then declined and leveled off as the whiteflies got older. As the temperature increased the curves skewed to the left, i.e. the peak in fecundity occurred at an earlier age. The average maximum number of eggs (±s.e.) laid per *B.tabaci* female per day was reached at the age of 12 days (19°C), 10 days (22°C), 8 days (25°C) and 5 days (28°C), and was 5.8 ± 0.6, 6.6 ± 0.7, 6.5 ± 0.9 and 7.1 ± 0.8 eggs, respectively. These maximum values were not, however, significantly different. At 16°C it was difficult to recognize the same shape of the curve. However, a slight increase and subsequent slight decline could be seen. The increase in number of eggs was slow: the maximum average value (2.5 ± 0.4 eggs) was reached at the age of 14 days.

The curves of age-specific fecundity versus age were fitted to the model of Bieri et al. (1983) by eye. The model is: $FR = w(A-PO)/q^{(A-PO)}$, where FR is the observed age-specific fecundity rate, A is age, w and q are constants and PO are the preoviposition period. The fit of the model to the observed values was quite good at 28°C, 25°C and 19°C. The parameters estimated for the best fit of the curves are shown in the figure. The parameter PO had to be adjusted at 28°C to PO=0 days for a proper fit. At 22°C the variation is large and at 16°C the model does not fit very well.

4. Discussion

The average longevity of *B.tabaci* females on Poinsettia was dependent of temperature and shortened as temperature increased - at 28°C the longevity was 15 days, which was half of the longevity at 16°C. This is comparable to the study of Sharaf and Batta (1985) on female longevity on tomato, where longevity of 27.3 days and 14.3 days at 14°C and 25°C, respectively, were reported. Longevity of *B.tabaci* female on bean, cucmber, eggplant and squash was found to be 12 days, 9.1 days, 14 days and 12 days, respectively, at temperatures of 22-23°C (Sharaf et al., 1985). This is considerably shorter than the 22 days found on Poinsettia at 22°C in this study and could indicate that Poinsettia has qualities as a host plant different from the host plants cited. On cotton, longevity has been reported between 8 and 29 days from laboratory experiments at temperatures around 25-27°C. Thus, comparison of longevity between Poinsettia and cotton is difficult.

The previposition period of *B.tabaci* on Poinsettia varied with temperature between approximately 2 and 4 days. The design of the experiments, however, did not permit determination of periods less than 2 days, as the first observation on egglaying was made at this age. The percentages of females observed laying eggs 2 days old increased with temperature, however, and was especially high at 28°C, indicating that a large number of females may have laid eggs already at the age of 1 day. Consequently, the actual preoviposition period may be shorter than the ones found, at least for *B.tabaci* females kept at 28°C. Still, the difference between the two extremes (16°C and 28°C) is relatively small. Studies including observations on the preoviposition period of *B.tabaci* under controlled conditions are scarce, but on tomato preoviposition periods of 4.9 and 3.6 days at 14°C and 25°C, respectively, have been reported (Sharaf and Batta, 1985). This is longer than the values found on Poinsettia in this study. The earlier start of oviposition on Poinsettia could indicate, that this host is more suitable to *B.tabaci* than tomato. However, comparison of the results and conclusions on host acceptability is not straightforward, as experimental conditions (relative humidity and photoperiod) in the two studies was different.

The pattern of oviposition of *B.tabaci* on Poinsettia was influenced by temperature. The lower the temperature, the lower the average daily number of eggs laid per female and the longer the time before the maximum preformance was reached. In the study of von Arx et al. (1985) the daily fecundity rate at 27°C was determined on cotton. The shape of the curve compares with the one found on Poinsettia at 25°C and 28°C. However, an average maximum fecundity of 16 eggs/day was obtained on cotton as compared with 6.5 and 7.1 eggs/day on Poinsettia at 25°C and 28°C, respectively. The maximum daily oviposition on cotton occurred when the whiteflies were 5 days old. This is similiar to the results on Poinsettia, where maximum oviposition occurred at the age of 8 days at 25°C and 5 days at 28°C. Compared to these results fecundity of *B.tabaci* on Poinsettia seems to be lower than on cotton. Normally, fecundity of *B.tabaci* has been determined as the total number of eggs per female. Thus at temperatures around 25-27°C the total number of eggs per female has been found to be 50 (eggplant) (Avidov, 1956), 127.5 (cotton) (von Arx et al., 1983), 81 (cotton) (Butler et al., 1983), 76 (tomato) (Sharaf & Batta, 1985). An estimate of the average total number of eggs per female on Poinsettia was obtained by summing the daily egglaying up to the age

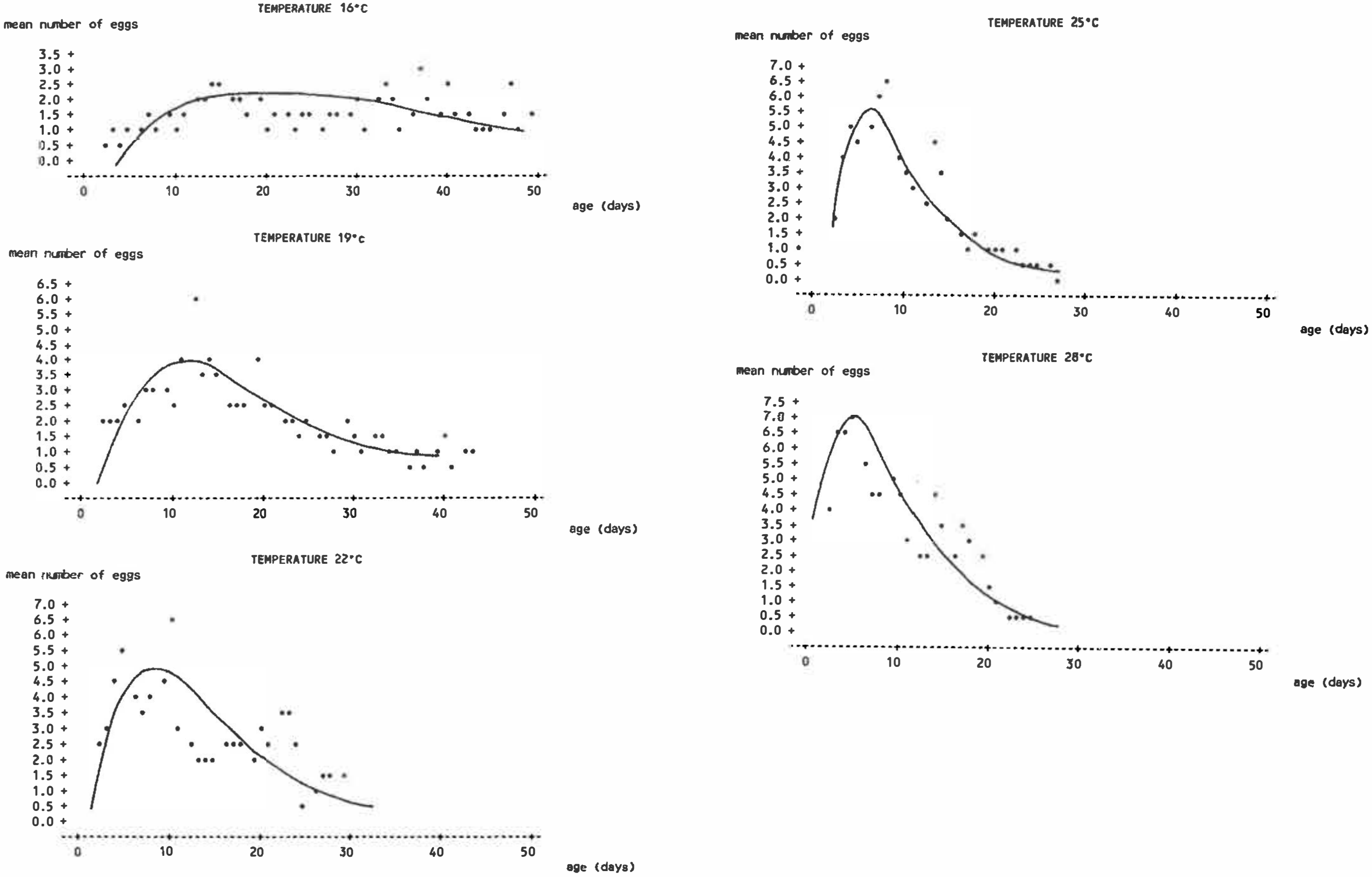

Fig. 1. Age-specific fecundity of B.tabaci on Poinsettia at different temperatures.
Models are: 16°C $FR=0.415(A-3.7)/1.0725^{(A-3.7)}$; 19°C $FR=1.2(A-2.6)/1.12^{(A-2.6)}$; 22°C $FR=2.5(A-2.4)/1.2^{(A-2.4)}$; 25°C $FR=4(A-2.5)/1.3^{(A-2.5)}$; 28°C $FR=4A/1.23^{A}$.

corresponding to the average lifespan at the respective temperatures. This value was 64 eggs/♀ at temperatures comparable to the cited results (25°C and 28°C) and is reasonably similiar to the results from eggplant and tomato, but lower than results obtained from cotton. This supports that Poinsettia presumably is a less suitable host for *B.tabaci* than cotton.

5. Conclusion

From the present study it is apparant that *B.tabaci* is able to survive and reproduce on Poinsettia at temperatures between 16° and 28°C. None of the two extreme temperatures therefore constitutes a limit for survival and reproduction. Based on results on fecundity, Poinsettia seems to be less suitable than cotton and equal to tomato and eggplant as a host for *B.tabaci*. On tomato and Poinsettia longevity is similiar which supports that these plant species are of equal quality to *B.tabaci*. Longevity on eggplant, on the other hand, is shorter than on Poinsettia, making the conclusions on host plant quality more difficult.

For a more precise evaluation of host plant quality to *B.tabaci* parameters like sex-ratio, mortality and developmental time in relation to various environmental conditions (temperature, humidity, photoperiod etc.) have to be taken into consideration. Experiments to evaluate these parameters on Poinsettia have been planned and initiated.

Finally both fecundity and survival of *B.tabaci* on Poinsettia may turn out to be higher than determined in this study, as the females used for the experiment were reared on tobacco. By rearing *B.tabaci* on Poinsettia for one or more generations, adaptation to the host plant may increase both fecundity and survival. The influence of periods of adaptation to Poinsettia will be investigated in subsequent studies.

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DEVELOPMENT OF *BEMISIA TABACI* GENNADIUS (HOMOPTERA: ALEYRODIDAE) ON POINSETTIA AND OTHER POTPLANTS GROWN UNDER GLASS

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Summary

Recently the whitefly, *Bemisia tabaci*, became a pest in poinsettias grown in greenhouses. This insect originating from tropic and subtropic regions has been studied on outdoor crops like cotton and tobacco. There is not much known about its life cycle on ornamentals or vegetables under glass. The development rate of sweetpotato whitefly was determined on poinsettia, Gerbera, Hibiscus, and Begonia. All four pot-plant species appeared to be good host plants. Development from egg to adult took 46.5 days on Begonia, 47 days on Hibiscus, 49 days on Poinsettia and 50 days on Gerbera at 20°C in a glasshouse. At 25°C the development from egg to adult ranged from 22 days on Begonia to 29 days on Gerbera.

1. Introduction

The sweetpotato whitefly, *Bemisia tabaci* Gennadius, has been known as a severe pest on tropical and subtropical crops like cotton, tobacco and sweetpotato. The insect is very polyphagous as was shown by Greathead (1986) who mentioned 506 plant species belonging to 74 families being host plants of this whitefly. However, it was not a pest in greenhouses until recently. The first reports of *B. tabaci* causing problems in Poinsettias, Gerbera daisy and Hibiscus were from Florida, Georgia and California (Miller, 1987). Also in the Netherlands sweetpotato whitefly was found on Poinsettias during the autumn of 1987. The whiteflies may infest a greenhouse crop by three main routes: (1) from young cuttings received from the propagator, (2) from infested weeds or hobby plants in the same greenhouse, (3) from other host plants grown in neighbouring compartments or greenhouses.

Poinsettia is a short-term crop grown for the market in November and December. Thus, growers are not specialised on Poinsettias but have other crops as well which can be exposed to the risc of infestation by *B. tabaci.* In the Netherlands besides on Poinsettia this whitefly was occasionally found on Begonia, Hibiscus and Bouvardia. A program aiming for eradication was started in winter and spring 1987/1988. Sofar the number of growers having sweetpotato whitefly has not increased compared with the number in 1988. Poinsettia propagation is under regular supervision by the Plant Protection Service. Although this whitefly has not yet been eradicated, its disperal has been restricted and control of *B. tabaci* generally causes the same problems as greenhouse whitefly, *Trialeurodes vaporariorum*.

The application of chemical compounds like selective insect growth regulators, and the introduction of parasitoids like *Encarsia formosa*, require detailed information on the biology of *B. tabaci*. Thus, in 1988 and 1989 experiments were carried out to determine the development rate of *B. tabaci* on Poinsettia, Hibiscus, Gerbera and Begonia.

2. Material and Methods

2.1 Experiment 1

The first experiment was carried out in autumn 1988 in a greenhouse with a controlled climate. The temperature was kept at 20°C but raised at 21-22°C during sunny midday periods. Natural daylength decreased during the experiment from a 12 h photoperiod to about an 8 h photoperiod. *B. tabaci* females were put in clip cages onto the plants to lay eggs for 24 h. The whiteflies originated from the same host plant species as on which they laid their eggs. Poinsettia (*Euphorbia pulcherrima*) cv Top White, Begonia cv Cristel, Hibiscus cv Paramaribo, and Gerbera cv Terra Fame were used as host plants.

Twenty leaves per host-plant species carrying whitefly eggs -two per plant- were inspected daily. The development of whitefly from egg, first, second, third and fourth instar larva to pupa and finally emergence of adults was observed by counting the numbers of whiteflies belonging to the different stages on the leaves.

2.2 Experiment 2

The second experiment was carried out in winter and spring 1989. Controlled-climate rooms were used at 20o and 25°C. Plants were kept at a 16 h photoperiod. For infestation by *B. tabaci* the same procedure was followed as in Experiment 1. Sixteen leaves per host-plant species and temperature regime carrying whitefly eggs -also two per plant- were inspected daily.

3. Results and Discussion

3.1 Egg hatch

The overall 50% hatch of first instar larvae on Poinsettia takes place after 15 days in the greenhouse environment and after 16.5 days in the controlled-climate room at 20°C. At 25°C the development is about twice as fast, lasting about 8 days (Table 1). The developmental time of the eggs does not depend much on plant species. On Begonia it is impossible to locate the eggs because the undersurface of the leaves reflects the light and plants are easily damaged when handling them under a binocular. Thus, on Begonia only the emergence of adult whitefly from the pupae was observed. The 50 % levels were calculated by using the total amounts of eggs compared with the total amounts of first instar larvae. The analysis of the development rate per separate leaf has still to be carried out (Fransen, in prep.).

Table 1. Development period (days) of *Bemisia tabaci* from egg to first instar larva until hatching of the first larvae (min) and the period until 50% hatching

host plant	Exp.1		Exp.2			
	20°C		20°C		25°C	
	min	50%hatch	min	50%hatch	min	50%hatch
Begonia	-	-	-	-	-	-
Hibiscus	12	14.5	12	15.5	7	8.0
Poinsettia	12	15.0	14	16.5	7	8.0
Gerbera	12	15.0	14	16.5	6	8.0

B. tabaci took 6.14, 7.3 and 7.67 days for 50% hatching on bean, tomato and cotton, respectively, at 25°C and a 16 h photoperiod (Lopez-Avila, 1986). Butler et al. (1983) found that 50% of the larvae hatched after 7.6 days at 25°C and after 11.5 days at 20°C on cotton as a host plant. The development of the eggs on potplants takes longer than on cotton, especially at the temperature of 20°C.

3.2 Development from egg to adult

On Begonia the development from egg to adult emergence was the shortest compared with the development on the other host plants (Table 2). The impact of an increase of temperature from 20 to 25°C is very great. The differences in the 50% emergence period for

B. tabaci in the greenhouse and the controlled-climate room at 20°C can be caused by slight differences in temperature regime. The difference in photoperiod does not seem to have much influence in this set-up. However, there may be an influence on the rate of emergence. The period between the emergence of the first adults and 50% emergence for Poinsettia was 11 days in experiment 1 and 7.5 days in experiment 2 at 20°C. This deviation is not expected to be merely caused by temperature differences, but data have still to be analysed in detail.

Table 2. Development period (days) of *Bemisia tabaci* from egg to adult emergence until emergence of the first adults (min) and emergence of 50% of the adults.

host plant	Exp.1		Exp.2			
	20°C		20°C		25°C	
	min	50%em	min	50%em	min	50%em
Begonia	38	46.5	-	-	20	22.0
Hibiscus	34	47.0	40	46.0	20	25.0
Poinsettia	38	49.0	39	46.5	19	23.0
Gerbera	37	50.0	41	50.0	21	29.0

Regarding the development of sweetpotato whitefly on other host plants, Lopez-Avila (1986) reported that the development from egg to adult took 21.5 days on bean, 23.0 days on cotton and 23.5 days on tomato at 25°C and a 16 h photoperiod. Also Butler et al. (1983) found a development period of 23.6 days on cotton at that temperature. These results show that the potplants tested in these experiments fit in the range of other host plants for *B. tabaci*. However, the development at 20°C is shorter for cotton being 34.7 days as found by Butler et al. (1983). Besides being less adapted to lower temperatures than other *B. tabaci* strains the sweetpotato whitefly in the Netherlands seems also different from greenhouse whitefly, *T. vaporariorum*. Dorsman & Van de Vrie (1987) reported a developmental time of 32.2 days at 20°C and 22.1 days at 25°C for greenhouse whitefly on Gerbera cv Terra Fame.

It is worthwhile mentioning that the pupae of *B. tabaci* form setae on hairy plants like the Poinsettia and Gerbera cultivars used in this experiment, whereas the pupae totally lack any setae on glabrous plants like the Hibiscus and Begonia cultivars used. This phenomenon is also described by Mound (1963) regarding *B. tabaci* on cotton, cassave and tobacco. Further analysis of the data has to be carried out also including information on the development rates of sweetpotato whitefly in the different larval instar stages. It can be concluded that one of the causes of *B. tabaci* being a problem during the summer rather than during other times of the year is the extremely long development period at temperatures of 20°C compared with that period at 25°C.

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BIOLOGICAL CONTROL OF APHIDS IN GREENHOUSE SWEET PEPPERS AND TOMATOES

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Summary

This paper describes release rates, sampling and management methods developed over three growing seasons for biological control of aphids in sweet peppers and tomatoes grown in Canadian greenhouses. A combination of the aphid predator *Aphidoletes aphidimyza* and the parasitoid *Aphidius matricariae* provided the best control throughout a long-season crop. The suggested release rate schedule for predators, as well as using lighting to prevent diapause, changes needed to plastic covered floors to ensure pupation, and detrimental effects of spot-spraying with pirimicarb are also described.

1. Introduction

In the western Canadian province of British Columbia, commercial plantings of sweet peppers increased from 0.5 ha in 1986 to over 16 ha of peppers in 1990, most of which is concentrated in large holdings of 2-5 ha each. The key pest in peppers is green peach aphid (*Myzus persicae*). Biological control of western flower thrips (*Frankliniella occidentalis*) is usually successful with applications of the predatory mite *Amblyseius cucumeris*, and two-spotted spider mites (*Tetranychus urticae*) are controlled with *Phytoseiulus persimilis*. Greenhouse tomatoes in Canada are seldom infested with aphids, but when they are, chemical control of aphids interferes with the biological control programs for greenhouse whitefly using *Encarsia formosa*. Although pirimicarb controls most strains of green peach aphids, residues are not allowed on food exported to the U.S.A., which is an important market for Canadian greenhouse produce. The goal of this research project was to determine whether biological control of aphids in peppers and tomatoes would be economical for Canadian growers. If successful, using *Aphidoletes aphidimyza* at the rate suggested by Markkula and Tiittanen (1977) of 2-5 pupae per m^2 (or about 1-2 pupae per plant, assuming a density of 2-2.5 plants per m^2) was likely to be economical, whereas other experimental rates, such as 20 to 50 midges per plant (c.f. Hofsvang & Hagvar, 1982) would cost too much at current prices (CD$35 per 1000 pupae). This paper reports the results of three years of monitoring pepper greenhouses and one season of monitoring a tomato greenhouse to develop release rate recommendations.

2. Methods

2.1 Test Greenhouses

In the first year, three greenhouses were monitored: a 0.5 ha pepper greenhouse (A) with plants set out from December to November, a 0.1 ha pepper greenhouse (B) with plants set out from June through October, and a 0.5 ha tomato greenhouse (C), with plants set out from January to November. All crops were grown in rock wool blocks set in sawdust bags, However, bags were placed on a white plastic floor in greenhouse A and on a gravel floor in greenhouses B and C. In the second year, three greenhouses were monitored: greenhouses A and B, both with the same timing and growing system as the previous year, and another pepper greenhouse (D), a 0.5 ha greenhouse with a January to November crop, also grown in sawdust bags on a plastic covered floor. In the third year, only greenhouse A, with the same timing and growing system as previous years, was monitored.

2.2 Sampling Methods

Sampling methods were the same for all greenhouses. A randomly chosen top, middle and bottom leaf was checked weekly from each of 30 plants per greenhouse. During the first and second season, different plants were chosen randomly each week throughout the greenhouse, whereas during the third year, the same sample plants, spaced throughout the greenhouse, were checked each week. Each leaf was bagged separately and all aphids. *A. aphidimyza* eggs and larvae and unemerged mummies of the native aphid parasitoid, *Aphidius matricariae*, were counted.

2.3 Release Rates

A. aphidimyza were released as needed according to whether the mean numbers of aphids per leaf had increased or decreased each week. Very low release rates of 1 pupa per 5-6 plants were used initially the first year in both tomatoes and peppers. On peppers, in mid-summer, a rate of 1 pupa per 2-3 plants was used, however, later in the season, when plants were larger, a rate of 1 pupa per 1-2 plants was used. High release rates (1-1.5 pupae per plant) were tried in the smaller greenhouse B. During the second season, in both large pepper greenhouses (A and D) releases of *A. aphidimyza* (1 pupa per 1-4 plants) were combined with early season inoculative releases of *Aphidius matricariae* at the rate of one parasitoid per 100 plants, weekly, for 2-3 weeks in each test greenhouse. In greenhouse B, rates of 1-1.5 predator pupae per plant were again used; *Aphidius* was not released because mummies were already present when plants were set out in late June. During the third year, higher releases of both *A. matricariae* (1 per 25 plants) and *A. aphidimyza* (an average of 1 pupa per plant) were used in greenhouse A.

3. Tomato Greenhouse Results

Aphids, most *M. persicae* and *Aulacorthum solani* appeared on lower leaves of tomato plants in May. A mean of ca. 6 aphids per lower leaf was found on May 26, when 1 *A. aphidimyza* pupa was released per 6 plants. Although probably unnecessary because aphid numbers had already dropped, 1 *A. aphidimyza* per 12 plants was released on June 9. By June 30, aphids had been eliminated and no aphids were found in samples for the remainder of the season. Subsequently, it was recommended that commercial growers apply 2 releases of *A. aphidimyza*, at a rate of 1 pupa per 6 plants, one or two weeks apart. No further research was planned because growers reported satisfactory results with this schedule.

4. Pepper Greenhouses Results

4.1 Release Rates and Timing

In all years, the total number of *A. aphidimyza* released over the growing season in the 0.5 ha greenhouses (A and D) ranged from 8.2 to 9.4 pupae per plant regardless of release pattern, duration of crop or effect on aphids. In greenhouse B, higher releases of 9.4 to 10 pupae per plant per year were used over a short growing season.

In greenhouse A, the first year of experimental releases started in May, after the crop was well grown.The first releases of 1 *A. aphidimyza* per 5-6 plants did not seem to become established. Releases were increased to 1 pupa per 2-3 plants in late summer, but aphid populations were only controlled when rates of 1 pupa per 1-2 plants were tried in September. During the second season, monitoring started as soon as the crop was set out in December; early releases of 1 pupa per 5-10 plants, along with inoculative releases of *A. matricariae* (1 parasitoid per 100 plants), controlled aphids until April. By mid-summer, releases of 1 *A. aphidimyza* per 1-2 plants were necessary to control aphids on the larger plants. During the same year, in greenhouse D, initial releases of 1 pupa per 2 plants along with two inoculative releases of 1 *A. matricariae* per 130 plants controlled aphids early in the year (Figure 1).

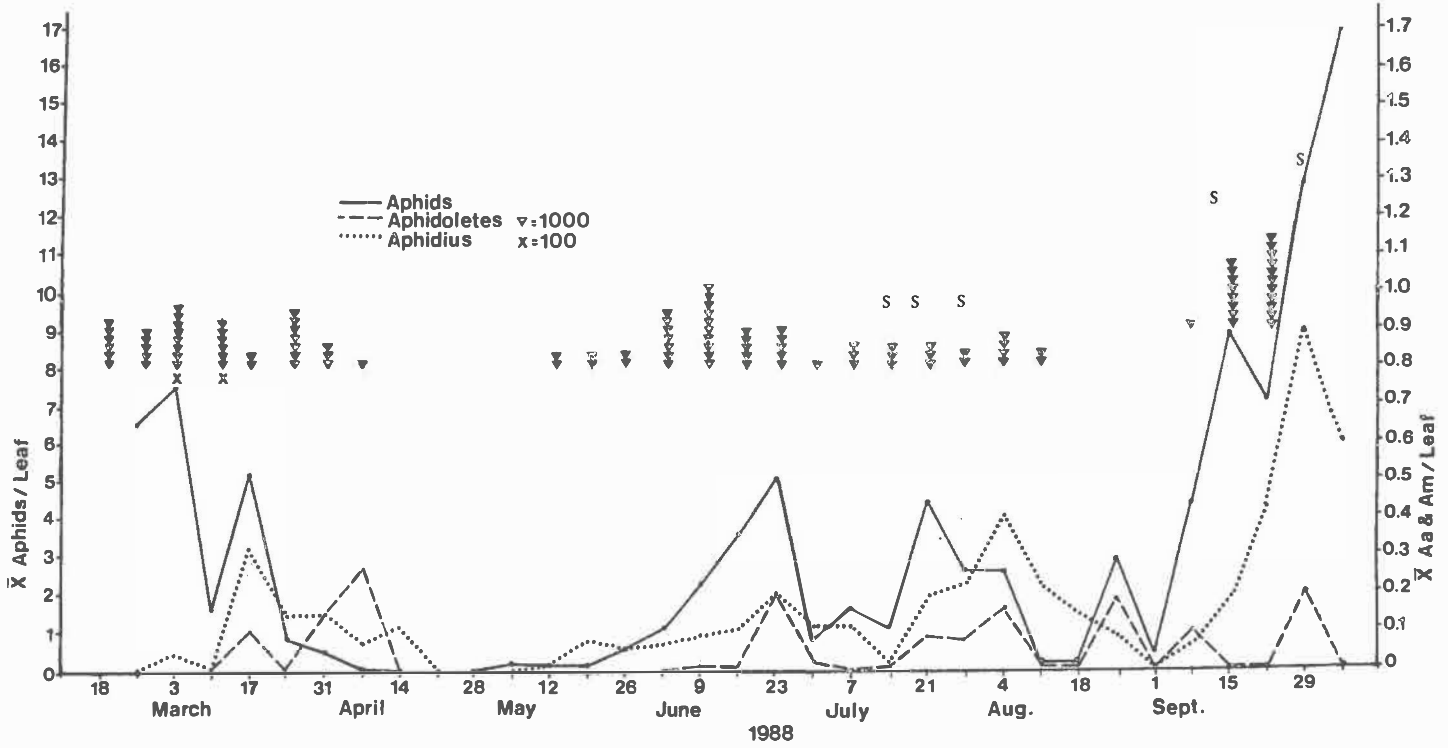

Figure 1. Application of biological controls in greenhouse D on 05 ha of sweet pepper. X = release of A. aphidimyza; • = release of A. matricariae; S = sprays of Safer's insecticidal soap.

This grower experimented with spot-sprays of pirimicarb early in the year, which seemed to inhibit effectiveness of the predators (see below).

In greenhouse B, the very high rates of release used resulted in swift control of the aphids, but the second generation of predator larvae appearing about 3 weeks after the first release, were often seen starving on leaves. Release rates were probably too high and resulted in predator populations dying out in the second generation. Aphid populations rebounded sooner in this greenhouse than in the greenhouses with somewhat lower release rates. Perhaps introducing additional *A. matricariae* at this time, might have been beneficial.

It became clear during the first two years, that *A. aphidimyza* are most effective if released at moderately high rates over a short period of time with the interval between groups of releases dictated by reoccurrence of aphids. During the third year, higher rates of release for short intervals were tried, along with larger releases of *A. matricariae*, and results were generally very good (Figure 2). Unfortunately, the grower tried to spot-spray pirimicarb in April to balance a rapidly increasing aphid population and disrupted the control programme, which required a complete spraying of the house. Thereafter,both predators and parasitoids were re-introduced and aphid control was excellent for the remainder of the year. From these results we concluded that the best release pattern for *A. aphidimyza* seems to be 2 to 3 releases of 1 pupa per 1-2 plants at weekly intervals. A higher rate of 1-2 pupae per plant is advisable when aphid populations begin to increase rapidly in March and April, even if aphid populations are low (means of <1 aphid per leaf).

4.2 Role of *A. matricariae*

The role of *A. matricariae*, which often enters through greenhouse vents, was at first thought to be minimal because native hyperparasitoids suppress their populations in the greenhouse during spring and summer. In 1987, however, in greenhouse A, a naturally established *A. matricariae* population, present when plants were set out, kept aphid populations low in January and February while plants were small and aphid reproduction was relatively slow. Following this observation, *A. matricariae* were reared and released early the second year in test greenhouses. The parasitoids remained present during the entire season in all greenhouses but appeared to be most effective early in the year and in the fall, about the time *A. aphidimyza* began to diapause in September. Whether this was due to decreased hyperparaistoid activity (possible diapause?) or reduced interference from *A. aphidimyza* larvae is not known.

4.3 Distribution of Aphids

These studies confirmed that green peach aphids usually appear first on the lowest leaves and next in the growing tips of peppers. An important observation for pest managers was that the location of aphids, relative to the zone of developing fruit as it changed over the season, was more important than the overall mean number of aphids per leaf in samples. The number of aphids tolerable on lower leaves increases as the zone of ripening fruit moves higher on the plant stem. Aphids on leaves below the picking zone cause little damage and act as a food reservoir for biocontrol agents. Pest managers should, therefore, concentrate on sampling lower leaves to find aphid colonies early in the year, and be most concerned with changes in aphid populations in and above the fruit picking zone later in the year.

4.4 Preventing Diapause in *A. aphidimyza*

The onset of shorter days in mid-August induces diapause in *A. aphidimyza* by mid-September in Canadian greenhouses unless the grower uses supplementary night lighting. *A. aphidimyza* are extremely sensitive to low light intensities and it is possible to avert diapause in most of the population by leaving 100-W incandescent bulbs on at night, spaced 22 m apart

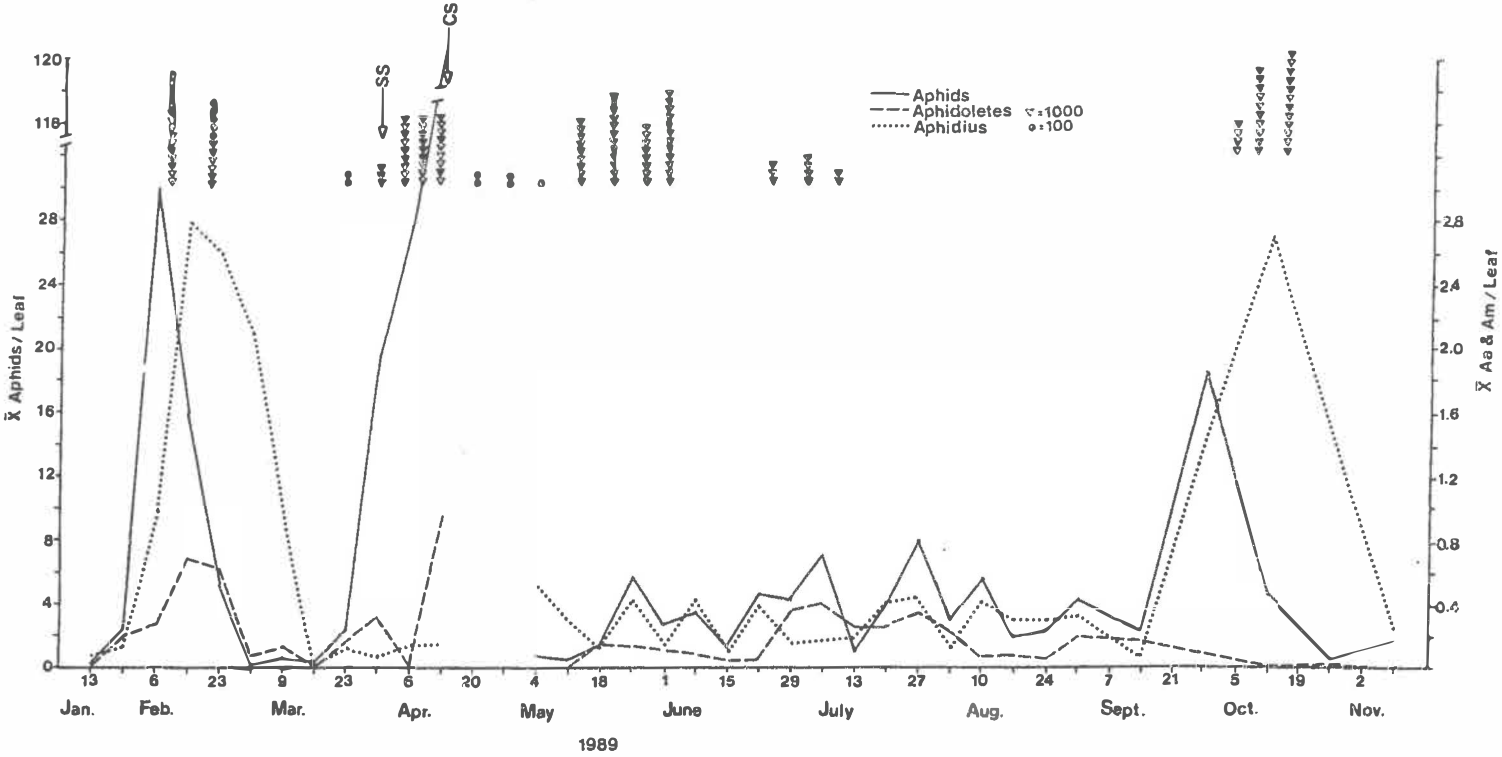

Figure 2. Application of biological controls during the third season in greenhouse A on 0.5 ha of sweet peppers. ▽ = release of A. aphidimyza, • = release of A. matricariae; SS = spot spray of Pirimor®; CS = complete spray of Pirimor®.

(Gilkeson and Hill, 1986). In practice, this is most useful early in the season, when plants are short and overhead lights illuminate the widest area. In January (with plants 20-30 cm high), even the illumination from a neighbouring greenhouse using high intensity lights to extend day length was sufficient to avert diapause. At the end of the season, however, when plants are over 2 m tall and densely leaved, it is difficult for the grower to provide enough lights to adequately illuminate the area. The inclusion of *A. matricariae* in the biological control programme is also valuable because they do not diapause in greenhouses in the fall.

4.5 **Type of Greenhouse Floor**

The type of floor appears to affect the success of biocontrol with *A. aphidimyza*. During the first season in greenhouse A, *A. aphidimyza* populations did not become established even when aphids were numerous as they did in greenhouses B and C, which may have been because pupae did not survive on the plastic covered floor. Growers with soil, sand or gravel floors or those growing in large open bags of sawdust (commonly used in western Canada) seem to have the best results with *A. aphidimyza*, therefore it is recommended that growers spread a thin layer of sawdust, peat or other material on plastic floors, between the double rows, to provide a refuge for predator pupation. Accumulated leaf and crop residues on the floor of the greenhouse probably also protect pupae and should not be removed during the growing season.

5. **Compatibility of Biological Controls with Pesticides**

In greenhouse D, pirimicarb was used early in the season to balance aphid populations and more predators were required than in greenhouse A at the same time of year. During the third year in greenhouse A, pirimicarb was spot-sprayed in April and aphid populations subsequently escaped control by predators. Pirimicarb is known to be repellant to some aphids (Lowery & Boiteau, 1988), therefore it was decided to test the repellant effects of pirimicarb on ovipositing *A. aphidimyza*. Two groups of plants were sprayed with Pirimor® at label rates, one group treated only on growing tips, the other sprayed completely. Plants were reinfested with aphids and used when residues were 3 weeks old. Pairs of plants, one sprayed and one control, were placed in a cage overnight with adult *A. aphidimyza*; each test was replicated 3 times. All eggs laid on each plant were counted the following day. It was found that female *A. aphidimyza* always laid more eggs on control plants than on those with 3-week-old residues, even those that had only been sprayed on the tips. As many as 11 times more eggs were laid on control plants, with an average of 4 times more for all pairs, which seems to show that Pirimor® treated plants remained repellant to predator females for at least 3 weeks.

In greenhouse D, at the end of the season, the grower attempted to balance a late resurgence of aphids using insecticidal soap sprays. This damaged plant leaves although it appeared to have little effect on aphids (Figure 2) and may have been detrimental to both predator and parasitoid populations, which both dropped after spraying.

6. **Conclusion**

According to these results, a total release of one *A. aphidimyza* per 3-4 tomato plants per year should be sufficient to control aphids (a cost of ca. CD$150 per 0.5 ha). Considerably more predators are needed to control aphids on peppers, averaging about 9 *A. aphidimyza* per plant for the year, plus an inoculative release of *A. matricariae* at the beginning of the season (ca. CD$4000 per 0.5 ha). This is expensive, but tolerable if aphid control is good, because there are few alternatives for use on export peppers.

Another finding of this study was that regardless of the care and accuracy of sampling, it was difficult to match recommendations to the mean counts of aphids obtained in samples. The location of the aphids in relation to the fruit picking zone on the plants, the time of year, the leaf area of the plants, and the interaction between populations of predators and parasitoids are variables to consider when deciding the number of *A. aphidimyza* to release. It is possible that monitoring aphid populations by counting insects on leaves may not be necessary and that growers may have good results simply by releasing suggested numbers of biocontrols as soon as the first aphids are seen and whenever they reoccur.

Table 1. Recommendations for biological control of aphids in a long season crop of greenhouse peppers.

December to early March:
A. aphidimyza: 1 pupa/2 plants weekly for 2-4 weeks
AND
A. matricariae: 500 pupae/0.5 ha

March and April:
A. aphidimyza: 1-2 pupae/plant weekly for 2-4 weeks

Summer months:
A. aphidimyza: 1 pupa/plant weekly for 2-4 weeks

September and later:
A. aphidimyza: 1 pupa/plant weekly for 2-4 weeks
(only if there are sufficient lights at night to prevent diapause)
OR
A. matricariae: 500-2000 pupae/0.5 ha

Acknowledgement

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CURRENT STATUS OF BIOLOGICAL CONTROL OF THRIPS IN CANADIAN GREENHOUSES WITH *AMBLYSEIUS CUCUMERIS* AND *ORIUS TRISTICOLOR*

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Summary

Despite widespread use of *Amblyseius cucumeris* to control thrips in Canadian greenhouses, it was necessary to investigate the reason for several inexplicable failures in fall and winter crops. Research on diapause induction in *A. cucumeris* showed that under day lengths of 8 hrs., with a daytime temperature of 22°C, the percentage of mites that diapaused was inversely related to night temperatures. When night temperatures were 15°C, 100% of females diapaused. A decreasing proportion of females diapaused with increasing temperatures and no diapause was evident when night temperatures reached 21°C. Critical daylength for inducing diapause was 12.5 hours when day temperatures were 22° and nights 17°C. This was consistent with the trend in diapause incidence in *A. cucumeris* collected from an established greenhouse population during the fall. To improve the reliability of biological control of thrips, the potential for the use of the minute pirate bug, *Orius tristicolor*, against thrips was investigated in a release rate experiment in a commercial cucumber greenhouse. In this test it was found that a single release of 1 pirate bug per plant was sufficient to provide control of thrips during a late season crop.

1. Introduction

The use of *A. cucumeris* to control western flower thrips (*Frankliniella occidentalis*) in cucumber and pepper greenhouses has become widespread in western Canadian greenhouses since 1986. In 1989, it was the main control for thrips applied on about 25 ha of commercial greenhouses in the two western provinces of British Columbia and Alberta. In 1987, after the predators failed to become established from January through March on a crop of peppers and on an early fall crop of cucumbers we investigated the possibility that they were diapausing. We collected *A. cucumeris* from commercial greenhouses from late September through October and found that 50-100% of the females recovered did not lay eggs. To find out if they definitely were in reproductive diapause, detailed experiments were conducted to define temperature and photoperiodic interactions under typical winter greenhouse conditions.

A promising new direction for improving biological control of thrips was the recent research on the use of the minute pirate bug, *O. tristicolor*, which unlike *A. cucumeris* is predacious on adult thrips. Another advantage is that pirate bug adults are attracted to flowers where western flower thrips do the most damage. Although long known as a promising biocontrol for thrips (Stolz & Stern, 1978; Hodgson & Aveling, 1988), *O. tristicolor* has been difficult to mass-produce because of the cannibalistic nature of nymphs and adults in crowded conditions. After developing rearing systems in 1989, pirate bugs were available for a trial in a commercial cucumber greenhouse.

2. Diapause in *A. cucumeris*

A. cucumeris from commercial cultures at Applied Bio-Nomics were kept on floating arenas and fed the mold mite, *Tyrophagous putrescentiae*, during incubator tests simulating winter greenhouse conditions. In experiments involving combinations of photoperiod and thermoperiod, the thermophase coincided in time and duration with the photophase. Diapause inducing conditions of 8 h light to 16 h dark with a 22°C day temperature and 17°C night temperature were chosen to approximate winter growing conditions in most of the Canadian greenhouse regions (ca. 48°31' N. latitude). Because phytoseiids overwinter as adult females in reproductive diapause (Overmeer 1985), we assumed mites kept with an ample food supply were in diapause if they failed to lay eggs for at least 7 days after mating.

2.1 Effect of Diet

Dietary components are known to influence diapause response in phytoseiids (c.f. Overmeer & van Zon, 1983), therefore we first checked diapause incidence in mites reared on diets of thrips nymphs, mold mites, mold mites plus pepper pollen, mold mites plus commercial bee pollen and mold mites plus crystalline ß-carotene. Although recent work (Overmeer et al., 1989) showed that caretenoids are indeed important for expression of diapause in *A. cucumeris*, we found that diapause incidence (a mean of 74%) did not differ significantly for all five diets, and that therefore we could use mold mites as a diet without confounding diapause results.

2.2 Effect of Night Temperature

To determine the effect of different night temperatures on diapause incidence under an 8 hr daylength, with day temperature of 22°C, we reared groups of mites (20-71 females per group) from egg to adult under a range of night temperatures (15,16,17,18 and 21°C). We found an inverse linear relationship (Figure 1) between night temperature and diapause incidence, with about 74% of mites diapausing even when night temperatures were kept at 17°C, a common temperature in sweet pepper after an initial warm growing period. Interpolating our results, it appears that even at a night temperature of 20°C, about 20% of females would diapause, which could impair the effectiveness of *A. cucumeris* releases against thrips.

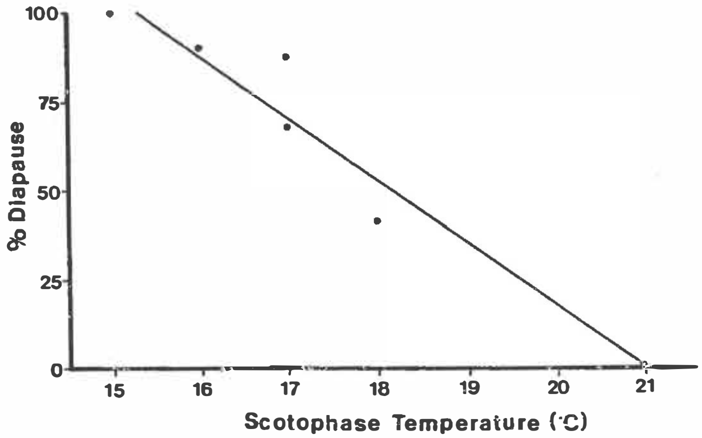

Figure 1. Effect of night temperature on diapause incidence in *A. cucumeris* reared under 8 hr daylength, with 22°C day temperature. Regression line ($y = 117.7x + 371.0$);correlation coefficient $r = -0.967$.

2.3 Critical Thermo-Photoperiod for Diapause Induction

To determine the greenhouse conditions under which 50% of the population would enter diapause, we reared groups of mites (77-211 females per group) under daylengths of 16,14,13,12.5,12 and 10 hours with matching thermoperiods of 22° for the light period, 17°C during the dark period. We found a well defined critical threshold between daylengths of 12 and 13 hours, with 43.6% of the population diapausing under a 12.5 h day. From this curve, the critical daylength for diapause induction under these conditions was calculated as 12.45 h. We do not know whether this is typical of *A. cucumeris* from other areas or whether this critical photoperiod is a constant for the species, but it has important implications for greenhouse growers who receive their stock of *A. cucumeris* from the same commercial culture.

2.4 Diapause under Greenhouse Conditions

A study was conducted in a commercial pepper greenhouse during the fall to check laboratory results against real greenhouse conditions. From August 30 to November 3, 1988, all *A. cucumeris* found in weekly leaf samples of 200-300 leaves were removed and held on arenas with prey for five days to determine their oviposition status. We found that nearly all females recovered in late August laid eggs, whereas by early November ca. 80 were in diapause (Figure 2). The critical daylength of 12.45 h established in laboratory experiments occurs about September 18 at this latitude. We expected that 2-3 weeks after the critical photoperiod occurred, the proportion of diapausing individuals would start to increase as older, nondiapausing females died, and this was consistent with the trend we observed.

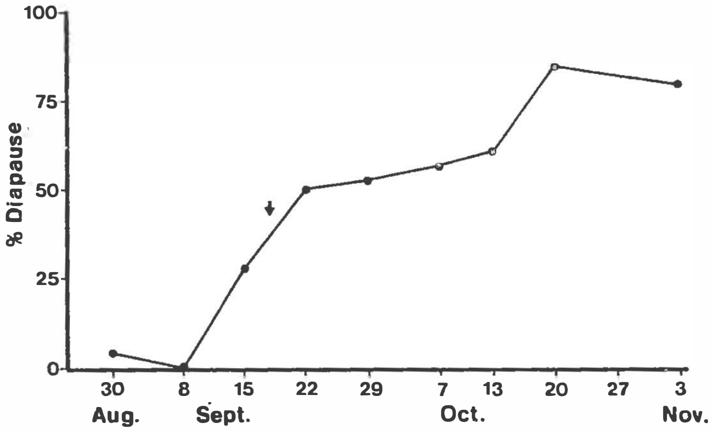

Figure 2. Diapause incidence in *A. cucumeris* females recovered from a commercial greenhouse in Cloverdale, B.C. (49°05' N lat.)during fall 1988.

As a result of this research we were able to explain previous failures of biological control for thrips in winter crops. At this time, we do not recommend using *A. cucumeris* on fall crops or for early winter release when greenhouse temperatures are below 21°C at night. Diapause should not be a problem where higher temperatures are maintained in winter, regardless of daylength, and this is supported by results from a Vegreville, Alberta, experimental greenhouse where minimum night temperatures were 22°C from November 1988 to March 1989. *A. cucumeris* were released November 30 and December 15 and populations were maintained, with females continuing to lay eggs all winter (M.Y. Steiner, pers. comm.). For growers with lower night temperatures, we recommend that they control thrips with non-residual pesticides until early March, when it is probably safe to release *A. cucumeris* because they will be developed under non-diapause inducing conditions. It is our experience that growers who achieve good control of thrips the previous year and who have rigorously cleaned and fumigated before setting out seedlings for the next crops usually do not need to control thrips before March.

3. Experimental Releases of Minute Pirate Bugs

A promising release trial, using only *O. tristicolor* to control thrips was conducted in a fall crop of cucumbers in a commercial greenhouse (0.4 ha, 3000 plants) in 1989. Both western flower thrips (*F. occidentalis*) and onion thrips (*Thrips tabaci*) were present in low numbers after the plants were set out the first week in July. Between July 21 and 28, 2960 minute pirate bug adults were released, approximately 1 per plant. Thirty lower-leaf samples were collected weekly from a grid of designated sample plants; leaves were bagged separately, washed over a series of sieves and the collected thrips nymphs, adults and pirate bug instars were counted under a microscope. The number of thrips nymphs increased from July 21 to August 1st, then declined steadily except for one week in late August when high numbers appeared in samples (Figure 3). Pirate bug nymphs were collected on all sample dates. In less than two months, the number of thrips nymphs declined to <10 per leaf. Starting August 8, additional sampling was conducted by checking 200-300 flowers per week for presence/absence of thrips and pirate bugs. Within 5 weeks, the proportion of flowers with thrips declined from 67% to 6% and remained low for the remainder of the season (Figure 4)

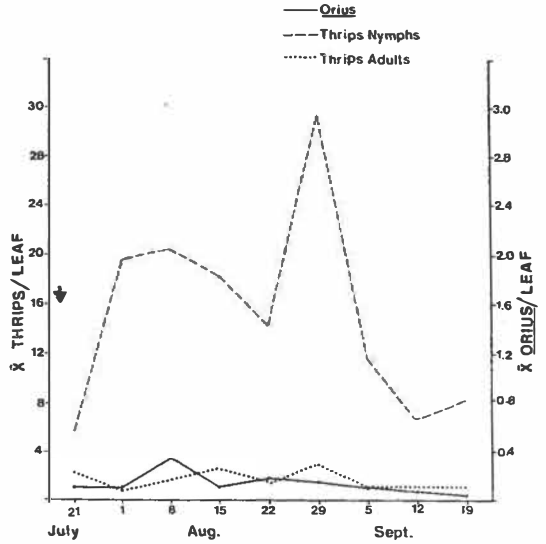

Figure 3. Application of *O. tristicolor* to control thrips in a 0.4 ha cucumber greenhouse. Arrow designates date 1 *O. tristicolor* per plant were released.

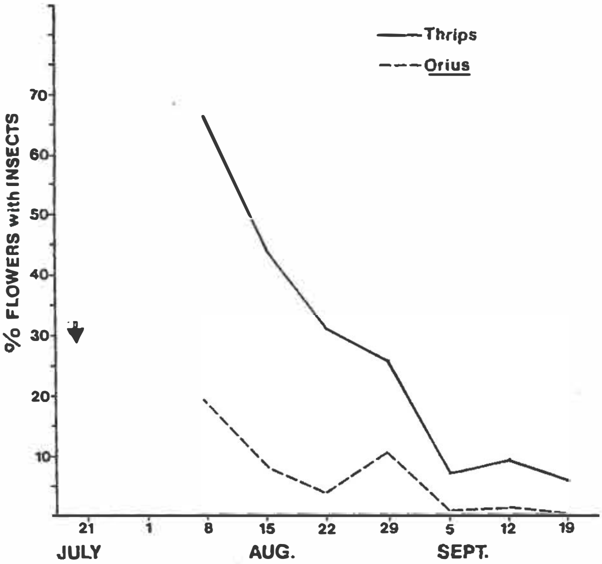

Figure 4. Proportion of cucumber flowers with thrips and *O. tristicolor* adults in a 0.4 ha cucumber greenhouse. Arrow designates date 1 *O. tristicolor* per plant were released.

For the 1990 season, mass-production of pirate bugs is expected to supply enough for large-scale greenhouse trials in the Canada. Questions that remain to be studied are whether biological control of thrips will be best with pirate bugs alone, with *A. cucumeris* alone, or with the two predators together. Pirate bugs feed on predator mites, therefore thrips control could be impaired if pirate bugs spend a significant amount of time preying on *A. cucumeris* rather than on thrips. It is equally possible that control of thrips nymphs will be better with both predators present even with interference between predators.

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PREDICTABILITY OF BIOLOGICAL CONTROL OF THE LEAFMINER *LIRIOMYZA TRIFOLII*, INFESTING GREENHOUSE CUT CHRYSANTHEMUMS

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Summary

Implementation of inundative biological control is fraught with problems due to the inability to answer fundamental questions regarding natural enemy releases such as how often?, how many?, how and where the natural enemies should be released? To facilitate biological control of the leafminer, *Liriomyza trifolii*, infesting greenhouse cut chrysanthemums using inundative releases of the parasitoid, *Diglyphus begini*, at grower-friendly predictive model has been developed for use on an IBM XT, AT, or compatible personal computer. The model is based on the Nicholson-Bailey equations which have been modified to incorporate age structure to increase biological realism. It is assumed that there is no immigration or emigration and that greenhouse temperatures are relatively constant. The output from the model, the number of parasitoids to be released per week for the duration of the crop, is derived using an iteration procedure which solves for the number of *D. begini* necessary to eradicate *L. trifolii* prior to the development of marketable foliage. Cage and field experiments have been used to validate the accuracy of the model. The model has been remarkably successful; following the predicted release rate, *L. trifolii* was successfully controlled by releases of *D. begini* which resulted in the production and harvest of a saleable cut chrysanthemum crop in California, U.S.A. without the use of any pesticides in 1989.

1. Introduction

Inundative/inoculative releases of natural enemies have been used for control of arthropod pests infesting a diversity of crops (King et al., 1985). The greatest consistent use occurs in glasshouse operations throughout the world. Van Lenteren and Woets (1988) estimated that more than 7000 ha. of glasshouse crops are under biological control where natural enemies are released on a regular basis and this number appears to be expanding yearly.

The efficacy of inundative releases of natural enemies for biological control on most corps have not been demonstrated nor has the economic feasibility of such programs (King et al., 1985). Fundamental questions such as how often?, how many?, how and when they should be released?, etc., are not known. Without answers to these questions, inundative release program is likely to be fraught with problems and numerous failures will result. Before augmentative releases of natural enemies can be used rationally, predictive models are required to answer the fundamental questions associated with these releases (King et al., 1985). Given the interest and application of biological control measures over the past 100 years (Doutt, 1989), as well as a growing body of theory on predator-prey or parasite-host interactions (see Hassell, 1986 and Hassell, 1978 for reviews), it is surprising that there have been very few attempts, based on scientific methodology, to determine the number and release schedule of natural enemies necessary to achieve control of pest populations.

The leafminer, *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae), is a major pest of a wide variety of greenhouse crops (van Lenteren & Woets, 1988; Parrella, 1987; Minkenberg

& van Lenteren, 1986, Wardlow, 1985). The major source of damage to plants is caused by larvae which feed in the mesophyll layer of the leaves and results in a permanent serpentine-like mine within the leaf tissue. On ornamental crops grown for their aesthetic value (i.e. chrysanthemums), damage to the marketable portion of the plant is not tolerable. The economic impact of *L. trifolii* in California (U.S.A.) has been considerable; from 1981 through 1985 it was estimated that the chrysanthemum industry lost approximately 93 million dollars due to this pest alone (Newman & Parrella, 1986).

Biological control of *L. trifolii* in greenhouse floricultural crops has recieved considerable attention because of the leafminer's ability to develop resistance to insekticides quikly (Parrella et al. 1989) and increasing regulations governing pesticide usage. Almost every grower would embrace this practice provided that he/she can be shown how to make use of it and that the concept actually works in practice. Inundative releases of the parasitoid wasp, *Diglyphus begini* (Ashmead) (Hymenoptera: Eulophidae), has successfully controlled outbreaks of *L. trifolii* infesting greenhouse ornamentals on a repeated basis (Heinz & Parrella, 1987, Heinz et al., 1988b, Heinz & Parrella, 1990a). In this paper, we describe preliminary results of our work aimed at developing a grower-friendly predictive model to determine the release rate of *D. begini* necessary to eradicate *L. trifolii* infesting cut chrysanthemums in greenhouses.

2. Model Construction

The model in loosely based on the Nicholson-Bailey (1935) model and has been written in Turbobasic for use on IBM and IBM compatible personal computers. Parasitoid and host age structure are incorporated into the algorithm in an attempt to maximize accuracy. The model provides daily estimates of the host and parasitoid population sizes instead of population estimates at the end of each generation as found in the Nicholson-Bailey model. This feature is advantageous to the testing and implementation of the model for the following reasons. 1) Under an inundative approach to biological control, numerous parasitoid releases are made per host generation. Therefore a time scale based on generations is too broad to easily accommodate these additions to the population. 2) All stages of the leafminer life cycle are not susceptible to attack by the parasitoid (Heinz & Parrella, 1989) nor are all stages of the parasitoid life cycle capable of causing mortality in the host population. Since the expression of the developmental stages represents a fraction of the generation time, it is easier to express changes in the population on a per day basis. 3) Generation times between the parasitoid and host are not synchronized. Use of a time scale decoupled from the life cycles of each species removes such complications from the modelling procedure without a loss of validity. 4) From a grower perspective, decisions on utilization of parasitoids are likely to be made based on days rather than generation(s). 5) Since the model predicts the abundance of each developmental stage of leafminers and parasitoids, and since the abundance of each of these stages is easily evaluated in the field (Heinz & Parrella 1987, 1990a; Heinz et al., 1988b), a powerful test of the model's accuracy is available. Providing that the model assumptions are met, deviations of the observed frequencies of each developmental stage from the predicted frequencies can be used to test the accuracy of parameters used to govern parasitoid and leafminer demography or the parameters describing parasitoid attack behavior. Properly controlled experiments permit each of these two hypotheses to be evaluated under greenhouse conditions.

The inclusion of age-structure permits the utilization of some parasitoid behavioral parameters which are extremely important to population dynamics. Age-specific survivorship, fecundity, and development rate for *L. trifolii* have been reviewed by Parrella (1987). Similar data, along with age-specific host utilization (oviposition vs. host kill), have been reported for *D. begini* by Heinz & Parrella (1990b) The influence of host size or age on *D. begini* host preference (Heinz & Parrella, 1989), handling time (Heinz et al., 1988a), and sex ratio Heinz

& Parrella, 1990c) have also been studied. Host preference and handling time are directly related to parasitoid searching efficiency. Factors influencing parasitoid sex ratio are extremely important since only female *D. begini* are capable of exerting an effect on the leafminer population.

The purpose of the model is to predict the number of *D. begini* to release on a weekly basis in order to bring *L. trifolii* under successful biological control (no more than 1 larvae per 1000 leaves) within 40 days of planting the crop. After day 40, marketable foliage is produced by the plant. Since cut chrysanthemums are produced for their aesthetic qualities, this upper foliage should be free of leafminer damage. The model uses an iterative algorithm to determine the number of wasps to release on a weekly basis for the duration of the crop. A flow diagram of the model structure is shown in fig. 1.

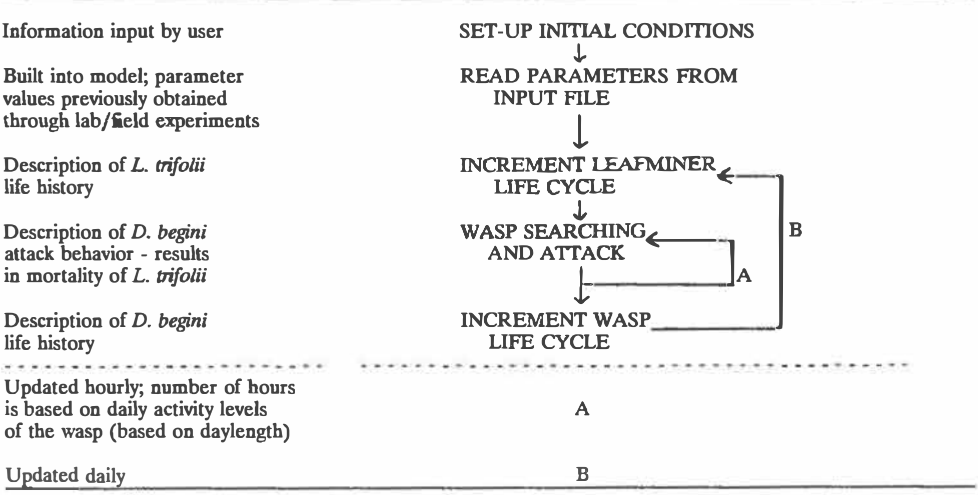
Matrix algebra provides the mathematical means to express insect age classes through time. *D. begini* attack behavior is modelled using Holling's (1959) disc equation. Due to age-specific differences in *D. begini* host utilization behavior (Heinz & Parrella, 1990b) and the influence of *L. trifolii* larvae size on *D. begini* behavior, we have modelled the attack behavior using the two equations shown below, one for each host stage attacked.

$$N_{ha2} = NP_e a_2(T_t\text{-}T_{h2}N_{ha2})$$

$$N_{ha3} = NP_1 a_3(T_t\text{-}(T_{h2}N_{ha2} + T_{ha3}N_{ha3}))$$

The number of *L. trifolii* larvae attacked by *D. begini* is depicted by N_{ha}; N represents the density of larvae susceptible to attack and P represents the density of *D. begini* searching. Search efficiency is depicted by a, total search time by T_t and handling time by T_h. The subscripts e and 1 are used to represent two non-overlapping age classes of *D. begini*. Similarly, the subscripts 2 and 3 represent second and third instar *L. trifolii* larvae. Values for search efficiency, total search time, and handling time are discussed in Heinz et al. (1988a). The two equations are solved simultaneously to determine a value for N_{ha}. This value is solved for each hunting cycle of the wasp and the wasp and host densities are modified after each hunting cycle.

Figure 1. Flow diagram of leafminer-parasitoid model



There are two simplifying assumptions inherent to the model; 1) there is no immigration or emigration, and 2) greenhouse temperatures are relatively constant. The model is extremely easy to use and requires the grower to supply only four pieces of information to initiate the model. The values supplied by the used are: 1) The average number of mines per leaf, 2) The average number of *L. trifolii* per yellow sticky trap; 3) The average number of *D. begini* per yellow sticky trap, and 4) The starting day for parasitoid releases. Sampling plans have already been developed which growers can use to obtain these values (Parrella & Jones, 1985, Jones & Parrella, 1986, Parrella et al., 1989).

4. Model Validation - Materials and Methods

Two-thousand chrysanthemum cuttings (var. "Florida Marble") were planted following typical grower practices in a production greenhouse located in Santa Barbara County, U.S.A. Five hundred 2-day old adult *L. trifolii* were released 3 days after planting. At this time, two control cages which covered 64 plants each, were randomly placed in the greenhouse. Following the output value from the model, 750 newly emerged adult *D. begini* were released on a weekly basis starting on day 7 after planting. Predicted population trends based on model output were compared to those within the greenhouse and control cages. Leaf samples were collected to ascertain immature populations (see Hein & Parrella, 1990a for details regarding the sampling procedure and establishment of control cages) on a weekly basis.

Model predictions were also tested using insect cages within the greenhouse facilities at Davis, California, U.S.A. Two cages, each containing 102 individually potted chrysanthemums (var. "Florida Marble") were inoculated with 25 adult, 2 day old, *L. trifolii* flies 3 days after planting. Following the model output, 40 neonate *D. begini* were released on a weekly basis into one of the cages starting on day 7 after planting. Leaf samples were collected using the same procedure outlined above to test model predictions against the population trends in the two cages.

5. Results and Conclusions

Predicted and observed leafminer population trends from the greenhouse trial are shown in Fig. 2. In each of the control cages, the leafminer populations caused excessive damage to the foliage prior to harvest. Fluctuations within the greenhouse leafminer population were similar to those predicted by the model but the amplitude of the fluctuations differed by more than an order of magnitude. However, the leafminer population was brought under successful biological control prior to the development of marketable foliage, around 40 days after planting, following the *D. begini* release rate predicted by the model. Most important, the cut chrysanthemum crop was grown in a production greenhouse, harvested, and sold without the use of any pesticides. To our knowledge, this result represents the first time an entire crop of chrysanthemums was grown and marketed in the United States without any pesticide applications. While the predictive power of the model needs to be increased, it represents a drastic improvement over the previously used trial-and-error method.

Results from the cage experiment were similar to those described above. The pattern of predicted and observed population trends under biological control were similar but there was up to a 3-fold difference in the amplitude of the fluctuations (Fig. 3). The leafminer population was again successfully controlled following the release rate recommended by the model by day 40 while the leafminer population within the control cage was rapidly increased after day 46.

While these results are exciting more work is needed to increase the predictive power and utility of the model. In its current form the model falsely assumes that a greenhouse represents a perfectly uniform environment or that the hosts and parasites are uniformly distributed within the area. To correct this wrong assumption, a degree of spatial structure will

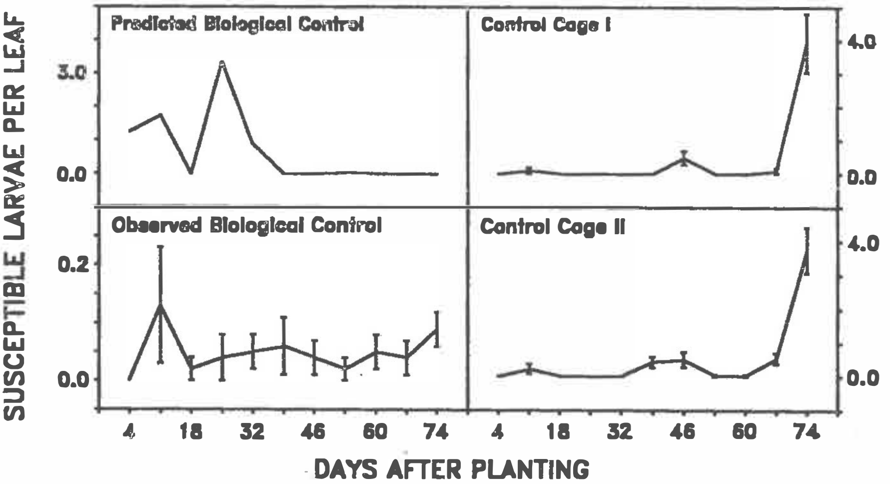


Figure 2. Results from greenhouse validation of predictive model expressed the number of second and third instar *L. trifolii* larvae per leaf (susceptible to attack by *D. begini*) over time. Larval abundances predicted by the model and observed in the greenhouse are shown on the left. The abundance of larvae observed in two control cages that exclude parasitoids are shown on the right.

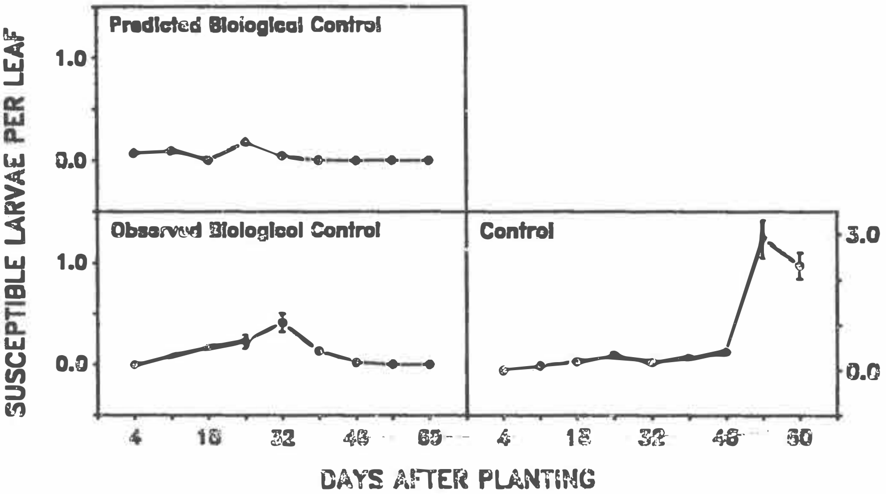


Figure 3. Results from cage validation of predictive model, axes are as in Figure 2. Larval abundances predicted by the model and observed in cage into which *D. begini* were released are shown on the left. The abundance of larvae observed in the cage with only *L. trifolii* is shown on the right.

have to be incorporated into the model. This modification will allow the model to simulate movement patterns and preferences exerted by leafminers and parasites. In a greenhouse planted with numerous chrysanthemum cultivars and plants of different ages, these preferences are likely to exist (Parrella et al., 1983, Bethke & Parrella, 1985, Minkenberg, 1988).

The second assumption may also be violated in California where chrysanthemums are grown under glass or plastic on a continual basis. Fluctuations in daily temperature are relatively small compared to seasonal or regional variability. Degree-day models are often successful for describing temperature-dependent insect development (Stinner et al., 1975, Zalom & Wilson, 1982, Wilson & Barnett, 1983) and can be used to modify the demography parameters within the model provided a grower can predict mean temperatures on a seasonal basis for input into the model.

The model structure relies heavily on an understanding of the behavioral mechanisms which influence birth and death rates. Rather than simply modelling the end-product of these behaviors, we are able to gain an understanding of how model parameters may vary in heterogeneous environments. Use of this methodology should make the model structure robust and facilitate its adaptability to other parasitoid-host or predator-prey systems in the future.

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THE SEASONAL VARIABILITY IN TOMATO LEAFMINER (*LIRIOMYZA BRYONIAE* (KALTENBACH)) LIFE CYCLE

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Summary

The length of the tomato leafminer life cycle begins to extend rapidly during August with the result that pupae formed at this time will emerge as adults in November and December when a new crop is planted. The period from egg laying to first adult emergence is also increased by about 2 weeks when compared to an early summer egg laying. It is vital, therefore, to ensure that no leafminers are laying eggs after the beginning of August which may either overwinter or re-infest a new planting.

1. Introduction

Liriomyza bryoniae (Kaltenbach), is the most important indigenous species of leafminer in the UK. It is capable of causing yield loss in tomato crops (Ledieu and Helyer 1985) and heavy infestations may cause dessication or even death of seedlings and young plants (Helyer and Payne 1986). Modern commercial growing practices, whereby soil sterilisation is rarely done, encourage the carry-over of ground or soil pupating insects from one crop to the next. Also, the earlier planting of long season crops, often in December, means that biological control of leafminer by parasites is less efficient due to low temperatures and low light intensity (Scopes and Biggerstaff 1973, Minkenberg and van Lenteren 1986). Therefore, if the number of over wintering insects can be reduced by timely applications of pesticide, the initial infestation to a new crop will also be reduced, thus improving the chances of successful biological control.

2. Methods

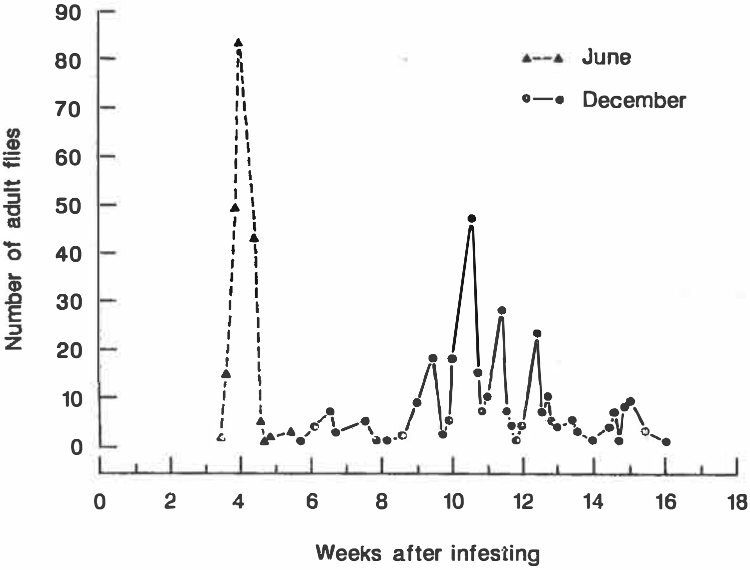
Liriomyza bryoniae were reared in nylon mesh cages within a glasshouse chamber maintained under natural daylight/daylength conditions. Minimum temperature was set at 15 ^oC with ventilation at 25 ^oC, the glass was treated with 'Coolglass' (P.B.I.(R)) shading material during the summer months. Tomato plants were produced in a separate glasshouse under similar conditions. Two cultures were started each week by introducing 25 adult leafminers, taken from previous cultures, onto 2 plants. When the larvae were almost ready to pupate, the plants were laid horizontally on tissue paper in large (80 X 35 X 3.5 cm) galvanized steel trays. Pupae were collected from above and below the tissue paper and counted according to their colour. The colour coding for the pupae was split into three categories; light (golden yellow to light brown), medium (brown) and dark (dark brown to black). The colour of the puparium remains constant throughout the pupal stage. Pupae from each culture were put into a Petri dish with a gauze lid which was kept in the glasshouse with the cultures. Emerging adults were counted daily. Maximum and minimum temperatures were also recorded daily.

3. Results and conclusions

When cultured under normal glasshouse conditions (15 - 25 ^oC, natural daylength), leafminer eggs laid between May and July began to emerge as adults 3.5 weeks later and the final adult emergence was about 5 - 6 weeks after infesting. Corresponding figures for

October and November were 6 and 15 - 17 weeks after infesting (Fig 1). Periods to both first and last emergence showed seasonal variation, though last emergence was more strongly affected than first emergence. Extension of the last emergence period began during August and rapidly increased to a point where the adults were still emerging 11 weeks after the first fly to emerge (Fig 2). Thus leafminer pupating during November and December would emerge throughout the following January and February when a new crop would be growing. During this period of the year the plants are less vigorous and more susceptible to phytotoxic reactions from pesticides. Similarly, establishment of biological control agents may be hampered by low light levels and low temperatures (Helyer *et al.* 1984).

Fig. 1 **Time of emergence of June and December infesting**



The number of light-coloured pupae was highest during early spring through to mid summer (end of March to end August) when no dark coloured pupae were found at all. During the autumn and winter months less light and more medium and dark coloured pupae were formed (Fig 3). Throughout the trial adults were found to emerge earlier from the light coloured pupae than from the dark coloured ones, whilst adults from the medium coloured pupae were intermediate. However, a proportion of light coloured pupae were found throughout the year. These puparium colour changes were noted by Minkenberg and van Lenteren (1986), who also state that during autumn and winter few flies emerge, possibly due to low temperatures rather than short photoperiod. In the present trials a minimum temperature of 15 °C was maintained throughout the year, higher temperatures being a result of solar gain. The onset of extended pupation begins during August when solar radiation is still reasonably high (Fig 4). These results would indicate photoperiod rather than temperature as the critical factor responsible for the period of extended pupation.

Fig. 2 **Time of first and last emergence**

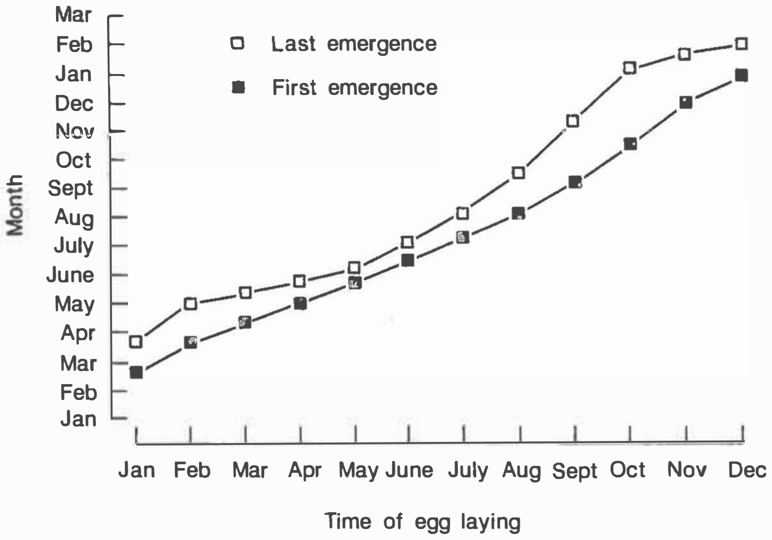


Fig. 3 **Colour changes of leafminer pupae through year**

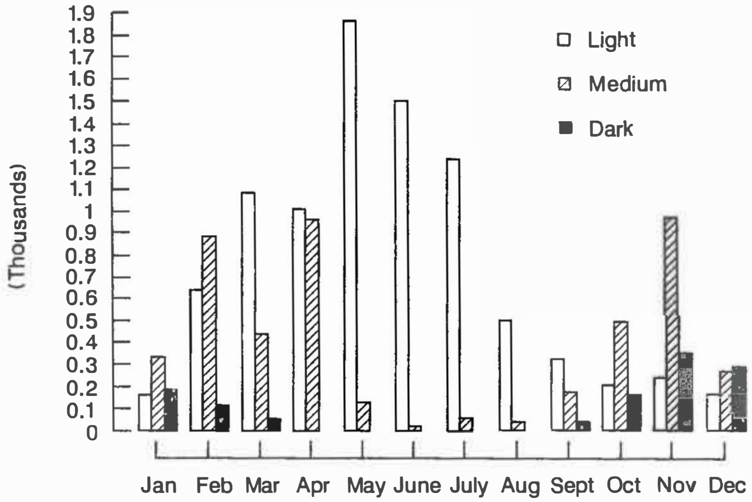
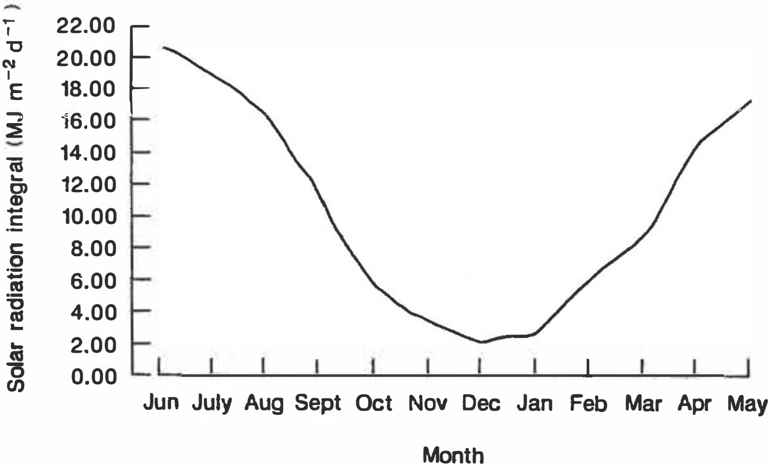


Fig. 4 **Seasonal variation of solar radiation at Littlehampton (50° N 49'N)**



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THE APHID PARASITOID *EPHEDRUS CERASICOLA*, A POSSIBLE CANDIDATE FOR BIOLOGICAL CONTROL IN GLASSHOUSES?

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Summary

The paper summarizes the biology and other characteristics in the host selection process of *Ephedrus cerasicola* parasitizing *Myzus persicae*.

1. *Introduction*

Aphid parasitoids in the family Aphidiidae are solitary endoparasitoids which can be an alternative to the aphid gall midge *Aphidoletes aphidimyza* (Rondani) for biological control of aphids in glasshouses. Several species have been mass-reared, particularly *Aphidius matricariae* Haliday, mostly for use on sweet peppers against *Myzus persicae* (Sulzer) (Wardlow, 1988; Ramakers, 1989). In this paper we summarize the biology and other characteristics in the host selection process of *Ephedrus cerasicola* Stary parasitizing *M. persicae* , which may be of importance in aphid biocontrol.

2. The biology of E. cerasicola.

The total developmental rate from oviposition to emergence is 17.0 days at 21° C in *E. cerasicola* (Hågvar & Hofsvang, 1986b). The development from oviposition to mummification and from mummification to emergence required 8.3 and 8.7 days, respectively. A literature review shows that species in the genus *Aphidius* have a shorter developmental rate than *Ephedrus*. The total developmental rates at 20-21° C are about 13-15 days in *Aphidius* spp. and 16-17 days in *Ephedrus* spp.(Hågvar & Hofsvang, unpublished).

Species within the genus *Ephedrus* seem to have a very high fecundity compared with other genera of Aphidiidae (Hågvar & Hofsvang, 1990). *E. cerasicola* has an average fecundity of 961 eggs. The parasitoid female has an average longevity of 18.0 days. Females oviposit throughout their lives with the most intensive egg laying period the first 13 days (21° C). In most of this period, a female can lay between 60 and 75 eggs a day (Hågvar & Hofsvang, 1990).

The functional response of *E. cerasicola* was investigated in single female experiments, showing a rather density-independent parasitism (Hofsvang & Hågvar, 1983). *E. cerasicola* seems to be efficient compared with other aphidiids examined (Hågvar & Hofsvang, 1988b).

Mummies of *E. cerasicola* can be stored at 0° C for six weeks without subsequent reduction in emergence and reproduction (Hofsvang & Hågvar, 1977). In this way, the synchronization of emergence for mass release programs can be faciliated. Mummies of *Aphidius* spp. seem not to be equally suited for long-term cold storage (Hofsvang & Hågvar, 1977; Polgar, 1986).

E. cerasicola is a parasitoid of mainly *Myzus*-related species (Gärdenfors, 1986), but is also reported to parasitize *Aulacortum solani* (Kaltenbach), another common aphid in glasshouses (Meadow, unpublished). *A. matricariae* parasitizes a broader range of aphid species, but is most effective against *M. persicae* (Ramakers, 1989). In the Netherlands, the use of *A. matricariae* in glasshouses was complicated by severe attacks of hyperparasitoids (Ramakers, 1989). Few problems with hyperparasitoids have been observed on *E. cerasicola* in Norway (Hofsvang & Hågvar, 1980, 1982).

3. The host selection prosess

The host selection prosess in insect parasitoids may be divided into five steps: 1) host habitat location, 2) host location, 3) host acceptance, 4) host suitability and 5) host regulation (Vinson 1976). In the first step, the parasitoids locate their habitat within the host plants. Little information is available on host habitat location in aphidiids, and no information exists on *E. cerasicola*. However, this step might be of less importance for biological control agents in glasshouses.

3.1 Host location

Once in the habitat, the parasitoid will search for hosts, usually close to or on the host plant. They often respond to volatile or non-volatile kairomones from their hosts. These kairomones might also include host-modified plant products, e.g. honeydew from aphids.

The colonization behaviour of *E. cerasicola* females was studied on plants differently infested with aphids in small glasshouses (Hågvar & Hofsvang, 1987). The study demonstrated that the parasitoids very soon gathered on the moderately to heavily infested plants (500-1000 aphids per plant), whereas aphid-free and low-infested plants (50-200 aphids per plant) were nearly free from parasitoids. However, the resulting parasitism was roughly density-independent. Aggregation as a desirable selection criterion for biological control agents are heavily debated (several references in Mackauer et al. (1990)).

Experiments in glasshouses and in cages showed that females of *E. cerasicola* responded positively to honeydew and aggregated quickly on plants contaminated with honeydew (Hågvar & Hofsvang, 1989). Observations on single leaves and on filter paper showed that the females increased the searching time on honeydew treated areas. Honeydew seems to act only as a contact kairomone (Hågvar & Hofsvang, unpublished).

3.2. Host acceptance

When a host is encountered, it is examined and either accepted for oviposition or rejected. The following aphid qualities have been examined in the acceptance step of *E. cerasicola*: aphid size or instar, aphids already parasitized by the same species and aphids parasitized by another species. The species of host offered is also important in the acceptance step but has not yet been thoroughly examined in *E. cerasicola*.

All instars of *M. persicae* are accepted for oviposition. Due to strong defence reactions in the older aphids, particularly in adults, first instars are most frequently parasitized (Hofsvang & Hågvar, 1986a). Aphids parasitized by conspecifics are recognized (discriminated) by use of antennae and the ovipositor and usually not accepted (Hofsvang & Hågvar, 1986a; Hofsvang, 1988). Such parasitized aphids are probably marked with an external pheromone during the first oviposition, and this pheromone is detected by the antennae of the second female within a few hours afterwards. After 2-3 hours, the second female apparently also uses her ovipositor to detect internal changes caused by the first oviposition (Hofsvang, 1988).

Aphids previously parasitized by other species (*Aphidius colemani* Viereck, *A. matricariae*) are accepted for oviposition by *E. cerasicola* (Hågvar, 1988; Hågvar & Hofsvang, 1988a; Hågvar, unpublished).

3.3 Host suitability

Once a parasitoid egg has been deposited into an aphid,the aphid can influence the developing parasitoid in several ways. The rate of development, mortality, sex ratio and fecundity of the emerging parasitoid may be influenced by aphid species, aphid size and whether the aphid had been parasitized before by a conspecific or by another parasitoid species.

The aphid instar at parasitization had negligible effect on parasitoid rate of development, mortality and sex ratio of the emerging adults of *E. cerasicola*.

In superparasitized aphids, which contain more than one egg of *E. cerasicola*, the supernumeraries will die either in the egg stage or as 1st instar larvae, depending on the time interval between the ovipositions (Hofsvang 1988). In multiparasitized aphids, containing parasitoid eggs of several species, *E. cerasicola* seems to kill the eggs of the first parasitoid (*A. colemani*, *A. matricariae*) by means of a venom injected during the oviposition. It thus appears as a superior competitior inside the host (Hågvar, 1988; Hågvar & Hofsvang, 1988a).

3.4. **Host regulation**

The developing parasitoid may exert various influence on the aphid before it eventually mummifies. Important for aphid population growth and biological control is whether parasitized aphids reproduce after they have been parasitized. *M. persicae* parasitized by *E. cerasicola* in the 2nd, 3rd, 4th instars and as newly moulted adults, produced 0.07%, 2%, 23% and 32% of the progeny number produced by the corresponding unparasitized aphid instars (Hågvar & Hofsvang, 1986b). Since young instars are most frequently parasitized (see 3.2 Host acceptance), *E. cerasicola* may efficiently reduce further aphid reproduction through its parasitization.

4. **Use of *E. cerasicola* in biological control in glasshouses.**

The introduction of the parasitoids can be summarized as follows (Hofsvang & Hågvar, 1980):

1. Parasitoids should be introduced as mummies.
2. Aphids should be introduced together with the first parasitoids.
3. Two introductions of mummies, 10 days apart, are sufficient.
4. Four mummies to one aphid are initially introduced. The same amount of mummies is used at the second introduction.
5. If the aphid population has grown considerably, and the parasitoids are absent or suspected not to control the aphid growth, it is recommended to release parasitoids (mummies) at a 1:10 parasitoid:host ratio.

5. **Conclusion.**

One can operate with two approaches for the selection of biological control agents: the reductionist and holistic. In the reductionist approach, the selection is based on life history characteristics such as fecundity, generation time and searching efficiency. The holistic approach focuses on community concepts of how the natural enemy fits into the broad ecology of the pest (Waage, 1990). The reductionist approach is used when selecting biological control agents for glasshouse pests.

In this paper we have given a review of some attributes of *E. cerasicola*, which may be of importance in controlling aphids in glasshouses. As a conclusion, we have summarized the advantages (+) and disadvantages (-) in using *E. cerasicola* compared with the much used *A. matricariae* as a control agent of *M. persicae*:

	E. cerasicola	*A. matricariae*
Host range	-	+
Developmental rate	-	+
Fecundity	+	-
Cold storage	+	-
Hyperparasitoids	+	-

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INTEGRATED PEST AND DISEASE MANAGEMENT IN PROTECTED CROPS: THE INESCAPABLE FUTURE

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Summary

The production of vegetables and ornamentals in glasshouses is characterized by an intensive use of pesticides. Resistance problems and environmental concern are necessitating a change from pure chemical control to integrated pest and disease management. Ways to realize a reduction in pesticide use are presented. Incorrect views of biological control that hamper its application are discussed, and issues to consider before starting biological control research and application are listed.

1. Introduction

Glasshouses offer an excellent opportunity to grow high quality products in large quantities within a small surface area. In The Netherlands only 0.5% of the area in use for agriculture is covered with glasshouses (9300 ha out of 2 million ha). On this small acreage 17% of the total value of agricultural production is realized, i.e. 3.2 billion US$.

Due to a high degree of specialization by the growers, crop rotation is very limited or non-existent. This specialization demands frequent soil disinfection and cleaning of the above ground parts of the glasshouse to prevent pest and disease survival from one growing season to another. The concentration of glasshouses in only a few areas leads to an almost continuous presence of pests and diseases in these areas. Abundant international trade has resulted in the unintentional import of numerous pests. Several of these pests were already resistant against most pesticides upon arrival in Europe. In combination, these factors have caused intensive pesticide usage (table 1).

Table 1. Use of pesticides in some glasshouse crops in The Netherland

crop	kilograms of active ingredient/ha/year **excluding** soil disinfection	kilograms of active ingredient/ha/year **including** soil disinfection
tomato	13.2	average for vegetables
lettuce	13.0	
cucumber	14.4	110
gerbera	18.0	average for ornamentals
rose	88.0	
chrysanthemum	223.0	112

all data for 1988

2. Anticipated reduction in pesticide use in The Netherlands

Because of the presently frequent use of pesticides, the government has decided to opt for a strong reduction in their usage during this decade. The Dutch Ministry of Agriculture has developed a long-term task-defining policy which aims at a 50% reduction in pesticide use by the year 2000 (expressed in kilograms of active ingredients). This year, reports will be published presenting strategic plans for each sector in agriculture, containing details on how to realize this.

3. How will this pesticide reduction be realized?

For the glasshouse sector this reduction in pesticide usage is predicted achievable as follows:

- Through legislation a complete stop of preventive chemical soil disinfection. This will result in roughly a 50% reduction of pesticide usage for the whole glasshouse sector. Realistic alternatives for chemical soil disinfection are already in use or in an advanced stage of development, e.g. soil steaming and production on a substrate other than soil. During the production season, chemical soil treatment will be allowed only when diseases or pests are present. Better detection techniques will be developed and more attention will be given to breeding for disease and pest resistant plants.
- Cleaning methods for above ground parts of the glasshouse will be developed using less pesticides. Spraying water under high pressure seems a viable option. By this a reduction in pesticide use of 10% is realistic.
- More biological and integrated pest and disease management will be used for control of above ground pests and diseases. Several options are applied or in development: designing more realistic damage thresholds, development of guided/supervised control programmes, breeding for pest and disease resistant cultivars, selection and use of new natural enemies, optimization of fertilization, proper disposal of old plant material, more critical choice of new crops (taking sensitivity for pests and diseases into account), and stricter control on the importing of plant material on the presence of pests and diseases. A combination of the above listed measures will lead to a further reduction in pesticide use of circa 5% in glasshouse vegetables (where already a drastic reduction has taken place because of the biological control systems in use) and 10% in glasshouse ornamentals.

For glasshouse crops a total reduction between 60 and 70% is anticipated. The current use of pesticides over different categories is given in figure 1.

The reasons behind this option of severely reducing pesticide use are diverse in origin. They partly originate from the agricultural sector, but also from environmental concerns. In addition to the actions at the Ministry of Agriculture, the Dutch Ministry of Environment is developing new guidelines for the admission of environmentally alien substances, which will result in an exclusion of 50 to 70% of the pesticides used today.

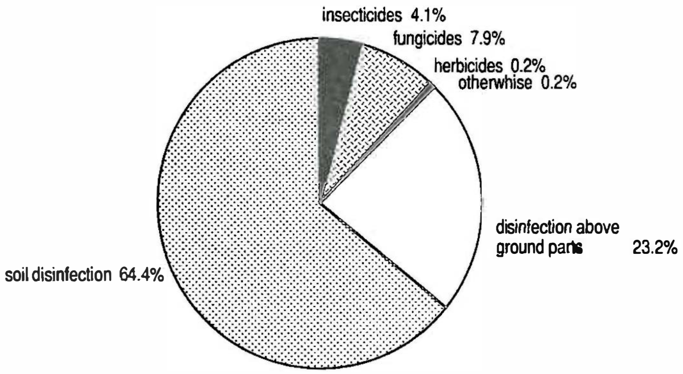
4. Incorrect views of biological control hampering its application

Because of these changes in crop protection policy, the interest for biological control methods has strongly increased. On the other hand it has triggered unfair criticism of biological control. In the following section I will discuss a number of often heard, but incorrect statements.

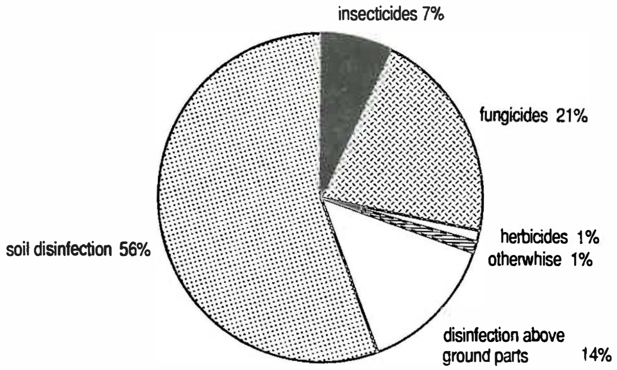
4.1. Biological control creates new pests

Use of biological control against one specific pest is said to lead to new pests due to a termination of spraying with broad spectrum pesticides. For the glasshouse situation this criticism is not correct. Research on biological control was started to control pests which were resistant to pesticides. During the first years (1965-1975) control of the key glasshouse pests, spider mite and greenhouse whitefly, did not result in the occurrence of new pests. The new pests which have occurred since 1975 were unintentional imports (*Spodoptera exigua*, *Liriomyza trifolii*, *Liriomyza huidobrensis*, *Frankliniella occidentalis*, *Bemisia tabaci*). These newly imported pests have created serious problems in glasshouses both under biological and chemical control.

They threatened the biological control of other pests because natural enemies for them could not always be identified quickly enough. Chemical control of these pests was also very difficult because the pests were already resistant against most pesticides before they were imported in Europe. Several of these pests are so hard to control chemically that biological control appears to be the only viable option.



PESTICIDE USE IN GLASSHOUSE VEGETABLES 1988



PESTICIDE USE IN GLASSHOUSE ORNAMENTALS 1988

Fig. 1. Pesticide use in Dutch glasshouse vegetables and ornamentals expressed as percentage of total pesticide use in 1988.

4.2. Biological control is unreliable

The idea that biological control is less reliable than chemical control has emerged mainly as a result of a strong pressure to market natural enemies which were not fully tested for efficacy. The criticism also arose because some amateuristic producers of natural enemies did not check whether the agents they sold were effective for control of the target pest. In The Netherlands it has always been our philosophy only to market natural enemies which have proven to be effective under practical conditions and within the total pest and disease programme.

Natural enemies for which such efficiency studies were performed, e.g. *Phytoseiulus persimilis*, *Encarsia formosa*, and leafminer parasites, have shown to be as reliable or even better than chemical control agents. The present difficulties in controlling *Frankliniella occidentalis*, has resulted in a too early large scale usage of predatory mites which have not been tested sufficiently under practical conditions. As in chemical control, a period of ten years between the start of research and marketing of an agent is often needed for correct evaluation of a natural enemy.

It is unrealistic to expect that researchers in biological control can solve pest control much faster than those working with chemical control. Biocontrol workers often have to deal with much more complex ecological variables than researchers in chemical control. Biological control workers should be careful - even if the pressure is very strong - not to release natural enemies too early due to the resultant negative advertisement for our profession.

4.3. Biological control research is expensive

All cost-benefit analyses show that biological control research is more cost effective than chemical control (cost-benefit ratio's of 30:1 for biological control and 5:1 for chemical control, e.g. DeBach 1964, 1974, Huffaker and Messenger 1976, Tisdell 1990). The fact that despite this biological control is not used on a larger scale is mainly due to the relatively cumbersome production and distribution of parasites and predators. The whole methodology of natural enemy production is very different from that of pesticides.

It is often thought that finding a natural enemy is more expensive and takes more time than identifying a new chemical agent. The opposite is usually true: costs for developing a natural enemy being on average 2 milion US$ and those for developing a pesticide on average 25 million US$.

4.4. Application of commercial biological control is expensive for the grower

An important incentive for the use of biological control in glasshouses has been that the costs of natural enemies have been lower than that of chemical pest control. Ramakers (1982) estimated costs (agent and labour) for chemical and biological pest control in 1980. At that time chemical control of whitefly was twice as expensive as biological control with the parasite *E. formosa* (table 2). Currently chemical control of *T. urticae* is almost twice as expensive as biological control with predatory mites (table 3).

Biological control is now so common in the main crops (tomato, cucumber and sweet pepper) that it is sometimes hard to make an estimate for pure chemical control costs. In figure 2 a comparison is given for total costs (labour and agent) of chemical and biological control.

4.5. Practical use of biological control develops very slowly

The total world area covered by glasshouses is 150.000 ha (van Lenteren & Woets, 1988). Small scale application of biological control in glasshouses started in 1968 with the use of the predatory mite *P. persimilis*. *E. formosa* has been used since 1970. Later, other natural enemies were selected, tested and introduced in programmes for commercial integrated pest control.

Table 2. Costs of whitefly control in US$ per square meter per season in 1980 (Ramakers 1982).

	chemical control	biological control
control agent	0.005	0.025
labour	0.015	-
	------	------
costs per treatment	0.020	0.025
treatments per season	10	4
	-------	-------
total costs	0.200	0.100

Table 3. Costs of spider mite control in US$ per square meter per season in 1988 (van Lenteren, 1990).

	chemical control	biological control
control agent	0.016	0.115
labour	0.0125	0.006
	--------	---------
costs per treatment	0.0285	0.121
treatments per season	6-10	1
	--------	---------
total costs	0.228	0.121

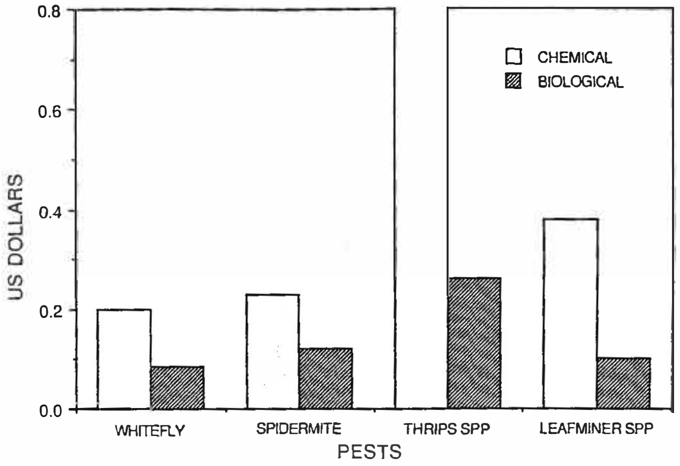


Figure 2. Total costs (labour and agent) for chemical and biological control in US$ per square meter per season; data for 1988 (van Lenteren 1990).

The developments in use of natural enemies over the period 1970-1988 is depicted in figure 3. The total area now under biological control amounts to 12,000 hectares, and represents 30% of the present potential area for biological control (van Lenteren & Woets, 1988). The method is applied mainly in vegetables, although recently many activities have been additionaly directed in developing biological control for ornamental crops. Figure 3 shows that after the initial phase when only *P. persimilis* and *E. formosa* were used, the natural enemy market has considerably diversified. Presently, biological control of whitefly and spider mite is applied in more than 20 countries out of the total 45 countries that have glasshouses. Several current trends will stimulate the application of IPM in glasshouses. Firstly, fewer new insecticides are becoming available because of escalating costs for development and registration. The few new insecticides that are being developed are not likely to be targeted for glasshouse use because the glasshouse area is too small and represents a poor opportunity for chemical companies to recover developmental costs. Secondly, pests continue to develop resistance to insecticides, a particularly prevalent problem in glasshouses where intensive management and repeated insecticide applications exert a strong selective pressure on insects. Therefore we expect a greater demand for non-conventional pest control methods. Satisfying this increasing demand will be a challenge for the entomological profession.

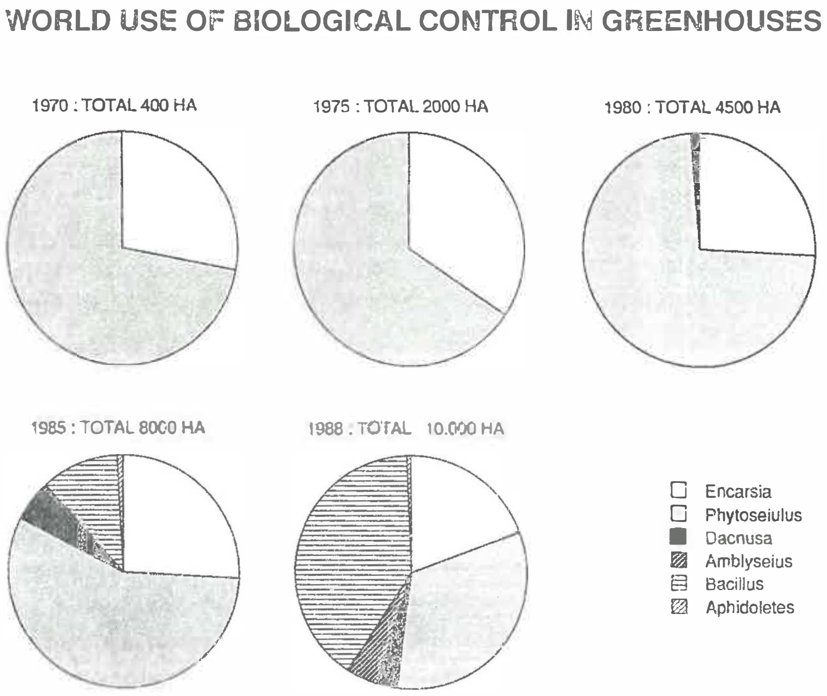


Fig. 3. Developments in use of different natural enemies for control of pests in glasshouses (van Lenteren, 1990).

5. Vital considerations before starting biological control research and application

5.1. Acceptance of biological and integrated control as the official pest control strategy of the country should be the first goal of biological control workers

The most important stimulus for an increase in use of biological control is the acceptance by governments of IPM as the main control strategy. If governmental bodies do not support implementation of IPM, activities of researchers should first and only be directed at a change of the policy at high levels. A change in policy should not only be expressed on paper, but has to be materialized in research, education and extension.

5.2. Without long-term planning of research and application, biological control programmes are doomed to fail

It is an essential prerequisite that all participants - including extension workers and farmers - in an IPM project are receptive for new developments and are willing to implement them. A goal-oriented, long-term planning of crop protection is necessary to base IPM developmental work on. With a good planning, existing alternative methods can be used to realize a gradual improvement of crop protection.

The applicability of new methods should be tested within the economic constraints of the farmer, to demonstrate and verify that these methods will not impair financial returns and will probably be beneficial, in the long-term, to society as a whole (Gruys et al., 1980).

5.3. Introduction of biological control demands a good advisory service

At the introduction of the first biological control agent in a crop, special attention should be paid to extension: the growers have to rediscover the way biological control works and learn to rely on it. For extension workers the problem is that proper guidance of biological control demands considerable entomological knowledge and understanding.

The phase of the initial implementation of biological control is often neglected. Experience in The Netherlands has shown that the amount of application of IPM is strongly related to the activity and attitude of extension personnel. If governmental extension services are weak, biological control will have no chance, unless the producer of natural enemies has well trained extension personnel and is willing to invest in guidance. For glasshouse growers a period of one or two years suffices to obtain additional knowledge of, and insight in, biological control.

5.4. Acceptance of biological control as a serious control technology necessitates good public relations and education

Although researchers often do not like to invest time in writing articles that are not for scientific publications, it is essential to do so. Publications in the public press, radio and television programmes are usually more helpful in gaining acceptance for biological control than pure scientific articles.

The teaching of crop protection should drastically change at all levels (from vocational schools to university). Presently essentially purely technical information is taught on how to spray and with what chemicals. This should partly be replaced with information on other forms of pest control, especially biological control.

In The Netherlands such changes have occurred already and discussions with young growers have undergone a positive change over the past decade: it is no longer a matter of trying to convince them to use biological control, it is more a matter of being able to appropriately satisfy them with natural enemies for new pests. Integration of natural enemies and (selective) chemical control is a normal procedure nowadays.

5.5. The role of the consumer should be exploited to the benefit of biological control

The consumer is generally very receptive to information on and use of pest control not involving chemical pesticides. He is even willing to pay more for non-sprayed produce. Problems with residues on food, accidents with pesticides at production sites and environmental pollution have resulted in a strong awareness of side-effects involved in the use of chemical pesticides. Those working in the field of IPM should now positively interfere with the present attitude of the consumer which is that any reduction in chemical treatments is considered an improvement.

A serious problem is that the consumer has no direct influence on the production and sale of pesticide free crops. It is the middle man who determines crop quality. Their standards are by no means influenced by the consumer, and their selection criteria result in an overuse of pesticides. It would be to the benefit of farmers and the general public if the last group could have more influence on pesticide-poor or -free production, e.g. by introducing a protected salesmark for food produced under IPM.

5.6. Information on biological and integrated control should be provided in the same books and pamphlets of the state advisory service which contain information on chemical control

The first Dutch state guide for pest control (The Crop Protection Guide issued by the Advisory Service and Plant Protection Service (both from the Ministry of Agriculture)) published in 1968 provided no information on biological control. In the 1981 volume (eight's edition) the first information on biological control was included, more than ten years after the use of *P. persimilis*. The 1987 edition contains 6 pages of information on biological and integrated control out of a total of 575 pages, including lists of which pesticides can safely be used in combination with specific natural enemies. The 1989 volume consisting of 589 pages has 7 pages on biological control. (This is all in sharp contrast with the contents of the first book written by a Dutch author - Ritzema Bos - on pest control "Pests and Beneficial Organisms" in 1891: of the 876 pages only 3 had information on chemical control.)

5.7. Reliable production of good quality natural enemies should be guaranteed

The past 30 years have been characterized by the appearance and disappearance of natural enemy producers. Only a few producers active in the 1970's are still in the market. The market has somewhat stabilized and besides many small, rather amateuristic producers, less than 5 large facilities are available providing qualitatively reliable material. The number of beneficials produced at these large production sites is often more than 5-10 million per agent per week (van Lenteren & Woets, 1988). The rise and fall of so many producers resulted in a negative marketability for biological control.

The background of producers is rather diverse. Rearing of natural enemies can be a full-time or part-time activity of glasshouse growers. They can be reared by companies related to the glasshouse industry like seed companies and producers of fertilizers. In some cases production was started by a research group with governmental support and later continued as a private endeavour.

The natural enemy producers mainly rear predators and parasites, only a few deal with microbial agents like nematodes, entomopathogenic fungi, bacteria or viruses. The chemical industries are interested primarily in production of microbials and it is expected that all activities in this area will soon be exclusively the domain of the pesticide industry.

The large natural enemy producers can now be considered as professionals, with research facilities, application of quality control, an international distribution network, P-R activities and an advisory service. They are well respected for their work and their market will certainly increase with the increasing demand for unsprayed food and the growing pesticide resistance problem.

5.8. Quarantine and inspection services should be improved to prevent unintentional imports of pest insects

During the past decade numerous pest insects have been imported into Europe (see 4.1 for examples). The initial chemical control programmes developed to eradicate these pests usually failed, but the spray frequencies advised were so high that each time a new pest was imported, the biological control of other pests was put at risk.

The creation of a database with information on potential invaders and methods to control these organisms might help to prevent panic reactions aimed at eradication.

5.9. Adaptation of export requirements to make biological control possible

Current export requirements are often unrealistic. They result in overuse of pesticides, with the additional risks of a fast development of resistance, high residue levels and health risks. Within Europe we should work for more realistic requirements, and the first priority should be to change the criterion that products should be without signs of damage, to that of products having no living pest insects.

Acknowledgements

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PROSPECTS FOR THE BIOLOGICAL CONTROL OF *LIRIOMYZA HUIDOBRENSIS* (BLANCHARD), A NEW LEAFMINER FOR EUROPE

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Summary

In 1989, *Liriomyza huidobrensis* (Blanchard) was found for the first time in The Netherlands. The leafminer attacked many vegetable and ornamental crops. It was tolerant to many pesticides. Parasitoids identified included *Dacnusa sibirica* Telenga, *Opius pallipes* Wesmael and *Diglyphus isaea* Walker. The utility of these parasitoids will be checked in crops like tomato and lettuce. The latter is most difficult for biological control because mines are hardly tolerated. A list of parasitoids occurring in The Netherlands and the New World is given. For a possible selection of an exotic parasitoid the crop itself should be used as a selective medium.

1. Established *Liriomyza* species

In greenhouse vegetables leafminers may cause severe damage. So far, the most widespread species has been the tomato leafminer *Liriomyza bryoniae* (Kaltenbach). The common name tomato leafminer is misleading, because this leafminer is polyphagous and occurs not only in tomato, but also in cucumber, sweet pepper, eggplant, lettuce, gerbera, gypsophila, carnation and some other less important crops.

An introduced species, *Liriomyza trifolii* (Burgess), gave many problems during the early 80s in chrysanthemum, gerbera, gypsophila, tomato, sweet pepper, eggplant and minor crops like beans. To-day, *L. trifolii* is no longer a serious problem on vegetables. Since the species is tolerant to many pesticides, the use of pesticides is often causing problems rather than solving them by killing the leafminers' parasitoids. Integrated control with these parasitoids gives better results.

2. New leafminer species

In 1989, *Liriomyza huidobrensis* (Blanchard) occurred for the first time in The Netherlands. The original source could not be traced. The species occurs in western North America, mainly California, and much of temperate South America: Columbia, Venezuela, Peru, Brazil, Argentina and Chile, in beet spinach, lettuce, melon, pea, broad bean, onion, flax, tomato, potato, sweet pepper, parsley, carnation, cineraria, petunia and chrysanthemum (Spencer, 1973, 1982). In The Netherlands it was found on many vegetable crops(lettuce, iceberg lettuce, bean, broccoli, cauliflower, pak choi, lollo rosso, radicchio, courgette cucumber, endive, eggplant, Chinese cabbage, melon, sweet pepper, celery, radish, rettich, tomato), several ornamentals (including chrysanthemum, gypsophila, carnation), and many weeds. Especially in lettuce it led to complete losses of crops. This leafminer is tolerant of many pesticides. *L. huidobrensis* is closely related to *L. bryoniae*. The flies are generally more black than those of *L. bryoniae*. Larvae of both species are able to form the same type of mines. The larvae of *L. bryoniae* are slightly more yellow at the anterior end. Both species show seasonal dimorphism. During autumn and winter the colour of the pupae becomes darker. Light brown pupae are found during spring and summer. The dark coloured pupae are able to survive the winters of the continental climate (Nowakowski 1962).

3. Rate of development

Development rate at 25°C on lettuce was found to be similar in *L. huidobrensis* and *L. bryoniae*: eggs 3 days, larvae 5 days and pupae 9 days, which makes a total of 17 days. When pupae were kept at 12°C, adults emerged after 3 weeks.

4. Sampled parasitoids

The parasitoid complex of *L. bryoniae* was also found associated with *L. huidobrensis*. *Dacnusa sibirica* was dominant in lettuce in 1989. It is not known whether this is because of host plant preference or because of selection by the use of pesticides. Both *D. sibirica* and *Opius pallipes* were recovered from bean, and *Diglyphus isaea* from melon.

Rearing the parasitoids *Opius pallipes* and *Chrysocharis oscinidis* on *L. huidobrensis* was easy. Tomato, bean and limabean were used as host plants.

5. Prospects for biological control

It is expected that the problem can be controlled in vegetable crops like tomato of which the leaves have no market value. Crops like lettuce will give much more difficulties. Neither chemical control nor biological control will completely eliminate the pest. For the use of parasitoids it is necessary to know which parasitoid performs best in lettuce, taking into consideration a possible host plant preference and the temperature regime. The greenhouse temperature regime for lettuce is 8 - 12°C during wintertime. Crops like lettuce are harvested within a short time. A system of biological control in lettuce only has a chance in the case of repeated plantings. Specialized lettuce growers have 6 to 7 crops per year. When there are no separate generations of the leafminer, it is expected that weekly release of parasitoids will be necessary to keep the leafminers at a low density. If the results with parasitoids are encouraging, an open rearing system might be a solution in future.

6. Parasitoid choice

For a start the native parasitoid complex: *Dacnusa sibirica, Opius pallipes* and *Diglyphus isaea* will be released in lettuce and tomato crops. Especially lettuce has much attention now. Depending on the results it might be necessary to introduce parasitoids from North and South America. A first selection could be made in the country of origin by means of collecting the parasitoids from lettuce. Then the first selection is partly made by the host plant. Table 1 is a list of the parasitoids of *L. huidobrensis*, known so far. Hansson (1987) revised the genus *Chrysocharis*. *Chrysocharis flacilla* (Walker) was formerly known as *Euparacrias (Chrysocharis) phytomyzae* (Brèthes), and *Chrysocharis oscinidis* Ashmead was formerly known as *Chrysocharis parksi* Crawford and *Chrysocharis viridis* Provancher.

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Table 1. Review of the parasitoids of *Liriomyza huidobrensis* (Blanchard) with host plant indication, country and references.

Parasitoid	Host plant	Country	Reference
Diglyphus begini (Ashmead)	spinach	California	Spencer, 1973
Diglyphus intermedium (Girault)	spinach	California	Spencer, 1973
Diglyphus isaea (Walker)	melon	The Netherlands	present paper
Diglyphus websteri (Crawford)	potato	Peru	Campos, 1982
Diglyphus spp.	broad bean potato	Argentina Peru	Arce de Hamity & Neder de Román 1984; Chavez & Raman, 1987: Raymundo & Alcazar, 1983
Chrysocharis ainsliei (Crawford)	-	California	Spencer, 1973
Chrysocharis caribea Boucek	bean	Brazil	Campos et al., 1984

Parasitoid	Host plant	Country	reference
Chrysocharis flacilla (Walker)	broad bean, potato	Argentina, Peru	Arce de Hamity & Neder de Román, 1984; Chavez & Raman, 1987; Neder de Román & Arce de Hamity, 1984; Serantes de Gonzalez, 1975
Chrysocharis oscinidis Ashmead	onion	Hawaii, California	Johnson & Mau, 1986; Spencer, 1973
Chrysocharis spp.	potato	Peru	Chavez & Raman. 1987; Raman & Palacios, 1986
Halticoptera circulus (Walker)	onion	Hawaii	Johnson & Mau, 1986
Halticoptera patellana (Dalman)	potato	Peru, California	Chavez & Raman, 1987; Raman & Redolfi, 1984; Raman & Palacios, 1986; Spencer, 1973
Opius pallipes Wesmael	bean	The Netherlands	present paper
Opius scabriventris Nixon	bean	Brazil	Campos et al., 1984;
	broad bean	Argentina	Neder de Román & Arce de Hamity, 1984; Serantes de Gonzalez, 1975
Opius spp.	potato tomato	Peru, Brazil, California	Chavez & Raman 1987; Cruz et al., 1988; Raman & Palacios, 1986; Spencer, 1973
Dacnusa sibirica Telenga	lettuce bean	The Netherlands	present paper
Agrostocynips clavatus Dias	-	Argentina	Diaz & Valladares, 1970
Mesora sp.	-	California	Spencer, 1973

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THE WESTERN FLOWER THRIPS IN FINLAND

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Summary

The western flower thrips, *Frankliniella occidentalis*, has within a few years become one of the main pests in Finnish greenhouses. In 1987, an extensive survey of Finnish greenhouse cultivations was performed to establish the distribution of *F. occidentalis*. The outcome of the chemical control measures in the infested greenhouse productions recommended in 1987 was evaluated in 1988. Most of the cucumber cultivations were also investigated. (In 1989, no extensive survey was performed on *F. occidentalis*). Some preliminary results of biological control of *F. occidentalis* with the predatory mite *Amblyseius barkeri* are also presented.

1. Introduction

The western flower thrips (WFT), *Frankliniella occidentalis* (Pergande), appeared in Finland in the late summer of 1987, and was first found in *Saintpaulia*. This pest was already expected to come to Finland as, by then it had already been found in southern Scandinavia (Brødsgaard 1989, Nedstam 1987). The WFT very soon became the most problematic pest in Finnish greenhouse cultivations.

By then, there was no practical method for biological control of thrips in Finland, although the biological control of other common pests on greenhouse vegetables have been used since the early 1970s (Markkula & Tiittanen 1982). In the 1980s growers occasionally had problems with the onion thrips and were therefore forced to use chemical control. As an answer to the growers' need for biological thrips control, a new method, based on the use of *Amblyseius barkeri* (Lindqvist & Tiittanen 1989), was introduced in 1988. Thus the introduction of this method coincided with the occurrence of WFT. This situation prompted new demands upon finding a efficient biological control method for the WFT. Good results have been obtained both in Canada (Elliot et al. 1987) and in Sweden (Lindhagen & Nedstam 1988) by using the predatory mite *A. cucumeris* Oud. for the control of WFT. To ascertain whether *A. barkeri* could be used against WFT, preliminary experiments were performed on greenhouse cucumber, using the same method as for biological control of *T. tabaci* (Lindqvist & Tiittanen 1989).

1.1 WFT situation in 1987

The appearance of the WFT in Finnish greenhouses led to immediate measures to investigate its distribution. The Finnish Plant Quarantine Service and consultants from the Horticultural Advisory Organisation collected samples from greenhouse vegetables and ornamentals during three months. A total of 1,417 samples from 216 greenhouse productions were examined, and WFT was found in 86 greenhouse productions (Table 1). In five of the infested greenhouse productions, only vegetables were grown. The remaining 81 gardens were mixed or pure ornamental cultivations. The most serious problems occurred in the mixed cultivations which had their own production and imported ornamentals in the same greenhouses.

Plant protection authorities informed the farmers about control measures against the WFT. The most important instructions were: to treat plants with pesticides, to destroy them, and to clean the houses carefully. Recommended pesticides, selected according to experiences from other countries, were dichlorvos and synthetic pyrethroids used alternately. The use of endosulfan was also allowed for disinfection of empty greenhouses. The growers were not allowed to sell their products. A temporary import prohibition of some host plants took effect in August 1987 and lasted for three months. Thereafter, in November 1987, some conditions for importation of the most important host plants of WFT took effect. Immediately before exportation to Finland, plant protection authorities in the country of origin should inspect the plants to find them free from pests. Also the greenhouse where the plants had been grown should be free from pests for at least four weeks before exportation. This had to be recorded in the health certificate of the plants.

1.2 **WFT situation in 1988**

In 1988, the Institute of Pest Investigation at the Agricultural Research Centre and the Plant Quarantine Service at the National Board of Agriculture evaluated the results of the chemical control program against WFT in the autumn 1987. Greenhouses infested with the WFT in the autumn 1987 were contacted. The growers were inquired about the disinfection measures taken and also were asked to send samples if presence of thrips was still suspected in the greenhouses. Some samples were also received from other growers. The total number of samples received was 60. Furthermore, technicians of the Institute of Pest Investigation visited 51 greenhouse productions and collected samples.

The results of the survey revealed that of the total of 111 productions, 56 were infested by WFT (Table 1). Only in three productions was cucumber the only cultivated plant. The remaining 53 productions comprised both mixed vegetable and ornamental cultivations or pure ornamental cultivations. Only 14 of the infested gardens in 1988 were on the list of infested gardens of 1987.

Later in the season, in September, the majority of greenhouse cucumber cultivations in Finland, including mixed cultivations, were surveyed (Table 1). WFT was found in 32 (13%) productions, but only 10 (4%) were pure cucumber cultivations.

1.3 **WFT situation in 1989**

In 1989, no extensive survey, like those of the two previous years, was carried out. The data of the distribution of WFT was based exclusively on samples sent by growers. Only one vegetables, cucumber, was reported to be infested with WFT. The other 12 infested productions were mostly mixed cultivations.

Resources of the Plant Quarantine Service and checking have been concentrated on plant producers, instead of on normal cultivations. Plant protection authorities regularly control these, and once WFT is found, prohibitions to sell products takes effect. The prohibition is cancelled only after the Plant Quarantine Service has found the plants to be absolutely free from the pest.

Table 1. Distribution of the western flower thrips (*Frankliniella occidentalis*) in greenhouse cultivations in 1987-1989 in Finland.

Year	Inspected	Infested		
		Vegetables	Others	Total
1987	216	5	81	86
1988	111	3	53	56
1989 *	239	10 (4%)	22 (9%)	32 (13%)

* samples from greenhouse cucumber cultivations.

2. Preliminary results of biological control of WFT

In 1988, three biological control experiments were performed in cooperation with two horticultural schools, where great problems were encountered in the autumn 1987 with WFT on cucumber. The predatory mite *A. barkeri* was used as a control organism.

Experiment I was started in mid-April, two months after planting, when the first thrips were noticed. A total of 50 predators/m² were distributed evenly on the plants. This was repeated in three successive weeks. Leaf samples were collected every two weeks from mid-May to mid-September.

The other two experiments were performed in the same greenhouse, one after the other. Experiment II was started when several thrips already were found in each flower, and the leaves were in some degree damaged. During five successive weeks, predators were distributed evenly on the plants, totally 300 predators/m². Samples were taken every week, until the experiment was completed in the beginning of June.

After thorough disinfection of the greenhouses, experiment III was started one month later, in the beginning of July. One week after planting of the cucumber plants, when thrips were not yet noticed, the first lot of predators was distributed in the cucumber pots at a rate of 20/m². Thereafter a total of 130 predators/m² were distributed on the plants during five successive weeks. Samples were taken every week until the experiment was completed in September.

3. Results

The first leaf samples from experiment I were collected three weeks after the last introduction of predatory mites. As shown in Fig. 1, the WFT population was at first as high as 29 thrips/leaf. One month later, the density of the thrips population had clearly diminished in contrast to the increasing predator population. A rather good balance between the prey and the predator had been established by the end of the season. However, the plants had suffered a lot due to spider mites and mildew.

Experiment II was started too late. The thrips population was multiplying so fast that the predators could not keep the thrips under control. Hence extensive damage of the plants could not be avoided. The experiment was completed after five weeks.

In experiment III, thrips were noticed one week after the first introduction of predators. One week later there were already several thrips in the flowers. The thrips population remained small during the experiment. At the end of the experiment the plants were heavily infested by spider mites and whiteflies.

4. Conclusion

The investigations revealed that by 1987 WFT had spread to almost all of Finland, except for the northern parts. The survey in 1988 indicated that the recommended disinfection program led to a decrease in the number of infested greenhouse productions. Compared to the situation in 1987, only 16% of the infested greenhouse productions were still infested in 1988. Furthermore, the decision of some growers to change from mixed cultures to either purely ornamental or purely vegetable cultivation improved the situation.

In 1989, there were probably many more infested greenhouses than estimated from the samples. Although the actual number of infested greenhouses in 1989 is unknown, it has probably decreased. Vegetable growers, at least, have been very thorough with the disinfection of empty greenhouses at the end of the growing season, and the disinfection results have been good.

The preliminary tests gave some information about the possibilities of using the predatory mite *A. barkeri* against WFT. Except for experiment II, which was started far too late, the other two experiments gave somewhat encouraging results. Experiments I and III are

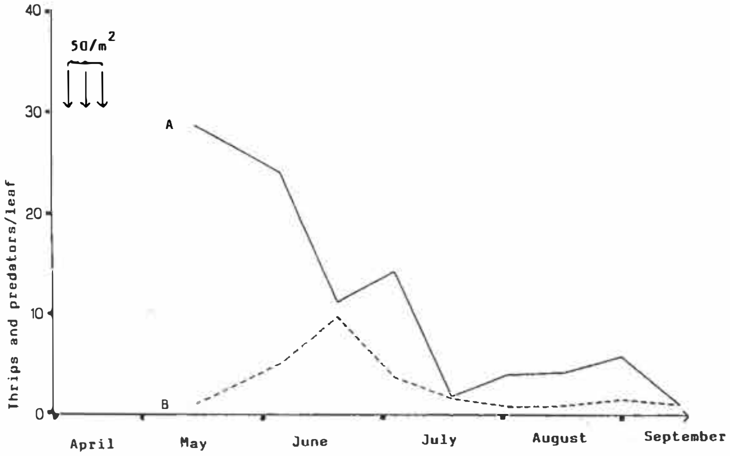

Fig. 1. Efficacy of *Amblyseius barkeri* predatory mites against western flower thrips (*Frankliniella occidentalis*) on greenhouse cucumber in 1987. Release of a total of 50 predators/m² (↓) Leaf samples were taken every two weeks.
Symbols:A = thrips; B = predators.

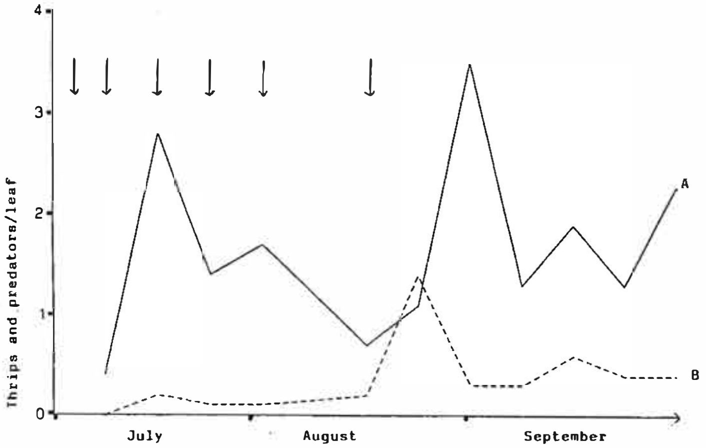

Fig. 2. Efficacy of *Amblyseius barkeri* predatory mites against western flower thrips (*Frankliniella occidentalis*) on greenhouse cucumber in 1987. Release of a total of 150 predators/m² (↓). Leaf samples were taken once a week.
Symbols:A = Thrips; B = predators.difficult to compare, because they were carried

carried out under different conditions. The first one was started in spring on two - months - old cucumber plants, and it lasted throughout the growing season. The other one was started in the middle of the summer, one week after planting, and it continued only three months. In both cases, however, the thrips populations were controlled without pesticides. In experiment I, the thrips population was still rather high three weeks after the last introduction of predators. Thereafter the thrips population decreased considerably, and as from July there was a good balance between the prey and the predator. In experiment III, the situation was good throughout the experiment. The number of thrips and predators per leaf remained quite small (Fig. 2). In this case it was necessary to introduce predators very soon after planting, because the neighbouring sections of the greenhouse were infested by WFT.

Experiences of these three preliminary experiments suggest that it is important to introduce the predators immediately upon detection of thrips. In these experiments it took several weeks for predators to become well established on the plants. According to Brødsgaard (1988), only 20% of the predatory mites reappear after one introduction on sweet pepper. Thus it is necessary to repeat the introduction of predators several times at short intervals.

As WFT seems to have become established in our greenhouses as one of the main pests, it is of great importance to maintain the WFT population on as low a level as possible. Particularly on vegetable cultivations, where biological control is used against other common pests, it is problematic to apply chemical control. Furthermore, the use of pesticides against WFT on ornamentals may become more difficult, because this species has been shown highly resistant to pesticides. Against this background the development of a biological control method seems extremely important.

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HYMENOPTEROUS PARASITES AS BIOLOGICAL CONTROL AGENTS OF *FRANKLINIELLA OCCIDENTALIS* (PERG.)?

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Summary

Frankliniella occidentalis has recently been imported into Europe and seriously complicates Integrated Pest Management of insects and mites in glasshouses, because no selective chemicals or sufficiently effective biological control agents are available to control this thrips species. Until now hymenopterous parasites have not been tested as control agents of thrips in Europe. As a first step towards research in this area, the literature information on insect parasites of *F. occidentalis* has been collected and evaluated.

1. Introduction

During recent years *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) has become one of the major pests in glasshouse crops throughout Europe (IOBC/WPRS workschop, September 1989, Denmark). It occurs on a wide range of host plants, where it is concentrated in buds, flowers and young, not yet unfolded leaves (Mantel & Van de Vrie 1988). Because of its occurrance on hidden places, *F. occidentalis* is difficult to control chemically and treatments have to be repeated frequently. All chemicals registered for thrips control are harmful to natural enemies used for the control of other pests. Therefore, an effective biological control agent of *F. occidentalis* would be highly desirable. It would not only reduce the necessity of chemical emergency treatments, it would also safeguard existing integrated control programmes for glasshouse crops.

2. Natural enemies of *F. occidentalis*

Natural enemies which are specific to *F. occidentalis* have not been found, to date. Presently, research on biological control agents of this species is largely focussed on two groups of predators: amblyseiids (*Amblyseius* spp.) and anthocorids (*Orius* spp.) (see articles in this volume). None of these agents, however, is yet able to keep *F. occidentalis* at sufficiently low population levels on e.g. cucumber. Up till now, there have been little or no attempts in using hymenopterous parasites for controlling thrips populations in glasshouses. Compared to predators, parasites are more host specific and are expected to be more effective at low population levels. Therefore, we recently started research to investigate the potential of parasites of thrips for controlling *F. occidentalis*. During the first year the emphasis will be on the following points:

1. conducting a survey of parasites of thrips already known in literature and selecting potential candidates for control,
2. exploration for parasites of thrips in field populations of *F. occidentalis* or closely related species, and
3. introduction of potential candidates into our laboratory, development of a rearing method and carrying out preliminary studies on their effectiveness.

In this paper, the results of our literature survey are presented. Besides working with publications on thrips parasites and checking of abstract and review journals and Mantel's bibliography on western flower thrips (Mantel, 1989), we have performed an intensive computer search whereby the files of the following databases were scanned:

- "Agricola", based on references of the US National Agricultural Library, since 1982;
- "Agris", based on references from FAO at Rome (Italy), since 1975;
- "Biosis Preview", based on references from Biological Abstracts, since 1970;
- "CAB", based on references of abstract journals from the Commonwealth Agricultural Bureaux at London, since 1973;
- "Phytomed", based on references from Bibliographie der Pflanzenschutzliteratur, since 1965.

This survey was based on the keywords "Frankliniella", "?thrip?", "?paras?" and several names of parasite genera, already known to parasitize thrips.

3. Parasites of thrips

Hymenopterous parasites of thrips are all tiny wasps belonging to the superfamily Chalcidoidea. Most of them are solitary, internal parasites of larvae and nymphs (Eulophidae) or eggs (Mymaridae, Trichogrammatidae). Identified species which have been reported in literature as parasites of Thysanoptera, are summarized in table 1, Appendix I (a compilation and revision of earlier reviews by Sakimura 1937, Thompson 1950, Ferrière 1958, Lewis 1973 and Ananthakrishnan 1984, with additions and corrections based on more recent literature). Species not known to parasitize thrips but closely related to thrips-parasitizing species, are also included (Boucek & Askew 1968, Domenichini 1966). The geographical distribution of the parasites is given, as are their known host associations.

In literature there are more records of thrips parasites than given in this article, but we have left out the species which need further confirmation of their correct host association. For instance, *Pediobius dipterae* Risbec, *Thriposoma grafi* Crawford (Eulophidae) and *Camptoptera pulla* Girault (Mymaridae) were all collected from plants bearing thrips, but none of the records state either that these species actually parasitize thrips or that they were reared from thrips. Parasites of thrips, which have only been determined to the genus level are also left out. For instance, Saxena (1971) reports *Ceranisus* sp. to parasitize on *Thrips tabaci* Lind. in India and Hirose (1989) found *Ceranisus* sp. and *Megaphragma* sp. to parasitize *Thrips palmi* Karny in Thailand. Some species belonging to the Eucharitidae are reported as ectoparasites of larvae of thrips (Johnson 1988).

A total of 32 parasite species of Thysanoptera has been identified. Most of these are described from tropical and subtropical climates. Species belonging to *Thripoctenoides* Erdös and a few species of *Ceranisus* Walker have been described from temperate regions. None of these, however, were found to parasitize thrips in The Netherlands, neither in glasshouses nor outside. Detailed biological studies have been conducted on some species only. Results of these studies are summarized below.

4. Biology of thrips parasites

Parasite species belonging to the Eulophidae are solitary, internal parasites of larvae, although sometimes the prepupae and pupae may be attacked. Details of the life history and habits of thrips parasites are known from observation on a small number of species only: *C. menes* (Sakimura 1937), *C. pacuvius* (Kutter 1936), *C. russelli* (Russell 1912), *C. vinctus* (Fullaway & Dobroscky 1934), *G. parvipennis* (Hessein & McMurtry 1989) and *T. gentilei* (Bournier 1967). Developmental time is influenced by temperature but sometimes also by host species attacked (Daniel 1986), even geographical races of the host species (Sakimura 1937) and host stage (ibid.) may influence developmental time. Adults normally emerge from the prepupa, but there are differences between the species. Some eulophid species reproduce sexually, in others males are unknown.

Parasite species belonging to the Mymaridae and Trichogrammatidae are solitary internal parasites of terebrantian species. They lay their egg in the host egg which is imbedded in the plant tissue; adult parasites, males as well as females, emerge before the host egg can hatch (e.g. *P. indica*: Daniel 1986; *M. mymaripenne*: Hessein & McMurtry 1988).

Chalcidoid planidia (Eucharitidae), parasitic on ants, are reported as ectoparasitic on larvae of thrips, for instance *F. occidentalis* (Wilson & Cooley 1972). No eucharitids however, are known to complete their development on their thrips host and the role of thrips in their life-cycle remains unclear (Johnson 1988).

Geographical strains of one parasite species may exist, but have never been properly evaluated. For instance, in Japan *C. menes* completes 4-5 generations a year on *T. tabaci*, whereas one generation a year has been reported in Europe on *Kakothrips robustus* Uzel; females predominate in material from Japan and India, whereas in Europe this species reproduces unisexually (Buhl 1937, Daniel 1986, Sakimura 1937).

5. Host range

As can be seen in table 1, only a few thrips species (mentioned as genus only) are recorded as hosts of each hymenopterous parasite; in some cases only one thrips species is known as host. However, of most species the full host range and degree of host specificity is uncertain. Under confinement, species are able to parasitize more hosts than in nature, but quantitative checks on host preference and host suitability are scarce (e.g. Sakimura 1937). An indication of host ranges of thrips parasites is known from observation of a small number of species (e.g. *C. menes, C. russelli, G. parvipennis*) only. Thrips parasites often are specific to genera within the same family or even subfamily (see table). For instance, *T. gentilei* is a parasite of phlaeothripid species and most *Ceranisus* species have thripine species as hosts.

Records of thrips parasites found on *F. occidentalis* or closely related species, are scarce to date. There is only one unconfirmed record of a parasite of *F. occidentalis* (Seamans 1923): *C. americensis* was found in association with this thrips in alfalfa in Alberta-Canada, but it has never been reared from it. It would be to our interest to recover this parasite from populations of *F. occidentalis* in the field.

Only few parasite species have been recorded from other species belonging to the genus *Frankliniella*: *C. menes* parasitizes *Frankliniella intonsa* (Trybom) in Japan (Murai 1988), *C. russelli* was reared from *Frankliniella tritici* (Fitch) by Russell (1912) in California and was found on *F. intonsa* in Britain (Bagnall 1914), *M. longiciliatum* has been recorded from *Frankliniella lilivora* Takahashi in India (Subba Rao 1969) and *G. parvipennis* from *Frankliniella parvula* Hood (Ananthakrishnan 1984); *C. rosilloi* was found in association with *Frankliniella schultzei* (Trybom) by De Santis (1961) in Argentina, but this record also needs confirmation.

6. Potential of hymenopterous parasites in the biological control of thrips pests in glasshouses.

In the past there have been various attempts to introduce parasite species against thrips pests from one region to another in order to establish biological control in a classical way. However, only few of them became established on thrips pests: *C. menes* in Hawaii and *G. parvipennis* in the Caribbean, but they were of little economic importance (Clausen 1978). During recent years, biological control of thrips pests has regained new attention in controlling various thrips pests in India (Daniel 1986) and Japan (Murai 1988) and in controlling *Heliothrips haemorrhoidalis* (Bouché) in California (Hessein & McMurtry 1988, 1989).

In field studies of thrips populations, thrips parasites are often found to parasitize to various levels, ranging from low (e.g. Saxena 1971: 2 - 18 %) and intermediate levels (Lewis 1973, Hessein & McMurtry 1989) up to 90 % (Daniel 1986). Parasitization by some species (e.g. *C. menes*) may often be very localized within one region. Factors influencing this level of parasitism are poorly investigated, although weather conditions may play a role (Lewis 1973). The assessment of the potential of parasites in the biological control of thrips pests in glasshouses remains difficult, because of the scarcety of information on this group. The biology of most species is poorly known, quantitative checks of host preference of the parasites and suitability of the host, especially *F. occidentalis*, is lacking. Factors, biotic as well as abiotic, affecting levels of parasitism are scarce.

It is unknown how thrips parasites will react under the circumstances of European glasshouses. Arrangements are in progress to introduce parasites of closely related thrips species (Thripidae: Thripinae) to evaluate their potential for biological control of *F. occidentalis* in the desired crops and under the required conditions. For this evalution we will use the procedure developed earlier by our group (e.g. van Lenteren 1986).

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APPENDIX I

Table 1. Hymenopterous species parasitic on thrips (Thysanoptera), their geographical distribution and known host associations (by genus, belonging to a: Terebrantia: Thripidae (Thripinae), b: Terebrantia: Thripidae (Panchaetothripinae) and c: Tubulifera: Phlaeothripidae); host species placed between brackets were only found to be parasitized in the laboratory, ? means that the thrips species was not recorded or that the parasite species was not actually reared from it.

CHALCIDOIDEA,
EULOPHIDAE:

1. *Ceranisus americensis* (Girault), (California-USA, Alberta-Canada)
   a: *Frankliniella* ?
2. *Ceranisus bicoloratus* (Ishii), (Japan)
   a: *Thrips* ?
3. *Ceranisus femoratus* (Gahan), (Philippines)
   a: *Taeniothrips*
4. *Ceranisus lepidotus* Graham, (Britain)
   ?:
5. *Ceranisus maculatus* (Waterston), (Punjab-India)
   b: *Rhipiphorothrips*
6. *Ceranisus menes* (Walker), (Asia, Europe, Dominican Republic, Hawaii)
   a: *Frankliniella, Kakothrips, Megalurothrips, Microcephalothrips, Taeniothrips, Thrips, Isoneurothrips* ?
   b: *Zaniothrips, Retithrips*
7. *Ceranisus nubilipennis* (Williams), (Massachusetts-USA)
   c: *Cryptothrips, Megalothrips*
8. *Ceranisus nigrifemora* De Santis, (Argentina)
   ?:
9. *Ceranisus pacuvius* (Walker), (Europe)
   a: *Kakothrips*
10. *Ceranisus planitianus* Erdös, (Hungary)
   ?:
11. *Ceranisus rosilloi* De Santis, (Argentina)
   a: *Thrips* ?, *Frankliniella* ?

12. *Ceranisus russelli* (Crawford), (Britain, Hawaii, California-USA)
    a: *Frankliniella, Taeniothrips, Thrips*
    b: *Caliothrips*
13. *Ceranisus vinctus* (Gahan), (Philippines)
    a: *Taeniothrips*
14. *Epomphale (=Ceranisus?) javae* Girault, (Indonesia)
    a: *Thrips* ?
15. *Goetheana incerta* Annecke, (South Africa)
    ?:
16. *Goetheana parvipennis* (Gahan), (Indonesia, West/South Africa, Caribbean, Venezuela, USA)
    a: *Thrips, Frankliniella*
    b: *Caliothrips, (Dinurothrips), Heliothrips, Selenothrips*
17. *Goetheana thripsivora* Narayanan et al., (India)
    b: *Caliothrips*
18. *Pediobius thysanopterus* Burks, (Egypt, Israel)
    c: *Gynaikothrips*
19. *Tetrastichus gentilei* Del Guercio, (mediterranean/subtropics: Europe, America, Fiji, India)
    [= *Thripastichus gentilei* (Del Guercio)]
    c: *Gynaikothrips, Hoplothrips, Liothrips, Arrhenothrips, Thilakothrips, Schedothrips, (etc.)*
20. *Tetrastichus rhipiphorothripsidis* Narayanan et al., (India)
    b: *Rhipiphorothrips*
    c: *Mallothrips*
21. *Thripobius hirticornis* Ferrière, (Ghana, Tanzania)
    b: *Retithrips*
22. *Thripobius semiluteus* Bouček, (Brazil, India, Sao Tomé, Australia, USA)
    b: *Brachyurothrips, Heliothrips, Panchaetothrips*
23. *Thripoctenoides albicoxis* Szelényi, (Hungary)
    ?:
24. *Thripoctenoides carbonarius* Erdös, (Czechoslovakia, Hungary)
    ?:
25. *Thripoctenoides gaussi* Ferrière, (Germany, Ukrain-USSR)
    c: *Acanthothrips, Cryptothrips, Hoplandrothrips, Liothrips, Phlaeothrips*

26: *Thripoctenoides kaulbarsi* Yoshimoto, (Ontario/Quebec-Canada, Florida-USA)
    ?:
27: *Thripoctenoides thione* (Walker), (Britain)
    ?:

MYMARIDAE:

28. *Polynema indica* Narayanan & Subba Rhao, (India)
    b: *Caliothrips*

TRICHOGRAMMATIDAE:

29. *Megaphragma ghesquièrei* (Nowicki), (Zaire)
    b: *Panchaetothrips*

30: *Megaphragma longiciliatum* Subba Rao, (India)
    a: *Frankliniella*

31. *Megaphragma mymaripenne* Timberlake, (Hawaii, Haiti, Chile, USA)
    a: *Leucothrips*
    b: *Heliothrips*
32. *Megaphragma priesneri* (Kryger) Nowicki, (Egypt)
    b: *Retithrips*

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INTEGRATED PEST MANAGEMENT FOR GREENHOUSE CROPS IN NEW ZEALAND: LOCAL FACTORS INFLUENCING SUCCESS

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Summary

Integrated Pest Management (IPM) programmes for greenhouse flower and vegetable crops are being or are about to be implemented. Political and economic changes since the research programme started make it particularly difficult to implement research for domestic crops and where growers cannot afford either government or private consultants. Costs of extension are high because properties are small and dispersed. One of DSIR's strategies is stronger involvement in demonstrating technologies. As a result IPM programmes for cymbidium orchids and greenhouse tomatoes will be demonstrated and supervised for groups of growers. From this experience, IPM training courses will be provided by DSIR for growers and consultants. IPM programmes were deliberately made simple, eg. *Phytoseiulus persimilis* is introduced into cymbidium orchids 4-5 times a year according to crop phenology rather than complex pest population monitoring. Transport for natural enemies is usually fast and reliable, but overheating of *P. persimilis* can occur. Quality of *Encarsia formosa* has varied and will be monitored by assessing vigour. Implementation of the IPM programme for greenhouse tomatoes is being delayed until a selective insecticide is available. Success of the IPM programmes will be measured through sales of natural enemies and by comparing future grower practices with those revealed in recent surveys.

1. Introduction

Encarsia formosa Gahan (Hymenoptera: Aphelinidae), a parasite of greenhouse whitefly (*Trialeurodes vaporariorum* (Westwood), (Homoptera: Aleyrodidae)) was successfully introduced into New Zealand in 1933 (Martin, 1989a) and *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae), a predator of two-spotted mite (*Tetranychus urticae* Koch (Acari: Tetranychidae) was first successfully introduced into New Zealand in 1967 (Thomas and Walker, 1989). The New Zealand Ministry of Agriculture and Fisheries (MAF) established colonies of both *E. formosa* and *P. persimilis* in the 1970's and supplied these natural enemies to growers of greenhouse crops (Martin, 1989a; Thomas and Walker, 1989). They appear to have been used by few growers. In 1981, DSIR started a research programme to develop Integrated Pest Management (IPM) programmes for greenhouse crops based on these two natural enemies (Martin, 1987a). The IPM programme for Cymbidium orchids, an export cut flower crop, is being implemented, whereas active promotion of the IPM programme for greenhouse tomatoes has been delayed until 1990 when the selective insecticide, buprofezin, should be available. IPM programmes are available for other minor vegetable, fruit and flower crops but are not being actively promoted.

A critical factor in the successful implementation of an IPM programme is the need for the programmes to fit the local environment (Wearing, 1988). While the research programme has addressed both the local growing and social environment, there have been recent political and economic changes in New Zealand which have altered the climate for the implementation of IPM. Now is an appropriate time to re-evaluate the prospects for the successful adoption of the IPM programmes by growers of greenhouse crops.

2. Implementation of Integrated Pest Management

Lenteren (1987) mentioned four main factors for the successful implementation of IPM which are also relevant to New Zealand greenhouse crops.

a) The availability (quantity) and quality of the natural enemies.
b) Changes in the availability of pesticides.
c) The complexity of the IPM programme.
d) The advisory service and the transfer of information to growers.

2.1 Natural enemies

Since 1981 DSIR has maintained colonies of *E. formosa* and *P. persimilis*. The *P. persimilis* colony has been frequently sprayed with pyrethroid insecticides and has been supplemented with field- collected predators, including those sprayed with pyrethroid pesticides. There has been a small increase in tolerance to these pesticides (Markwick pers. comm.). The predators are currently supplied on dwarf bean (*Phaseolus vulgaris*) or pepino (*Solanum muricatum*) leaves packed between layers of paper towelling. Each leaf is checked to see that it has a minimum of 10 female predators and low numbers of two-spotted mite. The predators, sold in boxes containing 1000 females, are distributed by overnight courier either direct to growers or preferably to local depots for collection. The main problem to avoid is overheating of the packages in transit. Growers are concerned about seeing dead predators squashed between the layers and about predators running over the paper towel and paper bags. Alternatives such as distributing predators in bottles of bran (Koppert B.V.) or as leaf pieces in paper sachets (Bunting Biological Control Ltd) both have merit but neither are ideal for all crops. For example it is difficult to sprinkle predators into a shelter or apple tree whereas paper sachets would be more awkward to attach to strawberry plants. The predators are available all year for greenhouse and outdoor crops. A minimum weekly production is guaranteed to the company distributing predators to the kiwifruit and berry fruit growers.

Precautions are taken to keep the hyperparasite, *E. pergandiella* Howard out of the *E. formosa* colony (Martin 1989a). The parasite was first distributed to growers as black scale on pieces of tobacco leaf glued to strips of aluminium foil; 100 puparia per foil. While this worked adequately during the research trials, many parasites failed to emerge when the glued leaves were mailed to growers in small boxes. Vapour from the PVA glue appeared to kill the parasites. There is some evidence that while the black scale are attached to the tobacco leaves the vigour of the female parasites is reduced. The black scale are now removed from the leaves and glued with a non-toxic gum to cards. Not only are the numbers of adults emerging regularly assessed but a simple measure of vigour is being developed which involves the adults travelling through a simple obstacle course. At times the numbers of parasites in the colony have been very low. The effect on genetic diversity and vigour of the colony of this mainly parthenogenetic species is unknown. The parasites are available all year.

Fast and generally reliable distribution systems that cover the whole country are available. In the near future a private company may take over production of natural enemies for seasonal inoculative release. Systems will be established to ensure that quality of the natural enemies will be maintained.

2.2 Availability of pesticides

The IPM programmes for New Zealand greenhouse crops require the use of pesticides to control diseases and pests. When the natural enemies are present the pesticide must be either harmless or applied in a way that causes least harm to the natural enemy. Availability of additional products for specific problems would be desirable, though not essential. For example, there is a need in Cymbidium orchids for a more effective pesticide which will control of the bush snail, *Zonitoides arboreus* [author] (Gastropoda: Zonitidae), and which is safe to *P. persimilis*. An effective pesticide for whitefly which is safe to *E. formosa* and *P. persimilis* is required for some crops. The IPM programme for greenhouse tomatoes has been delayed until buprofezin is registered, hopefully during 1990. This is because it is very difficult for growers to ensure that the numbers of whitefly at the start of *E. formosa* introductions are sufficiently low. This is aggravated in parts of the country by the need to delay *E. formosa* introduction until the plants are no longer susceptible to tomato stem-borer, *Symmetrischema plaesiosema* (Turner) (Lepidoptera: Gelichiidae). An insecticide-miticide that was safe to *P. persimilis* and could be used primarily for insect control on the flowering shoots of greenhouse roses would make the IPM programme for that crop easier to operate.

2.3 Complexity of integrated pest management

All the IPM programmes are as simple as possible. Originally the programmes for roses and orchids envisaged that *P. persimilis* would be introduced according to the populations of two-spotted mite and the predator determined by regularly monitoring the crops. This is very time consuming and needs doing frequently. A simpler and effective solution was found in which new predators are distributed throughout the crop several times a year at pre-determined intervals: 4-5 times for cymbidium orchids and 7-8 times a year for roses. However, IPM programmes using seasonal inoculative releases of natural enemies do require a different approach by growers which must be learnt.

2.4 Advisory service and extension

When the research programme started in 1981, it was assumed that the horticultural advisory officers of the Ministry of Agriculture and Fisheries (MAF) would provide the advisory service to assist growers implement IPM programmes using natural enemies. In the early 1980's MAF advisors changed from servicing crops for domestic production such as greenhouse tomatoes to crops produced for export such as Cymbidium orchids. After 1985, as a result of government policy, the services of MAF advisors (now called consultants) were increasingly restricted to those growers who paid for their services. A further problem now is that over half the MAF Horticultural Consultants have less than 5 years relevant experience. There are some private consultants and organisations that can provide a limited service to growers but there is no organisation that can provide an advisory service nationally. It is possible for DSIR to run courses to train consultants in IPM programmes for greenhouse crops but it is not certain that growers can afford the costs of consultants.

Lenteren (1987) mentions the many advantages of providing an advisory and extension service where growers are concentrated in a small geographic area eg. the Netherlands. In the Netherlands there is the additional advantage that the individual glasshouse properties are large. In New Zealand, greenhouses are located in many parts of the country though there are concentrations in some areas such as Auckland, Christchurch and Nelson. In these areas some greenhouses are close together. Recent surveys of growers (Martin, 1987b; Martin and Workman, 1988b; Martin; 1989b) have confirmed the small size of properties i.e. Cymbidium Orchids, mean 0.38, range 0.09-1.92 ha, (n=21); greenhouse roses, 0.33, 0.10-0.93 ha, (n=13); greenhouse tomatoes, 0.22, 0.05-1.22 ha, (n=31). The small size of properties and their dispersed distribution combine to make the cost of extension to individual growers high and beyond the short term economic benefits resulting from the IPM programme. The cost is also greater than can be built into a competitive price for the natural enemies.

DSIR has recently declared that it will strengthen involvement in demonstrating technologies and this will work to the benefit of IPM programmes.

3. The Growers

The grower surveys (Martin, 1987b; Martin and Workman, 1988b; Martin; 1989b) revealed that other growers were the main source of information on pest control. After successfully demonstrating IPM programmes to key growers, these growers should provide a nucleus of expertise and encouragement to other growers. A variety of factors such as cost, pest damage thresholds and attitude to pesticides will determine whether a grower adopts an IPM programme.

The surveys of pest and disease control for cymbidium orchids, roses and tomatoes (Martin, 1987a; Martin and Workman, 1988b; Martin, 1989b) were used to calculate the present costs of pest control (using standard wage and product costs) and to compare them with the use of natural enemies in IPM programmes. The outstanding feature was that costs varied between five to ten fold, eg mite control in roses varied from NZ$530-17 660 per hectare per year (Martin, 1987b). However, the annual cost per hectare of using *P. persimilis* in roses compared favourably with the average cost of using miticides in roses but was higher ($7 100) than the average cost ($2 620) of miticides used in Cymbidium orchids (Martin and Workman, 1988a). In practice, some growers are prepared to pay this extra for pest control using natural enemies provided this means less spraying.

The surveys showed that growers were more concerned with effective pest and disease control and less with cost. Some rose growers had difficulty controlling two-spotted mite and most tomato growers had problems controlling whitefly. This appears to be due to the available pesticides, the ability to apply them effectively and misinformation about whitefly biology. In these cases growers are seeking effective alternatives.

Growers of crops for export are particularly wary of using natural enemies because they believe that this means there will be unacceptable contamination of their produce by either pests or natural enemies. However, our IPM programmes are designed to meet the required standards before they are offered to growers. In fact it is usually the failure of growers to meet these standards when relying solely on pesticides that persuades them to try natural enemies.

An important aspect of implementing IPM programmes is the attitude of growers to using natural enemies. This has improved in recent years. Vegetable growers who have seen what has been achieved in Europe want to follow suit. They can also see a marketing advantage by contrasting use of natural enemies on New Zealand tomatoes with outdoor tomatoes from Queensland, Australia which have to be dipped in the insecticide dimethoate prior to packing to ensure freedom from fruitfly. The Tomato Division of the Vegetable and Potato Growers Federation is actively assisting the implementation of IPM. The growers of flower crops still do not have a single organisation representing them. However, one exporter is assisting with the introduction of IPM.

Retailers are increasingly concerned about the quality of produce and pesticide residues. The recent report, "Pesticides: issues and options for New Zealand" (MacIntyre et al., 1989) has encouraged the investigation of branded produce with no or low pesticide residues. This fits with the concept and practice of IPM.

4. Discussion

The main difficulty confronting the introduction and successful adoption of IPM by greenhouse growers in New Zealand is the lack of a national extension service affordable to the majority of growers.

The provision of sufficient high quality natural enemies is being planned and although the market is small the economics are aided by the demand for *P. persimilis* for outdoor crops and the requirements for *P. persimilis* and *E. formosa* over many months of the year.

If buprofezin is registered for use on New Zealand greenhouse crops in 1990, this will aid the implementation of IPM for greenhouse vegetables. There are other requirements for compatible pesticides eg. for bush snail control. Increased resistance of *P. persimilis* to pyrethroid insecticides would benefit IPM in crops such as roses. IPM programmes will always be vulnerable to the changing availability of compatible pesticides.

Similarly IPM programmes are vulnerable to new pests. Two important pests not in New Zealand, but already in the South Pacific region, are *Liriomyza trifolii* (Burgess), (Diptera: Agromyzidae) and *Thrips palmi* Karny (Thysanoptera: Thripidae). The damaging strain of Western flower thrips, (*Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae)) is also absent. There is a major danger that these pests will be introduced because large quantities of nursery stock are imported into New Zealand.

Although the IPM programmes for New Zealand greenhouse crops have been kept simple, they are still more complex than pest control programmes relying primarily on pesticides. Wearing (1988) reported that the most effective form of communication of IPM information was verbal and that the most effective methods were extension worker-grower, courses and field days, grower-scientist, demonstration projects and grower groups. A step-wise implementation programme is planned which incorporates these findings. In the first season, a DSIR extension worker will supervise a small number of key growers who are involved either in private discussion groups or those run by MAF. After this, the number of growers using IPM will be increased to a number that can still be supervised by DSIR staff. At this stage we hope to fine-tune the IPM programmes and the information growers require. Next, information packages for growers and advisors will be prepared and courses run for both growers and government and private advisors and consultants.

If suitable pesticides remain available, no new pests arrive and funds are available, then there are good prospects for successful implementation of IPM for greenhouse crops in the short term. It will be possible to assess progress not only by volume of sales of natural enemies, but also by comparing grower practices with those found in previous surveys (Martin, 1987b; Martin, 1989b; Martin and Workman, 1988b).

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HOST-PLANT QUALITY OF THREE HUNGARIAN SWEET PEPPER CULTIVARS (*CAPSICUM ANNUUM* L.) FOR THE GREENHOUSE WHITEFLY (*TRIALEURODES VAPORARIORUM* (WESTWOOD)).

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Summary

Suitability of three commonly used Hungarian sweet pepper cultivars (*Capsicum annuum*) as a host plant for the greenhouse whitefly (*Trialeurodes vaporariorum*) was tested by measuring the life-span of the females, the egg production, the immature developmental time and the immature mortality. The experiments revealed important differences for several components of host-plant quality. The information on different host-plant qualities will be used to attune biological or integrated control programmes.

1. Introduction

One aspect of the cooperative research programme of the Department of Entomology of the Wageningen Agricultural University (The Netherlands) and the Biological Control Laboratory of the Hódmezövásárhely Institute of Crop Protection and Soil Conservation Service (Hungary) is the examination of the host-plant quality of sweet pepper cultivars (*Capsicum annuum* L.) for the greenhouse whitefly (*Trialeurodes vaporariorum* (Westwood)). This programme was started because of a different pest status of greenhouse whitefly on sweet pepper in The Netherlands and Hungary. In Holland whitefly does not create problems, whereas in Hungary it often develops to pest status on certain sweet pepper cultivars. This situation might be explained by several factors, like a different genetic background of Dutch and Hungarian sweet pepper cultivars and/or a better adaptation of Hungarian whitefly strains to sweet pepper (van Lenteren et al., 1989).

Knowledge of host-plant quality of cultivars for greenhouse whitefly is necessary to develop strategies for introduction moment and frequency of the parasite *Encarsia formosa* Gahan, and for timing the occasional complementary treatments for a successful control of whitefly in IPM programmes. Two experiments were carried out to estimate the host-plant quality of three commonly used Hungarian sweet pepper cultivars. In this paper we describe the results obtained from a life-span/oviposition experiment and a developmental time/immature mortality experiment.

2. Material and methods

2.2 Experimental conditions and plants

The sweet pepper cultivars tested were Angeli emléke (AE), HRF and Fehérözön (F). The experimental plants were sown in pots (12cm diam.) with soil. The experiments were done in a heated glasshouse of 60m^2 at the Hódmezövásárhely Institute. The life-span/oviposition experiment lasted from 13-10-1989 to 2-12-1989, the developmental time/immature mortality experiment from 19-12-1989 to 30-01-1990. The temperature and humidity were recorded with a thermohygrograph. The average temperature was 24.1 (s.d. 2.73)^{o}C and the average relative humidity 43.6 (s.d. 8.01)%.

2.3 Life-span and oviposition experiment

The whiteflies were collected as pupae from the sweet pepper cultivar Rápidius (related to Angeli emléke and HRF), grown under plastic tunnels at the "Puskin" Cooperative farm (Szégvar, Hungary). Whitefly adults of maximum 24-hours-old were used. One female and one male were put into a leaf cage (Vet et al. 1981). The leaf cages were clipped to the underside of the youngest full grown leaves of the sweet pepper plants. Per cultivar 44 to 50 cages were used. Every second day it was checked whether the whiteflies were still alive, and the cages were moved to another place on the same leaf or on another leaf. The number of eggs laid in the two days was counted. This procedure was continued until all the females were dead. Four parameters were calculated: (a) average life-span of the females, (b) average number of eggs laid per female, (c) average number of eggs laid per introduced female per two days, and (d) average number of eggs laid per still living female per two days.

2.3 Developmental time and immature mortality experiment

Adult whiteflies were collected from a sweet pepper crop, cultivar HFR, in the experimental greenhouses of the institute. Three females and one male were put into one leaf cage. Per cultivar 20 to 28 leaf cages were clipped to the underside of the youngest full grown leaves of the plants. Whiteflies were allowed to oviposit for 24 hours, after which the cages were removed and the eggs were counted. The development of the whiteflies from egg to adult was determined by checking the larvae every day. To be able to follow the fate of individual larvae, a map of each leaf was drawn, on which the positions of settled larvae were marked. The following parameters were calculated: (a) average developmental time from egg to adult, (b) percentage of total immature mortality.

2.4 Statistics

Differences were tested for significancy with the Mann-Whitney-U test (MWU test) or the Chi-square test, both at a probability level of 5%.

3. Results

3.1 Life-span and oviposition experiment

The average life-span of the females on HFR was significantly longer than on Angeli emléke. On Fehérözön the average life-span of whitefly females did not show a significant difference from Angeli emléke or HFR (table 1). The average number of eggs laid per female was highest on HRF, significantly higher than on Angeli emléke and Fehérözön. Between Angeli emléke and Fehérözön no difference was found in the average number of eggs laid per female. The whiteflies showed a significantly higher daily egg production (expressed as average number of eggs per introduced female per two days) on HRF plants than on Angeli emléke. No difference was found between HRF and Fehérözön, nor between Angeli emléke and Fehérözön. In the oviposition frequencies expressed as average number of eggs per still living female per two days, and in the percentage of females laying at least one egg no significant differences were measured (table 1).

3.2 Developmental time and immature mortality experiment

The developmental time was significantly longer on HRF than on Angeli emléke and Fehérözön. The times found for Angeli emléke and Fehérözön showed no significant difference (table 2).

The immature mortality was significantly lower on Angeli emléke than on HRF and Fehérözön. Between Fehérözön and HRF no difference in mortality was observed (table 2).

Table 1. Life-span and oviposition of *Trialeurodes vaporariorum* on three sweet pepper cultivars.

sweet pepper cultivar	N	average life-span	average no. of eggs	average no. of eggs/intr. female/2days	average no. of eggs/still living female/2 d.	% females laying at least one egg
AE	49	10.3 A*	54.4 A*	2.4 A*	10.1 A*	65.3 A**
F	50	10.8 AB	57.4 A	3.6 AB	10.5 A	66.0 A
HRF	44	14.4 B	92.1 B	5.8 B	12.4 A	72.7 A

*=MWU test, alpha=0.05 **=Chi-square test, alpha=0.05

Table 2. Developmental time and immature mortality of *Trialeurodes vaporariorum* on three sweet pepper cultivars.

sweet pepper cultivar	number of eggs	number of adults	average development time	percentage alimmature mortality
AE	479	122	22.6 A*	60.1 A**
F	387	89	23.5 A	70.3 B
HRF	384	108	24.3 B	65.6 B

*=MWU test, alpha=0.05 **=Chi-square test, alpha=0.05

4. Discussion and conclusions

When grown under the same conditions, the suitability of the three tested Hungarian sweet pepper cultivars for the greenhouse whitefly differed considerably in some aspects, like average life-span, average number of eggs laid per female (fecundity), immature developmental time and immature mortality. When these data are used to estimate the rate of population increase (r), the following sequence could be established: rate of population growth is highest on HRF (r=0.095), followed by Angeli emléke (r= 0.086) and Fehérözön (r=0.075). Thus, the best host plant for greenhouse whitefly is HRF, in spite of the fact that the developmental time is longest on this cultivar. A high fecundity and average mortality compensate for the slow development.

The results found in these experiments help explain why greenhouse whitefly develops faster to pest status on particular cultivars and slower on others. The results can be used to determine economic threshold densities and to develop an introduction strategy for *E. formosa*. The differences which were found in suitability between cultivars of the same plant species for whitefly can be used to identify and breed more resistant cultivars to reduce whitefly problems.

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EVALUATION OF PARASITOIDS FOR THE BIOLOGICAL CONTROL OF LEAFMINERS ON GLASSHOUSE TOMATOES: DEVELOPMENT OF A PREINTRODUCTION SELECTION PROCEDURE

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Summary

A biological control method using the braconid wasp *Dacnusa sibirica* against the leafminers *Liriomyza bryoniae* and *L. trifolii* has been developed for implementation in northwestern European glasshouses, whereas in southern Europe *Diglyphus isaea* is applied as biological control agent. These systems are used to examine a preintroduction procedure proposed in here to select effective parasitoids. Its evaluation framework consists out of four criteria: 1) Complete Development and Offspring Quality, 2) Generation Synchrony, 3) Population Growth, and 4) Searching Efficiency. These concepts and their verification are discussed. Finally, plans for future research are given.

1. Introduction

Every new biological control project starts with the necessity of identifying an effective natural enemy or complex of natural enemies. Two approaches can be distinguished: (1) *empirical* and (2) *predictive* (Ehler, 1989). The *empirical* approach in classical biological control means the release of all natural enemies at hand, letting nature sort them out (Ehler, 1989), whereas in seasonal inoculative biological control natural enemies are usually tested separately in an agricultural setting, the one performing best being selected. The advantage of this approach is often its speed: an effective agent might be found after one trial in a commercial glasshouse. And when there is an outbreak of an insect time is crucial. The *predictive* investigations prior to the introduction of natural enemies. Only that group of candidates will be further tested in trials. This procedure allows predictions about the performance of the candidates and subsequently, these predictions can be verified by their introduction (Van Lenteren, 1980).

Selection procedure using a predictive approach are still in development. To date, there are no case studies reported. within the predictive approach, there are two distinct approaches (Waage, 1989): First, the *reductionist* approach which uses characteristics attributed to effective natural enemies to select them. Second, the *holistic* approach which proceeds from theoretical notions of how natural enemies fit into the broad ecology of the pest and its other mortality factors (Myers et al., 1989). We have used the *reductionist* approach to initiate the development of a preintroduction selection method of parasitoids.

2. The Problem: Leafmining Flies on Tomato Plants in a Greenhouse Habitat

Leafminers are troublesome in three ecological contexts: 1) *after pesticide sprays which destroy their natural enemies,* (2) *as naturally occurring, non-induced seasonal pests*, and (3) *when adults build up at other crops or weeds and migrate to a particular plot* (for reviews on *Liriomyza*, see Spencer, 1973; Minkenberg & Van Lenteren, 1986; Parrella, 1987).

More than 40 parasitoid species of *L. trifolii* and *L. bryoniae* are known (families:

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Braconidae, Eulophidae, Pteromalidae). Leafminer parasitoids have been introduced in many parts of the world for classical biological control programs: e.g. California, Canada, Guam, Hawaii, the Netherlands, New Zealand (e.g. Waterhouse & Norris, 1987). Although several parasitoids have been reported as being established in new areas, there are no data available on their impact on leafminer populations. Post-introduction evaluation projects are clearly required. Several parasitoids, *Dacnusa sibirica* Telenga, *Diglyphus isaea* (Walker) and *Diglyphus begini* (Ashmead), are presently being used in seasonal inoculative and inundative release programs (for a review on parasitoids and biological control, see Minkenberg & Van Lenteren, 1986; Johnson & Hara, 1987; Heinz & Parrella, 1990). *Dacnusa sibirica* and *D. isaea* are commercially produced and sold (250 adult wasps/bottle, Koppert, pers. com.)

3. Objectives

1) to examine these criteria specifically for the selection of leafminer parasitoids in seasonal inoculative biological control, in order to develop a *preintroduction selection procedure*.

Two related aims were:
2) to develop and integrate a *biological control method* for the imported American serpentine leafminer, *L. trifolii*, and its native relative *Liriomyza bryoniae* (Kalt.), on glasshouse tomatoes.
3) to gain insights into the *population dynamics* of the leafminers and their parasitoids and into the processes that determine changes in population densities.

We would like to refer for an earlier report to Minkenberg & Van Lenteren (1987).

4. Evaluation framework, selection criteria and concepts

The predictive approach should yield a procedure which can be used prior to introduction of natural enemies, and which will results in a higher probability of finding an effective natural enemy than by the traditional empirical process. To develop such a preintroduction selection procedure, general criteria that will indicate effectiveness need to be formulated from biological control theory and practice. An example of such a criterion is direct density dependence, which has been associated with effective biological control for a long time, and can be found in almost all listings of attributes of classical biological control agents. Recently, it has become clear that direct density dependence may be useless as a selection criterion, because both theoretical models and case studies of successful classical biological control show that direct density dependence is not a general characteristic, at least on basis of the studies conducted and the systems looked at. To date, only one greenhouse system whitefly-*Encarsia formosa* (Gahan), has been investigated. Although these parasitoids show aggregation, no direct density dependent parasitism is found (Noldus & Van Lenteren, 1989). We suggest that also in seasonal inoculative release programs direct density dependence may not be essential. Therefore, it may be useless as a selection criterion. Moreover, it cannot be readily measured in a laboratory setup.

On the basis of theoretical considerations and empirical evidence, four criteria are proposed: (1) *Development and Quality,* (2) *synchrony*, (3) *Population Growth* and (4) *Searching.* Measurements of these criteria and their significance are discussed. The entire preintroduction procedure is supposed to take place in the laboratory.

4.1 Development and Quality

Since seasonal inoculative programs rely partly on the numerical response of the agents, their offspring should complete development on the pest and should be viable. Abiotic conditions under which they have to operate should allow development and reproduction, and hence, quality of parasitoid offspring to be maintained over host generations.

4.2 Synchrony

Parasitoids emerging from the hosts parasitized after a release should be able to find suitable instars. When hosts generations are discrete, development of parasitoids needs to be synchronous with that of the pest. To analyze this phenomenon in the laboratory, the concept of "waiting period" is introduced, which is the minimum period that a newly emerged parasitoid has to bridge before suitable instars have become available, as a way to estimate asynchrony and hence, reduction in parasitoid impact on the next pest generation. On the basis of the life-history studies, convergence to the stable age distribution can be calculated and discrepancy between generations of hosts predicted.

4.3 Population Growth

The usual parameters for population growth are the intrinsic rate of increase, r, and net reproduction, R_0, both measured in the laboratory under specified conditions. It is argued that these parameters are not useful to compare population growth of the parasitoids with that of their hosts, in order to predict effectiveness, because (1) growth of the two populations re likely to be differently affected in each others presence, because (2) growth of the pest population will probably be reduced at high densities whereas that of the parasitoid increased, and because (3) the relative densities at the moment of release will in part determine the outcome of a program. Population growth rates can be used to compare between parasitoids, if everything in context of the other criteria is equal. Otherwise, data on *searching* have to be collected.

4.4 Searching

Parasitoids' searching efficiency will be increased when it is able to locate the host from a long distance. This can be examined in an olfactometer or wind tunnel. further estimates of searching can be derived from direct observations of individual parasitoids in the laboratory.

4.5 Example

The leafminer parasitoids *D. sibirica* and *D. isaea* are effective parasitoids gainst leafminers on tomatoes in northwest and southern Europe, respectively. Both agents develop and reproduce at these hosts under the conditions occurring in the regions (criterion 1). In northwestern Europe, leafminer generations are discrete during three to four generations after the beginning of the growing season, whereas in the South generations more readily overlap due to immigration and then,, asynchrony plays a minor role. Generations of *D. sibirica* synchronize well with that of the leafminers. Due to fast development, *D. isaea* has a waiting time of more than one week, which probably reduces its impact as a control agent in northwest Europe (criterion 2). At low temperatures *D. sibirica* has a higher net reproduction than *D. isaea*; *D. isaea* has the higher population growth rate at high temperatures (criterion 3). Data on their searching are not available yet (criterion 4). Generation synchrony and population growth appears to explain, at least in part, the effectiveness of these parasitoids in the different regions.

4.6 Preintroduction selection procedure

Laboratory measurements on the criteria will produce sets of values for each parasitoid. Some parasitoids can be discarded because they do not meet quantitative standards, such as successful development on the host. The parasitoids with the most optimal sets of values should be selected from the pool to start releases. However, it is unknown whether all essential criteria are listed, how essential the proposed criteria are, and how to interpret the outcome of the preintroduction procedure, because there is not a single case study. Thus, the prediction of which parasitoids are likely to perform best as biological control agents needs to be verified by testing *all* parasitoids that have been considered at the beginning of the procedure. This is the only conceivable way to evaluate the preintroduction selection procedure. Furthermore, it might develop insights into the relative importance of these criteria, though for this system only, and generate models that can actually weigh the different criteria. A detailed paper on the subject has been submitted (Minkenberg, unpubl.)

5. **Future Research**

In the entomological literature, many publications on the development, reproduction and population growth of natural enemies are available and this information might be useful in a selection procedure. However, we are greatly lacking in data on the *searching efficiency* of natural enemies (Hopper & King, 1986). A behavioral bioassay to measure searching at a range of host densities in the laboratory is in development (MInkenberg & Parrella, 1990=. Which behavioral components will enhance the searching efficiency of natural enemies has still to be determined (Kareiva & Odell, 1987).

In connection with the laboratory experiments, research models have further to be developed: (1) models that incorporate population growth rates of natural enemies and pests, their initial densities and time of introduction and which will allow predictions on the outcome of rials over several generations (Sabelis et al., 1983; Boot et al., 1991), and (2) models that incorporate behavioral components, such as probability of finding areas with a certain host density and the searching rate within these areas, and which will predict parasitism within one generation of the host. These models might substantially support the conclusion from the evaluation o the different criteria.

Last be not least, the theoretical considerations can only be verified in an agricultural setting, i.e. in the greenhouse or in the field. Not only studies which evaluate the outcome of introductions of biological control agents have to be conducted, but also specific experiments which test predictions stemming from the evaluation framework. In the case of the leafminer parasitoids, these include, (1) confirmation of the ineffectiveness of *D. isaea* in northwestern European glasshouses, by trials in commercial glasshouses, (2) examination of the (in)effectiveness *D. sibirica* in southern Europe, (3) examination of the temporal variability in leafminer density, i.e. quantification of the host free periods, (4) testing whether survival of *D. isaea* in the Northwest is reduced due to generation asynchrony and whether it is the main cause of it s supposed ineffectiveness, and (5) examination of the impact of low reproduction due to hight temperatures in *D. sibirica*, if it has been shown to be ineffective in the South.

As argued before, a large research project has to be initiated from scratch that facilitates selection of natural enemies through the preintroduction procedure. After thorough investigations in the laboratory and modelling, predictions need to be formulated concerning which natural enemies are the most promising and on why. Finally, both the predictions and reasons must be tested by field experiments, which will lead to re-evaluation of the preintroduction selection procedure. The continuous reciprocity between laboratory experiments, modelling and field trials using different systems may eventually lead to a generally applicable method to select natural enemies for seasonal inoculative biological control.

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EVALUATION OF PARASITOIDS FOR THE BIOLOGICAL CONTROL OF LEAFMINERS ON GREENHOUSE CHRYSANTHEMUMS: DEVELOPMENT OF A BEHAVIORAL BIOASSAY FOR PREDICTING SEARCHING EFFICIENCY

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Summary

One of the characteristics of effective parasitoids that may be important as a selection riterion in pre-introduction evaluation procedures is searching efficiency. The concept of searching efficiency and ways of quantifying this response variable are described and discussed. A laboratory facility, in which individual female parasitoids are observed at a range of host densities, is discussed. One of the objectives of these experiments is to determine behavioral components of foraging parasitoids that will have a predictive value in evaluating their searching efficiency in the greenhouse. The outcome of the behavioral bioassay should be related to their effectiveness in the greenhouse. Preliminary results are presented for the leafminer parasitoid *Diglyphus begini*.

1. Introduction

For many decades researchers in classical biological control have been trying to identify the general mechanisms underlying effective natural enemy-pest systems. More information is needed about the searching behavior of parasitoids in order to gain greater insight into the underlying mechanisms leading to effectiveness. One of the selection criteria proposed in a preintroduction procedure to identify effective biological control agents is searching efficiency (Minkenberg & Van Lenteren, 1990). To measure searching efficiency in the laboratory, two phases in host location by parasitoids and corresponding experimental designs are suggested: (1) long distance location of the hosts, and (2) foraging and parasitism one in an area with hosts. Host habitat finding and host location can be investigated by olfactometer or wind tunnel experiments (e.g. Vet et al., 1983; Noldus, 1989; Janssen et al. 1990; Dicke & Minkenberg, unpubl.). These relatively fast and simple experiments may greatly increase the probability of finding an effective biological control agent compared to randomly introducing beneficials (Janssen et al., 1990). Estimates on host location can be derived from directly observing parasitoids in a patch choice situation where the observation time is variable and depends on parasitoid behavior (Van Lenteren & Bakker, 1978).

This latter approach is the subject of this paper. Its experimental design and which behavioral components to measure and the predictive value of these measurements for selection of parasitoids will be discussed in relation to searching efficiency and effectiveness in the greenhouse. Currently, the foraging behavior of *Diglyphus* spp. between and within chrysanthemum plants infested by the leafminer *Liriomyza trifolii* (Burgess) is examied.

The hymenopterous extoparasitoids in the genus *Diglyphus* (Eulophidae) are commonly occurring on *Liriomyza* leafminers, which are major greenhouse pests (for a review on their biology, distribution and hosts, see Minkenberg & Helderman, 1990; Minkenberg & van Lenteren 1986, 1990; Parella 1987; Heinz & Parrella 1990a). *Diglyphus* spp. are presently used as biological control agents in inoculative release programs in vegetables in the field and indoors (Lyon, 1986; Westerman & Minkenberg, 1986; Minkenberg, 1989) and in inundative programs in greenhouse ornamentals (Wardlow, 1985; Jones et al. 1986; Parrella et al. 1987;

Heinz et al. 1988, Heinz & Parrella, 1990b).

2. material and Method

2.1 Experimental design

Freshly emerged female parasitoids were removed from rearing (Parrella et al., 1989) and kept singly in small glass vials.On successive days females were contained to petridishes with chrysanthemum leaves infested by 3-10 third instar *L. trifolii* leafminers for oviposition. Only parasitoids that have successfully parasitized leafminers in petridishes were used for observations. The entire pre-experimental procedure and foraging behavior experiments on individuals in *D. begini* were conducted in a controlled environment at 25 ± 1°C with 60-80% relative humidity. Wasps were released from a glass vial, which was placed in the center of a table (80 by 54 cm, height 81 cm) with two rows of five plants each; table surface with the plants is called the arena (Fig.1) Distance between rows was 38 cm and between plants within rows 14 cm.

In order to manipulate the density of leafminers on plants and to standardize the environment, artificial plans were constructed consisting of a plastic stake (sprinkler pipe) with ten small plastic vials attached for holding leaves (Fig. 1). Every artificial plant had ten leaves. Position of plants and leaves within plants was chosen randomly. A tent of white cloth (2m high by 2 m wide by 1.75 m deep) covered the table to facilitate observations of the parasitoid (size is ca. 1.5 to 2.0 mm). The observer followed the foraging wasp within the tent.

Four treatments were applied (none, low, middle and high) with a host density of 0, 1, 10 or 28 third instar *L. trifolii* leafminers, respectively, in the arena. Host density of plants was 0, 1, 9 or 18 and on leaves 0, 1 or 2. The high density arena contained all four types of plants and all three types of leaves, the middle density arena three plant and leaf types, the low density arena only two plant and leaf types, and the non treatment had one plant and leaf type.

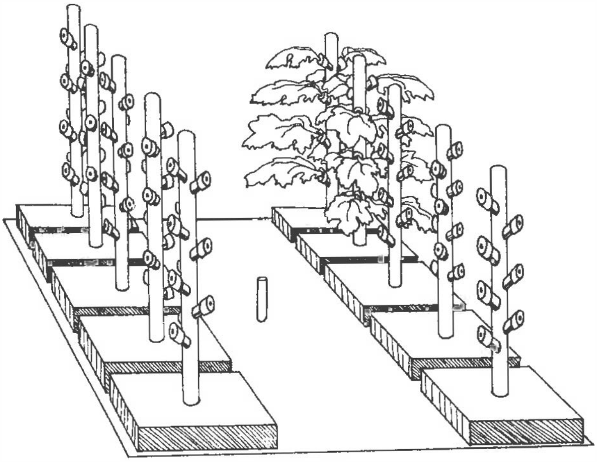

Figure 1. The arena with ten artificial plants consisting of ten test tubes on a stand, each with a chrysanthemum leaf. Female parasitoids were individually released from the vial in the center and subsequently observed.

2.2 Collection of behavioral data

After placing a plastic vial containing a parasitoid on the table, the period until take-off, i.e. latency time, was measured. When the parasitoid stayed within the vial for longer than 30 minutes, it was replaced. After a take-off, the observer registered further events within the tent on a portable computer (Tandy 102, Radio Shack) using the event-recording program "The Observer" (Noldus, 1989). Four classes of event were distinguished: (1) position on plants, (2) position on leaves, (3) behavior, and (4) contacts with hosts. *Plant position* was between plant 1 to 10 or off plant (i.e., on the table). *Leaf position* was between leaf 1, top to leaf 10, bottom, or off leaf (i.e., on the stem of the plant). *Four behavioral components* were recorded: flying, searching, standing still and handling a leafminer. Lastly, *contacts with hosts* were registered as contact with a new host or with a previously encountered host. It has been shown that contacts with parasitized hosts may reduce (Bakker & Van Alphen, 1988) or slightly increase the foraging time of parasitoids (Nelson & Roitberg, unpubl.). The computer registered the starting time for each event within a class, time of an event was stopped when a new event was started.We were thus able to calculate total visit time (T) on both plants and leaves as the sum of searching time (T_s) (T_h) and standing still time (T_r). Observations ended when wasps flew away from the plants, usually to the tent cloth, or when they stayed motionless for at least 30 minutes. After each set of observations, leafminers encountered by wasps were dissected to determine the outcome of the interaction: (1) oviposition, i.e. presence of eggs, (2) rejection, larva paralysed but no egg present, and (3) host feeding, leafminer killed (Heinz & Parrella, 1989, Minkenberg, 1989). Observed wasps were captured, placed in alcohol and later dissected to determine their egg compliment.

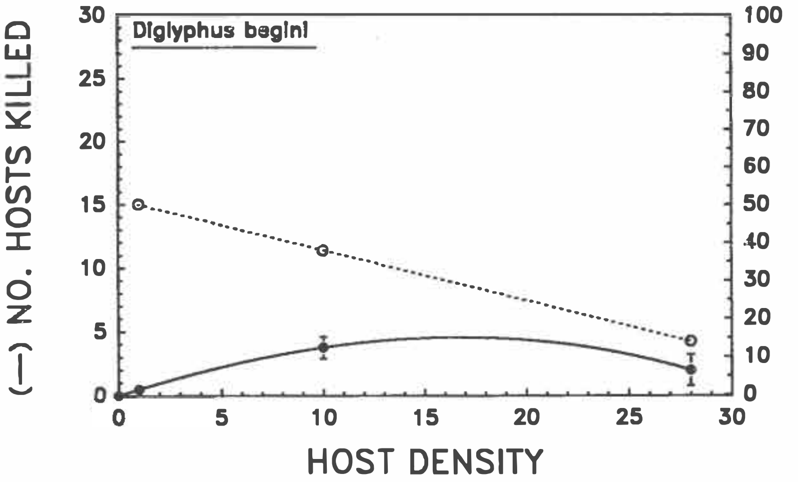

Figure 2. Functional response of *D. begini*. Number of percentage of leafminers killed versus host density(number of leafminers/10 plants, i.e. 100 leaves) in the arena (Note, data are preliminary; number of observations is not complete, particularly at host density 28).

2.3 Effect of host density on visits and parasitism

Effects of host density on (1) number of visits, (2) total visit and searching time, (3) number and proportion of leafminers parasitized and (4) oviposition rate (number of leafminers parasitized divided by either total visit or searching time) were analyzed by linear regression. In the case of superparasitism, a host was counted only once. Prior to analysis a logit transformation, log((P + 1)/(N - P + 1)), for the proportion parasitized was conducted (P = number of hosts parasitized, N = number of hosts) and a square root transformation was used on all other dependent variables. All observations were pooled for this linear regression analysis. Concordance between females was examined using a homogeneity-of-slopes model prior to pooling data for linear regression. Since data for individual females were unbalanced, the type III Sums of Squares were interpreted.

Table 1. Response, latency (i.e.means ± SE time (s) spent in vial before take-off) mean ± SE total time (s) spent foraging in the arena, mean number of leafminers attacked and percentage parasitism versus host density (numbers of leafminers offered in the arena). The number of observations is indicated by N.

Host density (No. leafminers)	Response	Latency	Total Time	No	%Par.	N
None (0)	Vial	>30 min	-	-	-	1
	Ceiling	40 ± 8	-	-	-	2
	Plants	124 ± 9	4181 ± 4099	0	0%	2
Low (1)	Vial	>30 min	-	-	-	0
	Ceiling	1205 ± 284	- -	-	-	7
	Plants	801 ± 274	4758 ± 1132	0.5	50%	4
Middle (10)	Vial	>30 min	- -	-	0	0
	Ceiling	300 ± 56	- -	-	-	24
	Plants	207 ± 50	5796 ± 1267	3.8	38%	13
High (28)	Vial	>30 min	- -	-	-	1
	Ceiling	282 ± 100	- -	-	-	4
	Plants	539 ± 135	8344 ± 3194	2	14%	4

3. Preliminary Results and Discussion

A large proportion of the wasps did not respond to the plants offered and stayed either in the vial or flew directly to the ceiling (Table 1). A trend between the proportion of wasps responding and treatment was not found (for None, Low, Middle and High, 60%, 64%, 65% and 56% of the parasitoids released did not respond to plants, respectively).

Latency time, i.e. time until take-off, did not show any consistent pattern with response or treatment. Total time spent in the arena increased with increasing host density. In an arena without leafminers, a substantial amount of time was spent (> 1 hour). Also at low host density (1 leafminer/10 plants) foraging time was approximately 1 and a half hour, resulting in finding and ovipositing the single leafminer present in 50% of the cases. At middle and high host densities, only a few leafminers were found and percentage parasitism was relatively low (Fig. 2).

The functional response found is similar to a type II curve (Holling, 1959), which is commonly found in parasitoids. But the response of *D. begini* is rather flat, hence the relative number of hosts attacked at increased host density sharply diminishes. Two explanations are usually given: 1) handling time with hosts proportionally increases at increased host density, and 2) number of eggs available for oviposition is limiting. Since handling time of *D. begini* with both unparasitized and parasitized leafminers is short, it is suggested that eggs available for oviposition are probably rapidly depleted. This possible explanation is supported by its low net reproduction estimated in greenhouse cages (at an average temperature of 24°C; fecundity is 5.9 offspring/female and maximal oviposition rate is 1.2 eggs/female/day). Some caution is necessary because this "egg availability" is only one of the possible explanations.

Since host densities in the greenhouse might actually be much lower than 1 leafminer/10 plants, this is a drawback of the laboratory setup; extremely low pest density cannot be offered and, obviously, the spatial scale is restricted.Nevertheless, *D. begini* was able to locate leafminers at low density. However, at high host density the number of leafminers found by individual wasps was low. This lack of "searching capacity" might be compensated for by releasing high numbers of parasitoids to achieve effective biological control as currently done in the effective inundative release program against *L. trifolii* in chrysanthemum (Heinz & Parrella, unpubl.). Comparing different parasitoids within the same genus may make it possible to identify those behavioral components that lead to high parasitism at all host densities offered. The biological control agent *Diglyphus isaea* (Walker), which is important in southern Europe will be examined in addition to others. Furthermore, to examine the predictive value of this bioassay, behavioral components that lead to high parasitism in the arena have to be related to searching efficiency in the greenhouse. Experiments to estimate searching efficiency and the impact of factors decreasing it (such as mutual interference) in the greenhouse have to be conducted.

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MODELLING THE EPIZOOTIOLOGY OF *SPODOPTERA EXIGUA* NUCLEAR POLYHEDROSIS VIRUS IN A SPATIALLY DISTRIBUTED POPULATION OF *SPODOPTERA EXIGUA* IN GREENHOUSE CHRYSANTHEMUMS

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Summary

An epizootiological simulation model was developed to study the feasibility of using Spodoptera exigua nuclear polyhedrosis virus for inoculative control of S. exigua in greenhouse chrysanthemum crops. In the model, eight developmental stages of the insect and three routes of infection are distinguished. S. exigua populations are made up of patches of caterpillars. Each patch originates from a single egg batch. Patches differ in the initial number of infected eggs. The epizootiology of SeMNPV in a patch depends strongly on the initial number of infected eggs. Therefore, a compound simulation approach is adopted, classifying patches according to initial number of infected eggs and time of initiation. The epizootiology of the virus in the whole population is obtained by summation over the different infection-age classes of patches.

Model results indicate that the presence of a stable polyhedra population is a crucial factor determining long-term control by inoculative spraying.

1. Introduction

Beet armyworm, Spodoptera exigua (Hübner), is a polyphagous pest of cultivated crops in tropical and subtropical regions (Brown & Dewhurst, 1975). After accidental introduction it became a serious pest in ornamental and vegetable crops in greenhouses in the Netherlands (Smits, 1987). Damage in chrysanthemum crops is mainly caused by late instar larvae feeding on the upper leaves and flowers. Resistance against insecticides (Poe et al., 1973; Cobb & Bass, 1975) makes chemical control very difficult, so that alternatives had to be found. Smits (1987) found that Beet armyworm can be controlled by inundative spraying of S. exigua multiply-embedded nuclear polyhedrosis virus (SeMNPV). In chrysanthemum crops little damage can be tolerated. Therefore, SeMNPV should be sprayed during the initial phase of exponential growth. A 100% control is rarely achieved, however. To prevent pest resurgence after spraying, the virus should maintain itself in the population and thereby reduce the net reproductive rate R (number of adult daughters per female) of the moth population below 1.

A simulation model was developed to study the long-term epizootiology of SeMNPV in S. exigua populations in glasshouse chrysanthemums and evaluate whether inoculative use of this virus may lead to effective control and lasting population regulation. The model is based on life-history and host-virus interaction data published in literature. Sensitivity analysis of the model increases the insight in the dynamics of the insect-virus system and pinpoints the main factors influencing its dynamics. This basic knowledge may be used to develop management strategies. In this paper we present the structure and some results of the model.

2. Description of the model

2.1 Structure

Age-structure. The model simulates the temporal dynamics of eight developmental stages of the insect: eggs, five larval stages (L1-L5), pupae and adult females. Males are ignored in the model, assuming that their number is sufficient to assure fertilization of the females. Numbers and development within each stage are represented using the fractional boxcar-train method (Goudriaan, 1986; Goudriaan & van Roermund, 1989), which allows for variable duration of development according to fluctuating temperature and individual variation. Mortality during development is calculated using a relative mortality rate which varies with temperature and developmental stage. Separate boxcars are used for infected individuals.

Infection-processes. Three routes of infection are distinguished:
(1) caterpillars consuming a sufficient amount of sprayed polyhedra
(2) caterpillars eating from a leaf contaminated by a deceased caterpillar (horizontal transmission)
(3) females laying infected eggs (vertical transmission)

Infection by sprayed polyhedra. It is assumed that sprayed polyhedra are distributed homogeneously over the leaf layers of the crop (Leaf area index=3). The rate of ingestion of polyhedra by caterpillars equals the product of the feeding rate and the density of polyhedra on the leaf surface. The feeding rate is instar dependent (Table 1). Each ingested polyhedron has the same chance (p) of causing a lethal infection.

Polyhedra are inactivated by UV-radiation at a constant relative rate, analogous to radioactive decay. A proportion of the polyhedra may be deposited at places sheltered from UV radiation. These sheltered polyhedra can remain active for several years (Jacques, 1985; Olofsson, 1988). In the model, unexposed polyhedra remain infectious throughout the simulated period of 150 days.

Horizontal transmission. The eggs are laid on the lower leaves of the hostplant. After emergence first instar larvae migrate vertically to the top leaves. From the third larval stage, larvae show horizontal dispersal. Finally, an area of 1 m^2 is infested (Smits & Vlak, 1988). The sizes of the dispersive ranges (i.e. all the leaves that can be visited during an instar) are listed in Table 1. In the model, polyhedra spread over one leaf after disintegration of an infected larva. The relative infection rate due to horizontal transmission is determined by the frequency of visits of caterpillars to such contaminated leaves. One visit is sufficient to cause a lethal infection.

Vertical transmission. Some of the infected fifth instar larvae develop into females that lay eggs that are virus infected. Eggs infected by such vertical transmission are supposed to be randomly (Poisson) distributed over the infected females' egg batches. The initial number of infected eggs in an egg batch has a strong curvilinear effect on the number of adult females that will emerge from it (Fig 1C). Therefore, constructing a 'homogeneous' model with an average number of initially infected eggs per patch would result in erroneous results. Instead, the compound simulation approach is adopted (Fransz, 1974; Rabbinge et al., 1984; Sabelis & Laane, 1986; Ward et al., 1989). Clusters are divided over classes, taking initial number of infected eggs and time since egglaying (= time of start of a cluster) as stratification criteria. The model is not valid at high densities because interactions between patches are neglected. As damage tolerance in chrysanthemum is very low, we are only interested in the low density situations which are correctly represented by the model.

2.2 Parameters

Temperature dependent development rates are calculated by linear interpolation using experimental data from Fye & McAda (1972). The sex ratio is 1:1 (Smits, 1986). Mortality during egg development totals to 10% at optimal temperatures (20-30°C) and increases to 40 % at 15°C and further to 90% at 8°C (Poe et al., 1973). Mortality during larval development is 15% (Fye & McAda, 1972). Mortality in the pupal stage is 15% at 20-30°C and 40% at 33°C (Fye & McAda, 1972). Eggs are laid 5.1 [Picture] 1.9 days after adult emergence, irrespective of temperature (Fye & McAda, 1972). Fecundity is [Picture] 500 eggs per female (Fye & McAda, 1972). The eggs are laid in batches of 25-50 (Smits et al., 1986). In the model, the number of eggs per batch is set to 35 eggs. Instar specific rates of leaf consumption are given in Table 1. To estimate the instar-specific infection chance per ingested polyhedron, p, the exponential model proposed by Hughes et al. (1984) is fitted to the experimental data of Smits & Vlak (1988). The estimated values of p are given in Table 1.

Table 1: Consumption rate[1] (C, $cm^2.day^{-1}$), infection chance per ingested SeMNPV polyhedron (p, $\#^{-1}$), product of C and p, indicating the susceptibility to virus spray, number of leaves visited per day (L_v, $\#.day^{-1}$) and the number of leaves in the dispersive range (L_r, #) for five larval instars of *Spodoptera exigua*.

Instar	C	p	C * p	L_v	L_r
L1	0.024	.14	.030	1	50
L2	0.22	.26	.057	1	5
L3	1.8	.014	.025	1	320
L4	7.3	.0038	.028	3	320
L5	14	.000056	.00078	5	320

[1] from Smits (1987).

Due to inactivation of polyhedra exposed to UV radiation, the proportion of infected caterpillars feeding on an infected medium, reduced from 66% to 33% in 1 to 3 days (MacCollom & Reed, 1971; Podgwaite et al., 1979; Jacques, 1985). Assuming an exponential decay of infective polyhedra and using the exponential infection model, these data yield estimates of the relative infection rate of 1 to .33 day^{-1}. In the model a relative infection rate of 0.7 day^{-1} is assumed, corresponding to a halflife of 1 day. No data from greenhouse environments, which have low UV levels, are available.

The incubation period (time elapsed between infection and death) decreases with temperature. Infected larvae disintegrate in 4 days at 30°C and in 8 days at 20°C. The instar-dependent numbers of leaves visited per day are given in Table 1. The fraction infected L5 larvae developing into infected females is rather arbitrarily set to 50%. Smits (1987) observed a percentage of infected eggs in broods of infected females of 10-28%. This proportion is set to 15% in the model. No differences in fecundity, mortality or egg hatchability could be shown between healthy and infected females (Smits, 1987).

3. Results

The interaction of the basic processes presented above can be studied on the level of the cluster and on that of the system as a whole. First some aspects of the behavior of separate clusters are presented.

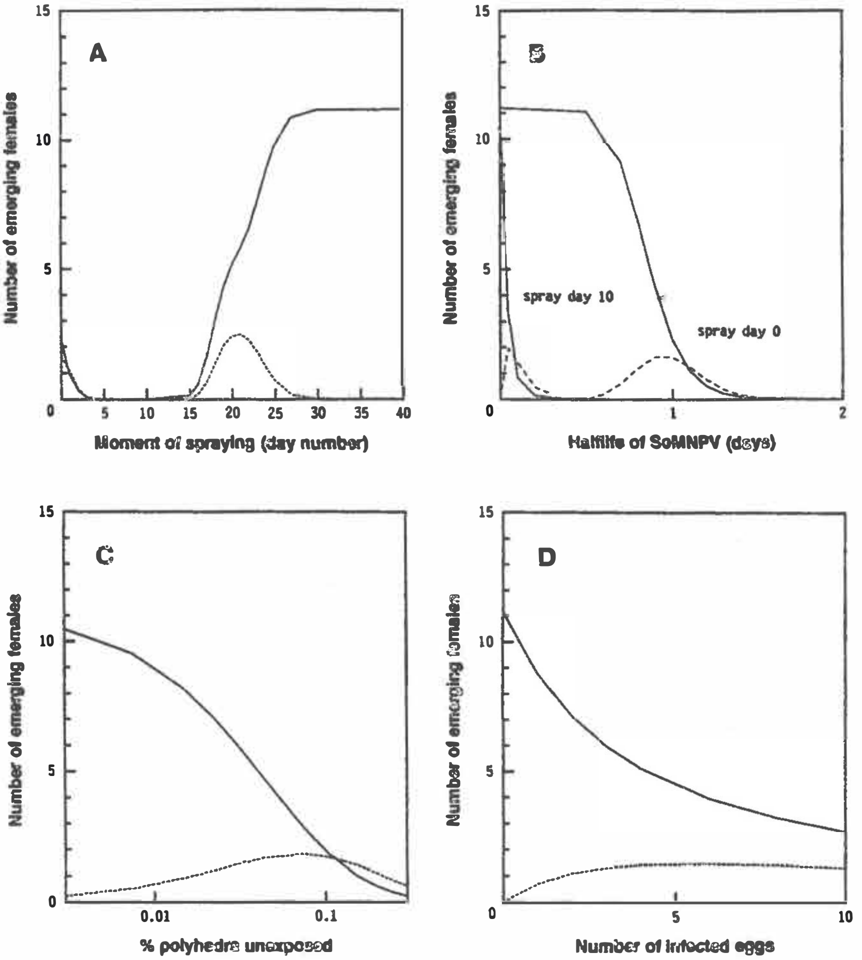

Figure 1: Analysis of cluster model. Figs A through D show the dependency of the number of healthy ([Picture]) and infected ([Picture]) females emerging from a cluster on (A) the time between oviposition and spraying; (B) the halflife of sprayed polyhedra for two spraying moments (u = 0); (C) the fraction unexposed polyhedra, u, for zero or five initially infected eggs (spray on the day of oviposition); and (D) the number of initially infected eggs (vertical transmission; no spray); In all figures, temperature is 20^oC and virus is sprayed at a dose of 10^8 polyhedra/m².

3.1 Cluster behavior

The behavior of a cluster is characterized by the number of healthy and infected females that emerge from it. A large reduction (almost 100%) of moth numbers is accomplished when SeMNPV is sprayed in a 'window' of 10 days between day 5 and 15 after oviposition (Fig 1A). In this period, the more susceptible L1 to L4 instars are predominating (Table 1). The relation between mortality and the halflife of SeMNPV depends on the day of spraying (Fig 1B). When the spraying is well timed (day 10) a short halflife, approximately 0.5 day, still gives 100% control. When the virus is sprayed too early (day 0) a halflife of 1.5 days is needed to obtain complete control. For both days of spraying there is an 'optimum' halflife giving the greatest output of infected females. Shorter halflifes hamper the infection process. Longer halflifes give such a rapid horizontal infection that all caterpillars are infected and killed before the fifth stage. The effect of the unexposed polyhedra on the reduction of moth numbers is shown in Fig 1C. The number of emerging females strongly decreases as the proportion of unexposed polyhedra, u, increases. When u exceeds 0.1% (10^5 polyhedra/m^2) more infected than healthy females emerge. Fig 1D shows that the initial number of infected eggs has a major effect on the number of emerging females. At a vertical transmission level of 15% (ca. 5 infected eggs per cluster), the number of healthy females emerging from a cluster is halved, compared to the disease-free situation. At higher vertical transmission rates the reduction is even greater. The number of infected females that emerges from a cluster varies little with the level of vertical transmission. At all vertical transmission levels, the number of healthy females emerging from a cluster exceeds the number of infected ones with a factor two, also at vertical transmission levels of 30%, the highest value found experimentally. This result shows that vertical transmission alone is insufficient to obtain long-term control of S. exigua by inoculative spray of SeMNPV. Healthy patches will outgrow infected ones in number.

3.2 Population model

Fig. 2 shows examples of population dynamics at the system level. In the absence of virus, the number of moths grows exponentially. The upper curve represents the dynamics when introduced virus is inactivated completely (u = 0). The virus is sprayed when small larval stages are most abundant, such that a large reduction of moth numbers after the spray is achieved. However, during later generations moth numbers gradually grow at the same relative rate as in the absence of virus. The lowest curve shows the time course of the number of larvae when 1.5% of the sprayed polyhedra is not inactivated by UV radiation. Long-term population regulation is then achieved. These simulations with the population model confirm the conclusions drawn from studying the cluster model.

4. Discussion

Due to the high value of the crop, little feeding injury can be tolerated in Dutch glasshouse chrysanthemums and moth numbers must be controlled during the initial exponential growth phase. Inundative SeMNPV sprays give very good immediate control of S. exigua; Percentages kill of 95 to 100% are achieved (Smits, 1987). To accomplish also a long-term suppression of the pest population, the virus must give a lasting reduction of the net reproductive rate R of S. exigua below 1 and thereby maintain itself in the insect population.

At low moth densities, interactions between clusters are rare, such that, if there is complete inactivation of sprayed polyhedra, the virus can only propagate by vertical transmission. Under these conditions no long-term control can be achieved because healthy patches outgrow infected ones in number (Fig 1D). According to our simulations (Fig 2), long-term control is possible when the proportion of polyhedra, not exposed to UV radiation, is in the order of magnitude of 1.5%. Under these conditions the virus apparently maintains itself in the insect population, while the number of emerging females decreases to a total of less than 1 for all

15 clusters produced per female.

Obviously, virus persistence plays a major role in long-term inoculative control of moth numbers. Our simulations show that for short-term control, the moment of spraying and the halflife of polyhedra are important. Data on the inactivation of baculoviruses in glasshouses are, however, lacking. Therefore the present modelling results with regard to long-term control are speculative and experiments are needed to test our results. Attention should be given to the proportion of unexposed polyhedra and their distribution in the canopy.

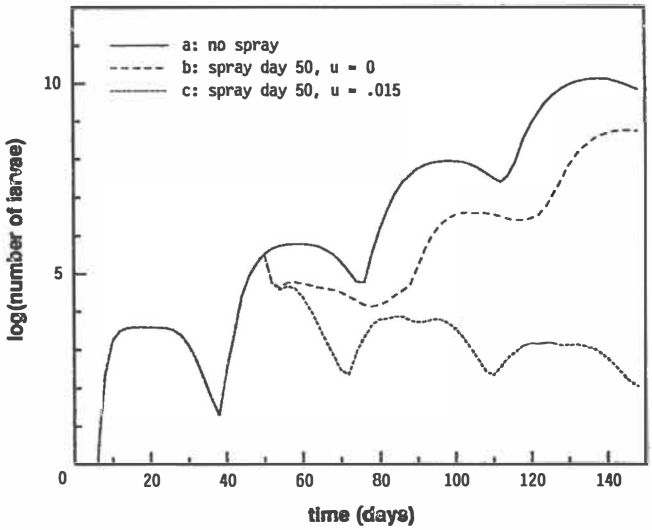

Figure 2: Analysis of population model: simulated total number of larvae over a period of 5 months (A) virus free; (B) sprayed with virus at day 50 without unexposed polyhedra (u = 0); (C) as (B) with 1.5% of the polyhedra not exposed to UV radiation (u = 0.015). Temperature: 20°C; Spray: 10^8 polyhedra/m2; $t_{1/2}$ = 1 day.

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REARING METHOD AND BIOLOGY OF THRIPS PARASITOID, *CERANISUS MENES*

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Summary

A simple rearing method for *Ceranisus menes* was devised in my laboratory. Parasitized thrips, *Frankliniella intonsa, Thrips tabaci, T. hawaiiensis* and *T. coloratus* were reared by the method of Murai and Ishii (1982) using pine pollen and honey solution (10%). Mass rearing of this parasitoid is practically possible by this method.

Developmental period of egg and larva of this parasitoid was synchronized with development of host thrips. The pupal period was very long in its life cycle and has wide variation. It was observed that this parasitoid produced males in autumn but reproduced parthenogenetically(thelytoky) in the following generations in constant conditions. the mean fecundity and the mean longevity of female adult at 25°C was 162 eggs and 10.4 days, respectively. The parameters of population increase were calculated. When this parasitoid reproduced parthenogenetically, intrinsic rate of increase(r) at 25°C and 20°C was 0.098 and 0.047, respectively.

1. Introduction

Flower bugs, parasitoids and nematodes are well-known natural enemies of thrips. Amongst the parasitoids, there are some species of Eulophidae, Trichogramma and Mymaridae (Lewis, 1973). There were few examples of biological control by parasitoid. Sakimura (1937c) had introduced *Thripoctenus brui* (synonym of *Ceranisus menes*) to Hawaii from Japan to control *Thrips tabaci*. Sakimura (1937a,b) reported the biology of *C. menes*. However, mass rearing method was not confirmed. Murai and Ishii (1982) devised rearing method of flower thrips by using some kinds of pollens and honey solution through this thin membrane. This method is available to rear thrips parasitoid.

2. Rearing method for *C. menes*

A glass tube (8 cm in diameter and 5 cm depth) was used for the rearing vessel for the thrips parasitoid (Fig. 1). *C. menes* attacked 5 species of Thysanoptera (*Frankliniella intonsa, Thrips tabaci, T. hawaiiensis* and *T. coloratus*) and completed its whole life cycle. *C. menes* attacked *Haplothrips chinensis*, but they could not develop. The rearing procedure is shown in Fig. 2. The thrips lay eggs in water through the thin membrane (stretched Sealonfilm) for two days at 25°C. These eggs were taken out and set on a film in a chamber at 25°C for two days. One or two hundred newly hatched larvae were set in the glass vessel with five or six female adult parasitoids at 20°C.

After eight days, parasitised mummies were put into small glass vessels with available moisture. By this method, mass rearing of *C. menes* could be completed successfully.

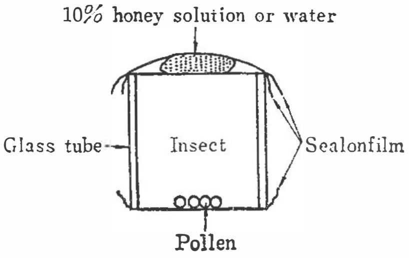

Fig. 1. Rearing apparatus for *C. menes*.

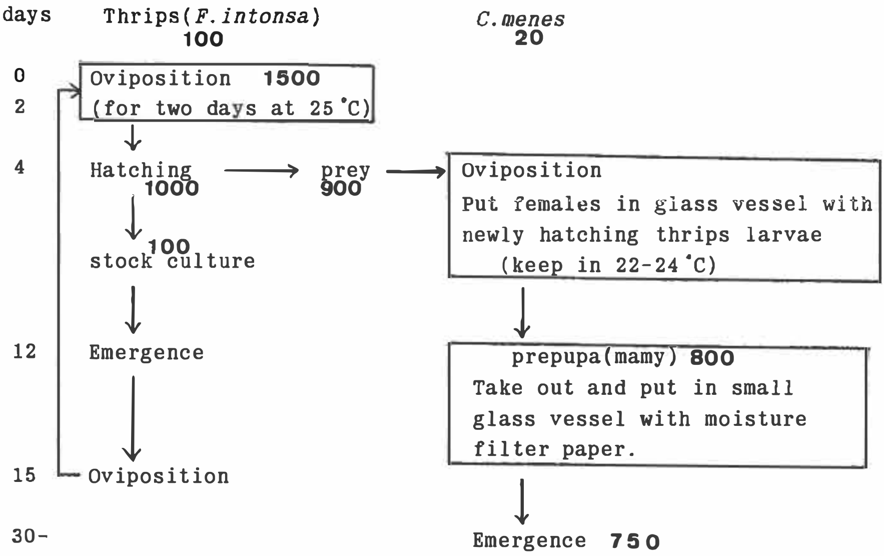

Fig. 2. Rearing procedure for *C. menes*.

3. Development of *C. menes*

Development of *C. menes* on three species of thrips was studied. Developmental duration of egg-larva at 17.5°C was synchronized with development of host thrips. Body size of *C. menes* was also synchronized with thrips size. Developmental duration on *F. intonsa* was longer than on other thrips (Table 1).

Table 1. Development of *C. menes* on some host thrips at 17.5°C.

Host thrips	Duration of development in days	
	egg+larva	pupa
F. intonsa	18.2±1.6	109.5±18.2
T. tabaci	18.5±0.6	112.0±14.6
T. hawaiiensis	14.3±0.9	113.5±14.2

Developmental duration at different temperatures is shown in Table 2. Egg+larva duration was shortening with temperature increasing. However, pupal duration was very long at less

than 20°C and bout three times as long at about 22.5°C. There was a marked variation in pupal development of *C. menes* (Fig. 3). This variation will probably be adaptive to the life cycle of host thrips. Sakimura (1937b) did not observe this developmental variation.
This will be a problem for mass rearing and release into the field. On the other hand, a long duration of the pupal stage will be of great advantage to transport and stock culture.

Table 2. Development of *C. menes* at some temperatures

Temp. (°C)	Duration of development in days. egg + larva	pupa
15	22.8±0.9	107.1±14.7
17.5	18.2±1.6	112.0±14.6
20	13.5±1.0	105.9±63.1
22.5	10.3±1.0	38.2±8.3
25	8.4±0.8	38.5±7.4

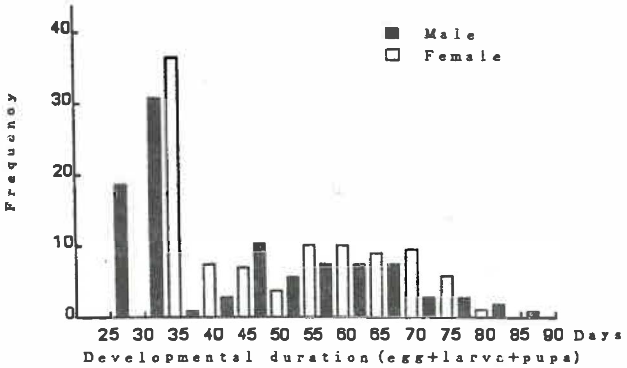

Fig. 3 Variation of developmental duration of *C. menes*.

4. **Reproduction of *C. menes***

Adult longevity of *C. menes* was 10.4 days and *C. menes* produced 162 offsprings at 25°C (Table 3). Adult females lay more than 20 eggs every day in their life. Fecundity curve and survival curve is shown in Fig. 4. Sex ratio of *C. menes* changed. Females produced females and males at the initial rearing. After several generations, however, females reproduce parthenogenetically. Population parameters were calculated as survival rate was 1.0 at emergence and sex ratio was 1.0 (Table 4)=. Intrinsic rate of *C. menes* was lower than that of the thrips. For example, the intrinsic rate of *F. intonsa* was 0.1580 at 25°C (Murai, 1988). Therefore, it was suggested that multiple releases will be needed to control thrips.

Table 3. Oviposition and female life span of *C. menes*

Tem.	life span in days	No. of offsprings per female
20	9.2(3-18)	61.0
25	10.4(2-18)	161.8

Table 4. Parameters of population increase of *C. menes*.

Tem. (℃)	Mean Time (days)	Intrinsic rate per days(r)	Net Re-production(R)
20	87.5	0.047	63.4
15	52.0	0.098	161.9

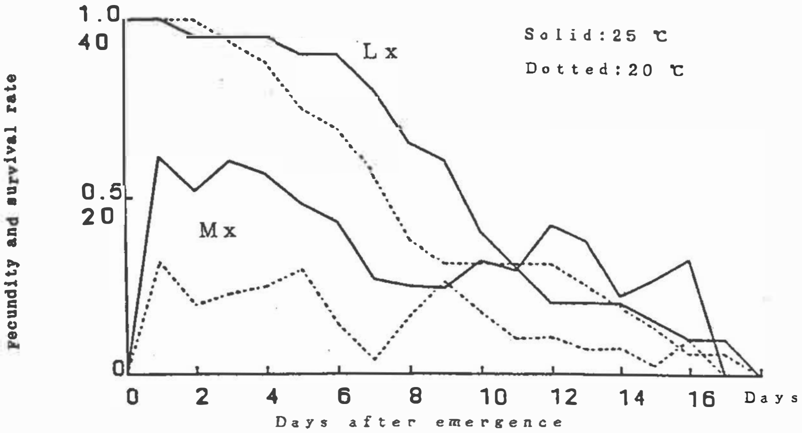

Fig. 4. Survivorship curve(Lx) and Fecundity curve(Mx) of *C. menes*.

5. Conclusion

1) Mass rearing method for *C. menes* was confirmed by thrips rearing method using pollen and honey solution. More than 100 parasitoids per glass vessel could be produced.
2) Development and size of *C. menes* were synchronized with host thrips. There was marked variation in pupal development.
3) Reproductive capacity of *C. menes* was lower than that of host thrips. Therefore, it was suggested that multiple releases will be required to control thrips effectively.

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THE USE OF NEMATODES AGAINST SCIARIDS IN SWEDISH GREENHOUSES

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Summary

The practical use of *Neoaplectana carpocapsae* Umeå-*Musca* strain against sciarids in greenhouse ornamentals has developed since 1987 in Sweden. In 1989 the method was applied in around 20% of the pot plant nurseries, mainly during propagation. Application technique is described briefly.

1. Introduction

Sciarid flies are important greenhouse pests, especially in ornamentals (Hussey et al., 1969, Meirleire and Phalip, 1989, Wardlow, 1989). The larvae damage roots, stems and leaves of seedlings and cuttings, sometimes also of older plants. In Sweden, sciarids used to be controlled by chemical treatments with organophosphorous compounds, but growers started to complain of poor effects some years ago. this could probably be due to build up of resistance in pest populations. There is some information available on possible alternatives for biological control of sciarids. In the USA *Bacillus thuringiensis* var. *israelensis* was tested for activity against sciarid larvae with good results (Osborne et al., 1985). A product containing the bacteria is on the market in Denmark for greenhouse application, but it is not registered for use in Sweden. Entomopathogenic nematodes can attack sciarid larvae. Hudson (1974) used *Tetradonema plicans* Cobb against *Bradysia paupera* Toum. in greenhouse experiments. *Lycoriella auripila* (Winnertz) in mushroom compost can be parasitized both by *Heterorhabditis heliothidis* Khan, Brooks and Hirschmann NZ strain and by *Steinernema feltiae* Filipjev agriotos strain when applied on freshly spawned compost or at casing (Richardson, 1987). The present paper describes the use in Sweden of *Neoaplectana carpocapsae* Weiser (= *S. feltiae*) Umeå-*Musca* strain against sciarids in greenhouses.

2. Development of biocontrol of sciarids with nematodes

In 1987, a small-scale Swedish production of the *N. carpocapsae* Umeå-*Musca* strain was running to supply nematodes for experimental purposes and for limited commercial use against root weevils (Burman, 1988). An application was made in a production unit for parsley in pots where sciarids were a constant problem because no efficient chemicals were available. The result was quite remarkable - damage incidence fell from around 70% to below 10% (Berglund, pers. comm.). Nematode treatments have since then been the only method for controlling sciarids in this nursery. A pilot study was then carried out demonstrating the ability of *N. carpocapsae* Umeå-*Musca* strain to parasitize sciarid larvae (*Bradysia* sp.). The first dead larvae were found 24 hours after treatment. The average number of emerging flies per pot was reduced from 38.5 control) to 0.6 (Malm et al., 1988). The results have been confirmed in other experiments (Berglund et al., in press). The nematodes were then applied in 10 nurseries with ornamental crops (mainly Kalanchoë and Poinsettia) giving overall good or satisfactory control of sciarid larvae during 1987. In 1988, more than 50 growers were regularly applying *N. carpocapsae* Umeå-*Musca* strain. During 1989 numbers have risen to around 130, that is approximately 20% of all Swedish pot plant producers. The method is used in propagation of Cyclamen, Gerbera, Kalanchoë, Poinsettia, Primula, Saintpaulia, Schefflera, Stereospermum and some minor crops.

3. Application methods

The infective nematode larvae are distributed in a granulated gel (a synthetic polymer) which gives the product ("Nemalogic") a rather long shelf life (2-3 weeks in cold storage). Direct use is recommended, anyhow, in order to minimize risks of diminishing quality. The product is available all year round and can be delivered on short notice (maximum 3 days), which makes storage at the nursery needless. Recommended dose is 20 millions per m^2 of substrate. Lower numbers (e.g. half dose) give good results only when the application technique can ensure an even distribution of the nematodes. Application of the recommended dose reduced fly emergence in a pot trial with 91% and 96% two and four weeks respectively after treatment. When 1/3 dose was applied fly emergence was reduced with 93% both two and four weeks after treatment (Nedstam, prel. results). There are several ways of applying the nematodes, from small-scale methods using the water can to large-scale using the drip irrigation system. A common way is to use ordinary spraying equipment at the lowest pressure and water out the nematode suspension over e.g. plug plants. Another possibility is to treat the substrate with nematodes in a soil-mixer. As the sciarid infestation sometimes seems to come with the substrate it is always recommended to make the treatments as early as possible during propagation.

4. Problems encountered in the use of nematodes

A few cases of poor effect of *N. carpocapsae* Umeå-*Musca* strain on sciarid larvae have been reported. In one case the nematodes had died during transport for some unknown reason. Growers are now advised to check the mobility of the infective under magnification before use. Other failures can generally be explained by the tendency of the nematodes to sediment very rapidly in water. A thorough and constant stirring of the nematode suspension during application is absolutely crucial.

5. Concluding remarks

In less than three years the method of controlling sciarids with *N. carpocapsae* Umeå-*Musca* strain became widely accepted among Swedish producers of ornamental crops. It is a case where a well-known biocontrol agent has worked its way into a completely new field of application. This has taken place with limited research support but with much interest and risk-taking from the side of the growers and a lot of time and energy spent from the commercial firm supplying the product, Svenska Predator AB in Helsingborg.

Lately other sources of nematodes for sciarid control have turned up, much to the benefit of Swedish growers who can count on price competition amongst the distributors in the future.

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PEST MANAGEMENT FOR STRAWBERRIES GROWN IN THE GREENHOUSE: MICROBIAL CONTROL OF THE TOBACCO CUT WORM, *Spodoptera litura*, AND CULTURAL, CHEMICAL AND PHYSICAL CONTROL OF APHIDS.

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Summary

From 1984 to 1986, a nuclear polyhedrosis virus of *Spodoptera litura* (SlNPV) was applied to the tobacco virus of *Spodoptera litura* on strawberries in greenhouses in Saitama prefecture, in Japan. Furthermore, the methods of prevention of aphid invasion into the greenhouse and reduction of aphid density on seedlings have been devised for integrated pest control of strawberries grown in the greenhouse.

1. **Introduction**

The tobacco cut worm, *Spodoptera litura* and the cotton aphid, *Aphis gossypii* causes serious damage to strawberries in greenhouses in Saitama prefecture, in Japan. It is difficult to control the pest only with chemical insecticides during the harvesting season, because of residual toxicity. Okada (1981) has described in detail techniques for the control of *Spodoptera litura* by a NPV isolated from the tobacco cutworm (SlNPV). One purpose of this investigation was to find out the role of the SlNPV in a pest management program for strawberries grown in the greenhouse.

The strawberry seedlings raised in pots were less infested with aphids than the seedlings raised in nursery beds (Nemoto, unpublished). But the effectiveness of the control of the population in greenhouses by merely raising seedlings in pots is not clear. Nemoto (1989) attempted to evaluate the effectiveness of chemicals for reducing aphid density on seedlings which were raised in pots.

2. Microbial control

SlNPV and a chemical pesticide (Dipterex® = DEP) were used to control tobacco cutworm on strawberries grown in the greenhouse in Saitama Horticultural Experiment Station (SHES). Trials were carried out from December 1984 to February 1985. A 4.3 m² plot was planted with 60 strawberry crowns. Egg masses collected in the laboratory were kept in the greenhouse until the larvae hatched and the newly hatched larvae were counted and then placed onto the strawberry leaves (December 20). SlNPV (3×10^8 PIBs/m²) was sprayed once, and DEP (x1000; active ingredient, 0.05%; 200ml/m²) was sprayed three times (December 20 and 29, 1985 and January 4, 1986).

SlNPV did not show any rapid efficacy in controlling the pest, but 20 days after spraying, larval density (number of larvae per plant) was 1, 2 and 17 in SlNPV, DEP, and control plots, respectively.

Furthermore, larval damage to strawberry leaves in SlNPV-sprayed plots were less marked than those in DEP-sprayed plots one month after spraying. The number of damaged strawberry fruits in SlNPV-sprayed plots was not lower than in DEP-sprayed plots (sprayed three times) (Table 1).

Table 1. Effect of SlNPV application on damage to strawberry fruit by *S. litura*.

Treatment	No. of damaged fruits/crown	No. of examined fruits/crown	% of injured fruits/crown
SlNPV	1.2	15.8	7.6
DEP	1.3	14.1	9.6
Control	10.2	13.6	75.0

Neonate larvae of *S. litura* were released onto the strawberry leaves in the plots treated with SlNPV at 1 day (November 10, 1985), 11 days (November 20), and 19 days (November 28) after application (November 9; 2 x 10^9 PIBs/m^2), to survey their persistence. Serious damage was observed in control plots, but in the SlNPV plot, the larvae were controlled almost perfectly at 1 day after application (Fig. 1).

these results suggest that SlNPV is one of the most effective control agents for tobacco cutworm on strawberries grown in the greenhouse.

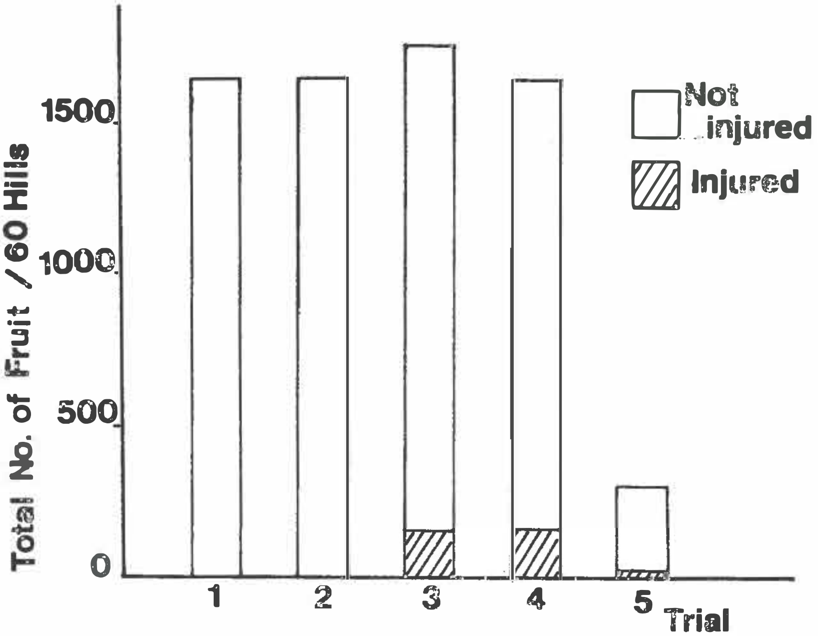

Figure 1.Effect of the released time of *S. litura* larvae onto the strawberry leaves in the plots after application of SlNPV on the number of damaged fruits. 1: *S. litura* larvae were not released onto the strawberry leaves; 2-4: *S. litura* larvae were released onto the strawberry leaves at 1 day (:2), 11 days (:3) and 19 days (:4) after application of SlNPV; 5: *S. litura* larvae were released onto the strawberry leaves without application of SlNPV

3. Cultural, chemical and physical control of aphids

Control experiments of aphids on strawberry were performed in greenhouse at SHES between 1988-1989. To reduce the density of aphids on seedlings, the strawberry seedlings in pots were treated with carbosulfan (granule formulation; 0.05g active ingredient/crown) at 8 days before planting (October 24, 1988). Furthermore, to prevent physical adult invasion by flight the greenhouse ventilation was covered with netting when the entire greenhouse was covered with vinyl film, and the ground in the greenhouse was mulched with silver polyethylene film after covering the entire greenhouse with vinyl film.

In all carbosulfan treated plots, the aphid density on strawberries in plots of seedlings raised in pots was smaller than that in plots of seedlings raised in nursery bed. The aphids on strawberries in the greenhouse covered with netting and mulched by silver polyethylene film were kept under control but not without covering and mulch. The combined use of covering and mulch was the best method for control of aphids (Fig. 2).

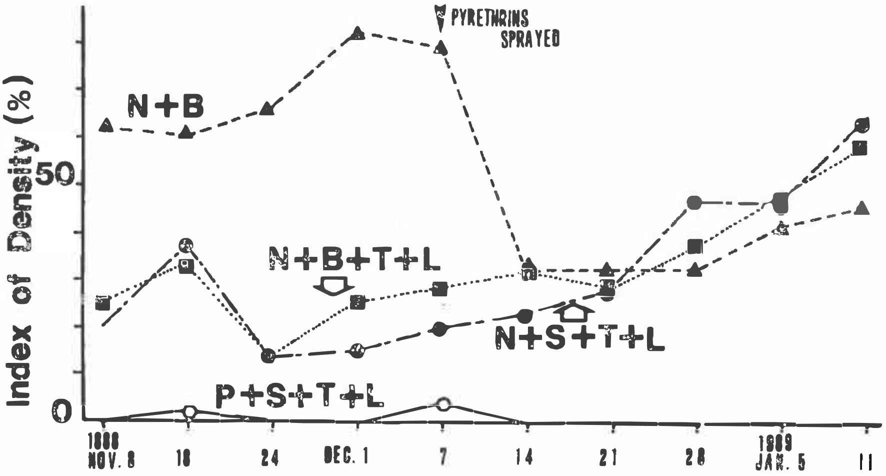

Fig. 2. Population changes of the cotton aphid, *Aphis gossypii* on strawberry seedlings under the combination of different control methods.
P: the strawberry seedlings raised in pots;
N: the strawberry seedlings raised in nursery bed;
T: treated with carbosulfan; L: covered with netting;
S: mulched with silver polyethylene film
B: mulched with black polyethylene film
Index= (sum (f)/s*N))*100; f: density of aphids on a seedling; (=0: none; 1: a few; 2: moderate; 3: heavy; N: number of seedling examined.

4. Discussion

Female adults of *Spodoptera litura* enter into the greenhouse from the time the strawberries are planted until the time when the greenhouse is covered with vinyl film. It is possible to control tobacco cutworm by applying SlNPV around the time when the greenhouse is covered with film.

In addition to microbial control of *S. litura*, cultural, chemical and physical control methods of aphids were devised. The frequency of pesticide applications when used in a combined integrated programme could be less than 1/3 of that of an ordinary control programme in Saitama prefecture in Japan.

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PROSPECTS FOR BIOLOGICAL CONTROL OF *BEMISIA TABACI*

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Summary

The prospects for biological control of *Bemisia tabaci* in the southeastern United States and elsewhere using natural enemies from Florida are discussed. An overview of research in progress on managing this whitefly with *Encarsia formosa, E. transvena, Eretmocerus californicus, Delphastus pusillus*, and *Paecilomyces fumosoroseus* is presented.

1. Introduction

The sweetpotato or cotton whitefly, *Bemisia tabaci*, is a major pest worldwide of economically important crops, including cotton, cucurbits, lettuce, soybeans, and tomatoes. This pest attacks over 500 different plants, many of which are widely distributed weeds and garden plants. Until late 1986 this whitefly was not considered a pest of plants grown under protected culture. In the past several years it has become one of the most important and economically damaging pests in North American greenhouses in addition to its increasing importance as a pest of field crops. The whitefly severely impacts important vegetable and ornamental crops by reducing host plant vigor, yield, and promoting growth of sooty mold. Transmission of viral diseases is a major problem in many parts of the whitefly's range and is now becoming a problem in the southeastern United States. Resistance to insecticides has been reported in many parts of *Bemisia*'s range. While attempting to control this pest growers are also under pressure to reduce applications of chemical pesticides as public awareness of pesticide usage increases. Crops grown in protected culture receive the greatest amount of pesticide applications per acre; groundwater contamination from this industry is now a major concern.

Numerous natural enemies of *B. tabaci* have been recorded (Cock 1986) from many parts of the world, but little is known about the resident natural enemy complex in the southeastern U. S. A. and other humid subtropical and tropical regions. It is expected that once these regions are surveyed, potentially valuable natural enemies of *B. tabaci* will be discovered. Many candidate species from other areas are also available for possible importation but biological information about many of these species is lacking and resources for exploration, collection and quarantine rearing are inadequate. A concerted effort is being made to manage *Bemisia* in many parts of the world where is has become a problem including North America and recent interest in biological control has been high. In the southeast U.S.A. the efforts of many scientists are being coordinated through a regional project entitled "Biological Control of Selected Arthropod Pests and Weeds Through Introduction of Natural Enemies".

2. General Approach to Control of *B. tabaci*

We agree with the views expressed by van Lenteren & Woets (1988) that natural enemies should ideally be used in protected cultures at low host levels. However, since 1) *B. tabaci* develops quickly, 2) occurs naturally in hot climates where control of temperature is limited (in cold countries there is more control of glasshouse temperature), and 3) there often is constant migration of whiteflies from the outside, growers are often faced with high localized populations even if we introduce natural enemies initially at low levels. Therefore, it may not be possible to rely on a single natural enemy species. Instead we may have to utilize several species to provide control under different host conditions (low and high density-efficient species).

Citrus blackfly is an example of effective biological control where several parasitoid species were initially introduced; one multiplied rapidly and quickly reduced blackfly numbers but another eventually became dominant while remaining effective at low and high blackfly densities (Summy et al. 1983, Thompson et al. 1987).

3. Natural enemies

3.1 Parasitoids

As most workers in this field are aware, many whitefly parasitoids belong to taxonomically unsettled groups. Species identifications are very difficult to obtain and often controversial for species in the genera *Encarsia* and *Eretmocerus*. Taxonomists urgently need financial support in order to provide the needed support services required for progress in research on parasitoids that attack *B. tabaci*. Additional funding is needed for surveys of the parasitoid fauna in many areas of the world, and for continued maintenance of parasitoid cultures that show promise in order to make them available when the need arises.

Encarsia formosa is the only species commercially available at this time. Reports on its ability to reduce *B. tabaci* populations have been mixed. There are many possible reasons for this; most probably relate to *Bemisia*'s occurrence over a wide range of host plants, cropping and environmental conditions. Studies are currently being conducted to compare this species with those found in Florida. It has been suggested that *Encarsia* formosa may provide acceptable control only under conditions where *B. tabaci* is limited by sub-optimal temperatures such as occur at the northern limits of its distribution in the field and in northern glasshouse culture or on plants which are marginally suitable for the development of whitefly populations.

Considerations of host finding efficiency and of rearing expense are very important in evaluating candidates. *Eretmocerus* species are generally more efficient in host finding and possess a desirable functional response; and being arrhenotokous unlike most *Encarsia* species, may be easier and cheaper to rear. Some species have longer developmental periods from oviposition, but this may be offset by higher searching and oviposition rates.

Five species of parasitoids (Hymenoptera: Aphelinidae) are found parasitizing *B. tabaci* in substantial numbers in Florida. Four have been tentatively identified as *Encarsia transvena* (or near *transvena*), *Encarsia nigricephala*, *Encarsia tabacivora*, and *Eretmocerus californicus*. Still unidentified is a species of *Encarsia* near *formosa*. We are currently rearing *Encarsia transvena*, *E. formosa* and *Eretmocerus californicus*.

Encarsia transvena is found in central Florida in populations of papaya whitefly, *Trialeurodes variabilis*, as well as in *B. tabaci* populations. This species has been reported from Africa, the Far East, and Hawaii. It has a highly female-biased sex ratio. There is some evidence for both unisexual and bisexual populations. Current laboratory cultures are bisexual. Males develop as hyperparasites of females, and have also been reared from parasitized aphids. Females prefer to oviposit in third and fourth instar *Bemisia* (fig. 1). This species has a relatively short development time for females of 12 to 14 days at 25° C (fig. 2), considerably less than the whitefly's development time of 24 to 25 days. Male *E. transvena* development is completed in as few as 9 days. Substantial host-feeding occurs, increasing its impact on whitefly populations. Female longevity (under glasshouse conditions in Florida) is greater than that of *E. formosa* (fig. 3) but its general level of activity as evidenced by parasitism in paired comparisons appears to be lower. The species is behaviorally difficult to experiment upon.

E. formosa has not established in field populations of *Bemisia* in Florida but reproduces well in greenhouse populations. The species is thelytokous on *B. tabaci*, as it is on greenhouse whitefly, although males are produced in low numbers. Oviposition and host-feeding behavior is similar to that of *E. transvena* (fig. 1), but development requires three more days at 25 °C (fig. 2). Low relative humidity appears to be especially detrimental to adult survival in this species (fig. 3). Survival is increased under higher humidity conditions but does not approach that of *E. transvena*.

Eretmocerus californicus occurs across the southern United States and into South America as far as Brazil. It adapts well to greenhouse rearing conditions. Females deposit eggs on the leaf surface underneath whitefly nymphs; they will accept all nymphal instars but prefer the second and third (fig. 1). After hatching, the larva eventually penetrates the host and completes development as an endoparasite. Development requires 18 to 24 days at 25 °C (fig. 2). Adult survival is similar to *Encarsia transvena* (fig.3). Females are very active relative to the species of *Encarsia* we have investigated. Fecundity studies in progress indicate that individual females lay five to six eggs per day during the first week following emergence, after which daily oviposition decreases. *E. californicus* also host-feeds, causing additional mortality. Both females and males develop as primary parasitoids. In contrast, males of most *Encarsia* species develop as hyperparasites of females. The potential of the other species remains to be investigated. Each has been recovered in abundance from field collections. Field populations of *B. tabaci* are sometimes heavily parasitized even at low densities.

In Florida, a modified banker-plant system is being evaluated as a method for distributing parasitoids. Papaya plants (*Carica papaya*) are infested with papaya whitefly and then exposed to parasitoids. These plants can be placed into or alongside crops without releasing additional *B. tabaci*, and could be helpful in overcoming the reluctance of growers to place natural enemies with pests into their crops. The suitability of this whitefly as a host for the above species of parasitoids is being studied. The predatory beetle *Delphastus pusillus* will also feed and reproduce on papaya whitefly.

3.2 Predators

There are many predators that will attack whiteflies. These include various Hemiptera (especially Anthocoridae, and predatory Miridae), Coleoptera (Coccinellidae), Neuroptera (Chrysopidae, Hemerobiidae, Coniopterygidae), Diptera (Dolichopodidae, Syrphidae, Anthomyiidae), Hymenoptera (Formicidae), Araneida and Acarina (Phytoseiidae, Stigmaeidae). Some of these are opportunistic predators of adult whitefly, others are general predators of leaf-feeding Homoptera, still others are specific predators of whiteflies. Very little information is available on the biology and impact of most predators of sweetpotato whitefly, especially in field crops.

The most promising predator to date for use in greenhouses is the coccinellid, *Delphastus pusillus* Casey. This species is distributed across most of the southern and eastern U. S. and throughout the Caribbean, Central and northeastern South America. Larval and adult beetles feed voraciously on eggs, immatures, and adult whiteflies. They feed specifically upon whiteflies, but will accept spider mites as alternate prey if whiteflies are not available. Eggs are typically laid on leaves with high densities of whitefly eggs. Eggs are deposited on the leaf surface; females also frequently place eggs inside *B. Tabaci* exuviae. Beetles prefer eggs to older whiteflies and can consume several hundred per day. Older larvae gradually cease feeding and move down the plant in search of protected places for pupation. Development time under greenhouse conditions (mean of 26-27 °C) is 21 to 22 days. Adult females live an average of 50 days, males about 40. Well-fed females lay 3 to 4 eggs per day. Initial results suggest that *D. pusillus* is best adapted to feeding and reproducing at high whitefly densities. Prospects for mass rearing appear promising.

Another coccinellid, *Clitostethus arcuatus* (Rossi), has been implicated in dramatic reductions of whiteflies in small research greenhouses in Israel but biological data is sparse. This species appeared on its own inside two greenhouses containing cotton plants and lantana. *C. arcuatus* was first detected in mid June. By the 3rd week of July both greenhouses were completely clean of *B. tabaci* and stayed clean until mid August. The beetles then disappeared and did not reappear when *B. tabaci* reappeared in September. This species was recently imported into California for evaluation against the recently introduced ash whitefly, *Siphoninus phillyreae* (Halliday).

A coniopterygid obtained from Kenya was released in Israel but disappeared after one generation in the field before significant data were obtained. Substantial mortality due to predation by coniopterygids has been observed on greenhouse whitefly in California in some tree crops.

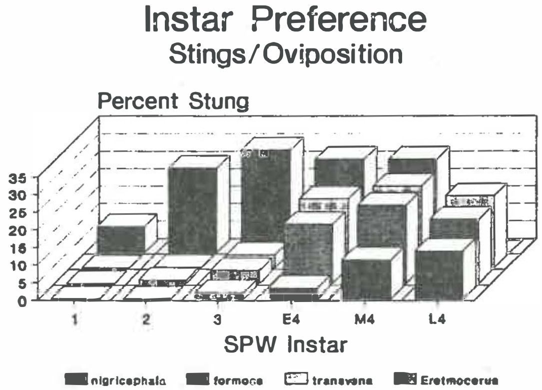
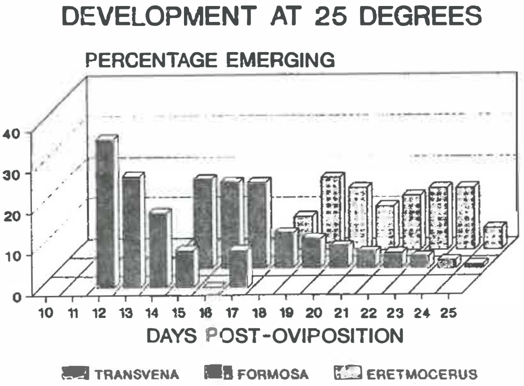


Fig. 1. Instar preference for ovipositon by 4 parasitoids of *B. tabaci* in Florida.



ONE DAY OVIPOSITION PERIOD GIVEN

Fig. 2. Development of 3 parasitoids of *B. tabaci* at 25°C.

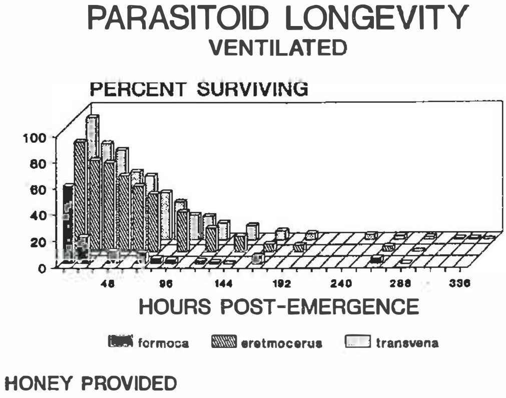


Fig. 3. Longevity of 3 parasitoids of *B. tabaci* in ventilated cages (60-70% RH)

3.3 Fungal Pathogens

The use of insect pathogens for the control of whiteflies dates back to the early part of this century when Florida citrus growers used *Aschersonia*. This fungus was encouraged to grow on whiteflies infesting citrus trees. Branches were then harvested from these trees and the infected whiteflies moved throughout the state to facilitate the spread and control of citrus whiteflies by *Aschersonia*. Problems with the control of greenhouse whitefly in greenhouses resulted in the development of a commercial products which contain strains of the fungus *Verticillium* (*Cephalosporium*) *lecanii*.

Studies have been conducted at the Central Florida Research and Education Center, Apopka to determine the potential for using *Paecilomyces fumosoroseus* to control *Bemisia tabaci*. This pathogen has been responsible for very dramatic epizootics in greenhouses and on raised benches and in relatively open structures that were covered with shade cloth. *P. fumosoroseus* possesses many desirable attributes; quick knockdown (fig.4), infects all stages (fig.5.) tolerance to pesticides, ease of production, and a broad spectrum of activity. The University of Florida and W.R. Grace have entered a cooperative agreement to pursue the development and commercialization of this pathogen. Therefore, many aspects of our current research with this pathogen can not be disclosed in print at this time.

4. Conservation of Natural Enemy Populations

Many species of whitefly parasitoids and predators will attack other species of whitefly when they are sympatric with *Bemisia*. Research is needed to determine the importance of wild populations of whitefly and enemy reservoirs in the vicinity of field crops and the influence of weedy and native plant hosts on the movement of whiteflies and natural enemies into adjacent areas. Existing opinions on the size and importance of wild populations of *Bemisia* are somewhat contradictory. Whitefly species in general do not reach damaging levels in undisrupted habitats, an indication of the impact of their natural enemies (DeBach and Rose 1977, Rose and Wooley 1984) and of environmental mortality factors (Horowitz et al. 1984). Further improvements in the specificity of new pesticides such as growth regulators are likely to create new opportunities for conservation of natural enemies.

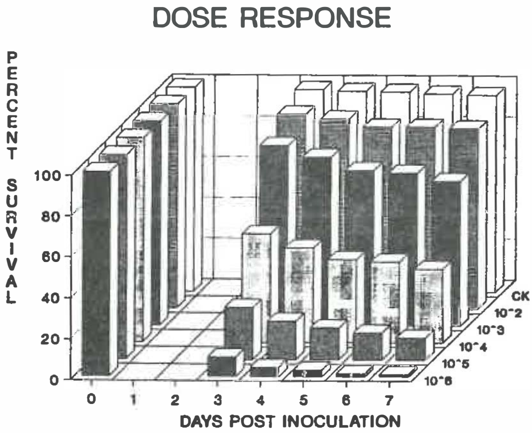


Fig. 4. Dose response of early fourth instar nymphs exposed to *P. fumosoroseus* at 100% RH.

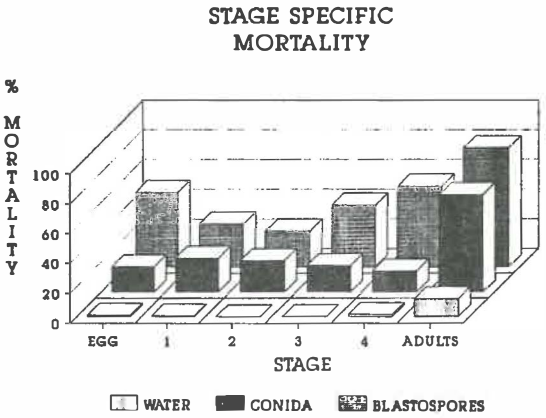


Fig. 5. stage specific mortality when exposed to $1x10^6$ conidia or blastospores.

5. Opportunities for Integration with Chemical Pesticides

Integration of natural enemy releases with existing pesticides used against *B. tabaci* will continue to be an important goal. Many currently registered pesticides are very detrimental to natural enemies. Insecticidal soaps and oils, and pesticides containing neem are a few compounds that allow some parasitoid and predator activity. Development of new growth regulators for whitefly control such as buprofezin and those compounds that belong to the benzoyl urea group (teflubenzuron, CGA-184699, andalin) offer additional hope for the future compatibility of selective insecticides and parasitoids. These materials have significant activity against specific whitefly stages: eggs and early instars. Since parasitoids will attack older nymphs and prepupae, we may be able to integrate the two. Selective compounds could be used to reduce the whitefly populations to manageable levels that parasitoids would be able to keep in check.

Initial results with potentially selective compounds from trials in Florida demonstrated that parasitoids persisted in trials using kinoprene, CGA-184699, teflubenzuron and fenoxycarb. Some IGRs (buprofezin) were so effective against *B. tabaci* that no nymphs remained for parasitoids to attack, so their immediate effect on the parasitoids could not be assessed. Buprofezin was evaluated under field conditions in Israel for two years. The effect of this compound on individual species varied: *Eretmocerus mundus* was negatively affected, perhaps because it selects younger whitefly nymphs to parasitize than *Encarsia* species, and parasitism due to it alone declined slightly in IGR treated plots. Parasitism by *Encarsia lutea* increased slightly in the treated plots.

By combining an effective IPM scouting program with judicious selection of biological, cultural and selective chemical controls, we are hopeful that this whitefly can be managed effectively using the variety of available agents. Figure 6 indicates the significant mortality factors and the corresponding whitefly stages most affected by various factors.

To obtain biological control of *Bemisia*, we suggest that the sequence of events should be:

1. Introduce density-efficient natural enemies when whitefly populations are low.

2. If *Bemisia* populations increase due to inadequacy of the original natural enemies, use an IGR, adulticide or mass-released predator effective at high host densities. This will:
    A) Quickly reduce the whitefly populations,
    B) Conserve the emerging parasitoids which will remain active,
    C) Allow continued activity of IGRs: because of their stability over time, they will continue to limit the growth of whiteflies on treated leaves. Parasitoids will have a more important role on newer foliage.

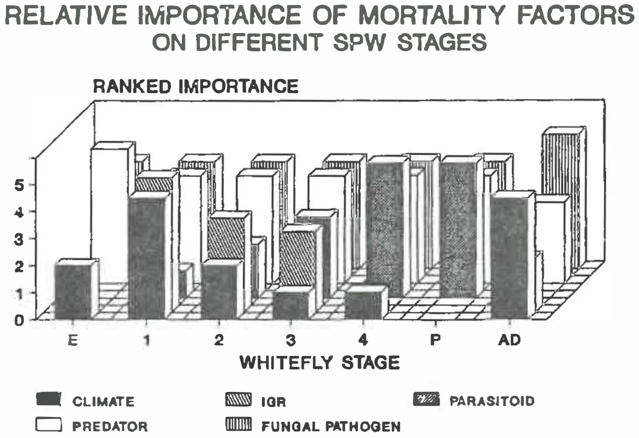


Fig. 6. Relative importance of various mortality factors on different stages of *B. tabaci*.

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BIOLOGICAL CONTROL IN ORNAMENTALS: STATUS AND PERSPECTIVES

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Summary

More than 32,000 ha of glasshouse production throughout the world are devoted to ornamentals; the majority of this is used for the production of cut flowers and potted foliage and flowering plants. Despite the size and importance of this industry, very little has been accomplished in the area of biological control of the major and minor pests attacking these crops. Some of the misconceptions concerning biological control of ornamentals are explored and the feasibility of using inundative releases of natural enemies on these crops is discussed. A political and economic analysis of pesticide use on ornamental crops is presented in order to show that growers are being forced to move away from strict reliance on pesticides. Finally, several crops grown under protected culture within the category of ornamentals are reviewed and the prospects for biological control on each are discussed.

I. Introduction

Major accomplishments in the area of biological control of glasshouse vegetable pests have been made over the past 20 years. More than 7000 ha of glasshouse vegetables worldwide are under successful biological control and this area is expanding yearly. Recent extensive overviews of biological control of vegetable pests in protected culture have been made (van Lenteren & Woets (1988), Parrella & Hansen (in press). Rather than review this well-traveled area, the focus of this manuscript will be to examine biological control on ornamentals under protected culture.

In contrast to vegetables, biological control in glasshouse ornamental crop production is still in its infancy. This is unfortunate but is a consequence of more restrictions or limiting factors inherent in the production of an ornamental crop. These have been reviewed by van Lenteren et al., (1980) and Parrella & Jones (1987) and include : 1) relatively low tolerance for the presence of arthropods and damage, 2) the historic, intensive use of pesticides that makes integration with natural enemies difficult, 3) the large cost of overall crop production which renders the cost of even intensive application of pesticides less than 1% of total crop productions costs, 4) the multiple pest complexes commonly found attacking ornamental crops, and 5) the fact that often all (i.e., pot plants) or a considerable portion of the crop (i.e., cut flowers) are exported to parts of the world where quarantine restrictions must be satisfied. The vegetable transplant industry is faced with similar quarantines, but the consequences are much less for production vegetables where only the commodity itself is shipped (e.g., tomatoes).

These factors, and others, are clearly restrictions to the implementation of biological control, but they are not insurmountable. The total area devoted to ornamental crop production throughout the world is considerable although it is difficult to obtain accurate figures. After reviewing several publications (Anon, 1982; 1989; van Lenteren and Woets 1988) a fair estimate is approximately 32,000 ha. The top five countries are the Netherlands (4,059 ha), the United States (3,770 ha), Japan (3,400 ha), the Federal Republic of Germany (2,600 ha) and France (2,025 ha). These figures do not include ornamental production outdoors or under shade cloth.

There is enormous diversity within the category of ornamental production (Table 1) but with this deversity comes opportunity. On some crops biological control will rarely be practical, while on others it is extremely feasible. Before discussing some of these crops on a category by category basis, it is important to review several basic differences in the underlying objectives that separate biological control on vegetables from biological control on ornamental crops.

In addition, some major changes are occuring in California, the United States, and in other areas of the world with respect to the future of pesticides in crop protection. These deserved to be briefly reviewed because they will dramatically impact biological control on all crops but the greatest effect may be in ornamental production.

2. Inundative vs. Inoculative Releases : Status for Ornamentals

Debach (1964) lists inundative releases and inoculative releases under the heading 'periodic colonization'. In this early work, he suggested that periodic colonization was necessary in the field when a natural enemy failed to provide control for any number of specific reasons. The concept of biological control in protected culture crops was not considered in this classic publication.

In an artificial situation such as the greenhouse, the intent is to plant the crop into a clean greenhouse on an approximate yearly cycle. In this situation there are no pests or natural enemies. As pests begin to build up in the crop, natural enemies may follow, but this usually occurs too slowly to effect control. Consequently, periodic colonization is necessary. In vegetables, this has been called the 'seasonal inoculative release method' because the culture method of the crop prevents the effects of a single release from lasting many years (van Lenteren & Woets 1988). Such releases are carried out with the objective of establishing the natural enemy early in the life of a crop in an effort to maintain the density of a pest below the economic injury level until harvest. This method has proven enormously successful and is widely practiced in greenhouses around the world. Although this strategy may be successful in some ornamental crops (see discussion which follows), seasonal inoculative releases will probably not be successful in many cases and inundative releases may be the only recourse.

In a true inundative release, natural enemies are dispensed and control of the pest results from the natural enemies released, not from their progeny (Debach 1964). This type of release is similar to using a pesticide where results are immidiately and there is no prolonged interaction with the pest population. Two important points separate an inundative release from an inoculative release: 1) there is a more immidiate effect; the time lag associated with a reduction in the pest population is reduced, 2) the initial ratio of natural enemy to pest at the time of release is not as critical, and 3) it is more feasible on short term crops where prolonged interaction between the natural enemy and pests in not possible. However, in situations where we have attempted biological control through inundative releases of natural enemies [on marigolds for control of *Liriomyza trifolii* (Burgess) with *Diglyphus begini* (Ashmead) (Heinz & Parrella, in press) and on poinsettia for control of *Bemisia tabaci* (Gennadius) with *Encarsia formosa* Gahan (Parrella, 1989a) production of offspring within the greenhouses where releases were made helped to achieve a reduction in the pest populations.

These factors are important in ornamentals where the number of pests and their damage that can be tolerated is low. In addition, many growers often fail to discover a pest until the population size is close to the aesthetic injury level. At this time the grower may have no recourse but to apply a spray or to use an effective natural enemy in an inundative release. Lack of information on how to sample pest populations in ornamentals together with limited information of natural enemy - pest interactions on these crops precludes the use of a scientifically developed natural enemy - pest ratio to guide the user with respect to the number of natural enemies to release.

As suggested by van Lenteren & Woets (1988), inundative releases are most likely to be successful against univoltine pests in annual field crops and against minor pests in greenhouses. Debach (1964) also believed that inundative releases would be limited to control of pests of high value crops having relatively light pest infestations. Obviously the latter idea coincides with the use of inundative releases in ornamental crops if releases are started early in the cropping cycle (see Heinz et al., this volume). Regardless of speculations as to where inundative releases will be effective, it is generally agreed that making many large releases during a single crop probably would not be economically feasible. The cost and availability of natural enemies is of critical importance. These limiting factors associated with the use of inundative releases in the field and/or greenhouse still hold true today, but there are indicators that this is rapidly changing. In both greenhouse and field crops in California and in U.S., biological control through inundative releases of natural enemies is more of a concept than an reality. However, as suggested above, this is changing dramatically.

More than 20 years ago, Oatman et al., (1968) demonstrated that mass releases of *Phytoseiulus persimilis* Athias-Henriot will suppress populations of *Tetranychus urticae* Koch in strawberry plantings. However, this approach was not considerede economically feasible (Kennedy et al., 1975) and the approach was subsequently abandoned. In 1989, the use of *P. persimilis* and *Amblyseius* spp. in releases up to 60,000 per acre three times during the season have been made on well over 5000 acres of strawberries in California with apparent good success (Grossman 1989). This acreage is expected to increase in 1990.

The strawberry growers in California in 1989 found themselves with the following : 1) a highly resistant population of spider mites, 2) the loss and restricted use of several key miticides on the crop, 3) ever encreasing cost of miticides/insecticides, and 4) pressure from the general public and the state regulatory structure to reduce pesticide use. These factors, when combined with a good supply of predaceous mites at reasonable prices, gave the economic edge to inundative releases.

The scenario outlined above for the strawberry growers in California is not unique; many growers of other crops (both in the field and greenhouse) find themselves in similar (and worsening) situations. It is clear that many of these growers are contemplating or are trying inundative releases of natural enemies for pest control in their respective crops. In addition, commercial insectaries are blossoming in California (with substantial investments by established European firms) so there should be a larger supply and a greater diversity of natural enemies at more reasonable prices. However, there is a danger in this rush to biological control through the use of the inundative approach because there is a lack of sound fundamental and applied data on which to base these releases. This was adequately summarized by King et al., (1985) :

> "Careful consideration of a number of complex factors is essential in dertermination whether or not adequate arthropod pest control can be obtained with the use of commercially available entomophagous arthropods. Reliance upon use of entomophagous arthropods to control pests should be limited to those situations where scientifically, environmentally, and economically sound procedures are available".

Clearly the efficacy of inundative field releases of natural ene-mies for biological control on most crops has not been demonstrated nor has the economic feasibility of such programs (King et al., 1985). Fundamental questions such as how often ?, how many ?, how and where they should be released ?, etc. are simply not known. Without answers to these vital questions which must be the foundation of any inundative release program, the program itself is likely to be fraugth with problems and numerous failures will result.

As noted by King et al., (1985), predictive models are needed for the rational use of any kind of augmentative release. We have developed such a model over the past 2.5 years. This model has been remarkably successful in predicting releases of the parasite, *D. begini* to achieve biological control of the leafminer, *L. trifolii* infesting greenhouse chrysanthemums (see Heinz et al. this volume). Unfortunately, the concept of using the inundative releases approach is often linked to that of a pesticide; that is, it is often assumed that very little biological information about the natural enemy-pest interaction is required for success. In other words, many people feel that inundative releases take the ecology out of biological control. However, this is not true. Information such as natural enemy foraging and attack behaviour, detailed information on the life of the natural and the host, etc., are necessary for effective use of natural enemies in inundative releases. In addition the selection criteria of parasites may differ when they are to be used in an inundative vs. an inoculative release (see Minkenberg and Parrella, this volume) Clearly, factors such as mutual interference become potentially more important.

Although leafminers in the genus *Liriomyza* are not the major pests they were in the early 1980s, they still pose problems for growers of chrysanthemums and other crops. Most crysanthemum crops in California are still under regular pesticide applications for leafminer control. The only insecticide working for these growers is abamectin which is a very expensive material. If this compound were lost to growers or if the leafminer developed resistance to this product the results could be potentially disastrous. At present there is a *Liriomyza* leafminer outbreak on lettuce in southern California and in Arizona to which there are no easy solutions. In Europe, *L. huidobrensis* Blanchard (a common species in field flower crops in California) has become a serious problem on ornamental and vegetable crops in many countries (Bartlett et al. 1989).

3. Changing Role of Pesticides

It is becomming increasing apparent all over the world that growers must reduce the amount of pesticides they are using in pest control programs. The greenhouse industry, and in particular ornamental production, is no exception. In fact the greenhouse industry is being targeted for a reduction in pesticide use because it is one of the largest pesticide users on a per acre basis. Furthermore, new, tougher laws and regulations governing pesticide use generally have greater impact on the greenhouse industry than on other segments of agriculture. Reasons for this include : 1) traditional heavy dependence on chemicals for pest control, 2) lack of training or education on alternatives, 3) up until recently, the lack of available alternatives and a rarity of researchers addressing these problems, 3) the labor intensive nature of production which forces regular contact with the crop, and 4) the enormous diversity of crops grown relatively small acreage when the industry is viewed in total.

Some specific ongoing changes can be cited in the United States and in California : 1) Revision of worker safety standards (1990). This ruling, among other things, increases the reentry time into fields or greenhouses to as much as 72h after pesticide application. In a field crop this can usually be accommodated -- in the greenhouse this virtually eliminates the pesticide form consideration for use. 2) Registration of all pesticides labeled before 1984 (to be completed this decade). This is expensive for the manufacturer (data gaps must be filled) and forces a tough evaluation of the cost/benefit for each material on each crop. This clearly puts ornamentals with it low acreage and high value (high risk) at a disadvantage. In addition, new labels must be written to address each site, crop and pest. This action has already resulted in the cancellation of about 20,000 pesticide registrations in the U.S. in 1989. 3) 100% use reporting (1990)(California only). All materials (including surfactants, adjuvant, etc.) must be recorded and reported to regulatory authorities on a monthly basis. This requires considereable time by the grower, and will clearly document the amount of pesticides used by each individual operation. Greenhouse/nursery operation where cropping and pesticide use occur all year long, will be among the heaviest pesticide users. 4) Proposition 65 (1986)(California only). This initiative was passed in the state by an overwhelming majority of voters, which, among other things, requires public warnings before exposing the public to toxic materials. Of concern here is the close proximity of many ornamental/greenhouse operations to the urban environment. This, coupled with a headhunter clause in this initiative which provides a bounty for any individual who turns in a violator, has already presented some problems. In addition, the reward is proportional to the fine levied. 5) Pesticide contamination act (1985)(California only). This has focused on the ground water contamination issue and has created pest management zones where restrictions are placed on pesticides used based on their potential to contaminate ground water.

There are many other laws and initiatives that are likely to be enacted in the near future. All of these will put more and more restrictions on the use of pesticides. A major initiative that is likely headed for passage in California in 1990 is the Environmental Protection Act which proposes to phase out gradually all pesticides known to cause cancer and birth defects in California agriculture by mid- summer 1996. This could potentially affect 70% of all the chemicals used in the state. A more realistic appraisal is that 175 of the 500 materials currently registered in California will be affected (Stimmann & Ferguson, 1990).

It is clearly an exciting time to be working in the area of biological control. The information I have provided in this section demonstrates that growers must change their pest control practices because they are being forced to do this. It is unfortunate that growers will not switch of their own accord, but it is very clear that there is nothing as easy or mindless as applying a pesticide. Experience has shown, at least in ornamentals, that as long as pesticides are available, growers will continue to use them. This is lamentable because there is overwhelming evidence that total reliance on pesticides is no longer cost effective. Factors such as pesticide resistance, increasing cost of materials, increasing cost of labor for application, and the general failure of pesticides to provide the 100% control growers often claim they must have in ornamentals is sufficient evidence to seek alternatives. It is unfortunate that a majority of growers sill cling to the past.

4. Biological Control in Ornamentals

My arguments to this point have been to demonstrate that: 1) inundative releases may be a viable strategy in the production of greenhouse grown ornamentals, 2) biology and ecology are not sacrified in this approach, 3) this concept is more economically feasible today than at any time in the past, and 4) growers are inclined to try and adopt such a strategy given the anti-pesticide climate in which they must operate and live. Under this scenario, the actual adoption of biological control strategies by growers becomes a much easier task to achieve. The view that adoption of IPM and biological control strategies will only be successful when they are perceived by growers to be better than conventional methods (van Lenteren & Woets 1988) is no longer entirely correct. Although it is incumbent for researchers to demonstrate the superiority of IPM and biological control, it may now be sufficient just to show and demonstrate that a high quality crop can be produced economically utilizing these techniques.

This is the type of information that must be generated by the research and extension community. Grower demand for these data greatly exceeds our ability to generate it. This is made more complicated given the diversity of crops and pest problems which must be addressed. An important component of any pest management or biological control program is knowledge concerning how to estimate pest populations through standardized sampling programs. Unfortunately, these are not available for most arthropods attacking ornamental crops (Parrella et al., 1989).

Furthermore, although it was important to develop and utilize information on the compatibility of pesticides with natural enemies on vegetable crops, this is even more important in the ornamental arena. Here, pesticide use is much greater and therefore compatibility with various insecticides and fungicides is more critical. This task should be made easier by the loss of registration of a number of products. In addition, although there are not that many new registrations, those materials under development may be compatible (i.e., insect growth regulators, botanicals, etc.) allowing for true integration.

Parrella and Hansen (1989) and Osborne & Oetting (1989) have provided the most recent reviews of biological control in ornamental crop production. From these accounts and the information presented in Table 1, it becomes clear that biological control will not be feasible on all crops grown. In addition, the use of biological control alone will probably rarely be satisfactory in producing an aesthetically perfect ornamental crop; an integrated approach will probably be more successful.

The cut flowers and cultivated greens offer some of the best potential for biological control because many of these crops are perennial in nature and therefore offer the potential of a long term interaction between the natural enemy and the pest. In this situation, the traditional economic injury level (Stern et al. 1959) applies as does the modified aesthetic injury level (Parrella & Jones 1987) where only the marketed portion of the crop must be kept free of damage. A combination of inoculative and inundative releases together with selective insecticides may be an ultimate solution in these crops. Good progress in biological control is being made on ideal crops such as roses, carnations and gerbera. However, considerable work needs to be done on all these (and others) to find out what can and cannot be done. Our preliminary work on gerbera grown for cut flowers has shown promising results with biological control of mites, thrips, aphids and leafminers. However, we have been unable to control whiteflies, the major pest of this crop. Consequently, we chose to use an integrated approach where a selective insecticide (buprofezin) provided good whitefly control and did not impact the leafminer parasite, *D. begini*.

Potted flowering crops, such as poinsettia and chrysanthemums, may be amenable to biological control but only through inundative releases of natural enemies. Here the short duration of the crop together with the fact that all the foliage is an inherent part of the aesthetic quality of the commodity make biological control via any other mechanism difficult to achieve. These two classes of ornamental production (cuts and pots) within greenhouses make up the largest segment of the industry and are clearly the areas where research and extension efforts should be focused.

Obviously, each greenhouse and grower are different and an assessment of the feasibility of biological control should be made prior to any attempt. For an example of a step wise procedure for evaluating the feasibility of biological control in an ornamental production range, see Parrella (in press).

On crops where there are multiple pests and numerous cultivars, a great deal of research need to be done. Control is often complicated by the appearance of new pests such as the South American or pea leafminer, *L. huidobrensis*, sweet potato whitefly, *B. tacaci*, and the western flower thrips, *Frankliniella occidentalis* (Pergande). Strategies for the biological control of these pests, as well as other new pests in the future, must be given priority. This is currently being done with promising results from many areas of the world.

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Table 1. Category, farm gate value, and injury levels for ornamentals in California.

Category	Value (dollars)(1)	Type of Injury (2)	Potential for Biological Control
Cut flowers and cultivated greens	342	EIL, AIL, MAIL, O	Excellent
Potted plants (flowering and foliage)	281	EIL, AIL, O	Excellent
Bedding plants	12	EIL, AIL, O	Poor
Bulbs, corms, etc.	8	EIL, O	Good
Flower seed Production	26	EIL	Excellent
Propagative materials	21	EIL, O	Poor
Rose plants	56	EIL, AIL	Excellent
Deciduous, evergreen, trees, & shrubs	457	EIL, AIL	Excellent
Herbaceous Perennials	26	EIL, AIL	Excellent
Turf (seed and sod)	20	EIL	Excellent
Christmas Trees	29	EIL, AIL, O	Poor

1. Millions of dollars; from Evans (1989)

2. EIL = Economic injury level from Stern et al., (1959). AIL = Aesthetic injury level from Olkowski (1974). MAIL = Modified aesthetic injury level from Parrella & Jones (1987).

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MANIPULATION OF PHYTOSEIID THRIPS PREDATORS IN THE ABSENCE OF THRIPS

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Summary

The thrips predator *Amblyseius cucumeris* (Oud.) was found to benefit from the presence of flowers on sweet pepper plants. Small open rearing units on the growing substrate (rockwool) produced predators during 7 weeks. Predator density 24 days after this way of introducing was 3.2 predators per leaf compared to 0.9 and 1.5 in plots with direct introduction on leaves. *Amblyseius barkeri* (Hughes) if introduced on pest-free cucumbers survived for about a month without producing any offspring.

1. Introduction

In thrips control experiments with *Amblyseius* spp. on sweet peppers it has been observed repeatedly that predator populations, especially of *Amblyseius cucumeris*, remain on a remarkably high level long after the reduction of thrips numbers. Apparently the predators exploit another food source. If introduced on recently planted crops, *A. cucumeris* - but not *A. barkeri* - is able to colonize the plants and to increase in numbers in the total absence of any other arthropod. Both predators fail to do so if cucumber (modern female varieties) is used as a host-plant. Because of the even distribution of the predators the alternative food was suspected to be plant-borne, possibly pollen (Dosse 1961). From laboratory tests it was known that *Tetranychus* sp. is an alternative prey for both predators (Dosse 1955; Lababidi 1988), that both predators feed on pollen, but only *A. cucumeris* was proven to reproduce on a diet of pollen and water (W.P.J. Overmeer, unpublished, G. Tognina, unpublished).

2. Flowering sweet pepper allows 'predator-in-first' introduction

To establish the actual significance of pollen in the field, predators were introduced on sweet pepper plants with and without flowers, but of equal age. Flowerless plants were obtained by removing flower buds by hand twice a week just before the petals unfolded. On the free-flowering control plants young fruits, if not aborting spontaneously, were removed in order to stimulate development of more flowers. Removal of flowers c.q. fruits started at least one month before the introduction of the predators. Since treated and untreated plots were close to each other, drift of pollen and migration of predators between plots was not impossible.

Experiments A and B were done on potted plants growing on water tables with minimal distance between treated and untreated plants. In experiment C, four rows of sweet peppers were planted in soil, alternately treated and untreated. The outer rows (1 and 4) were separated from the other plants by a path; the inner rows were planted without interspace and can be considered as one hedge with half of the plants flowering.

About three weeks after the introduction of predators leaves were sampled to establish the population density. In the presence of flowers, *A. cucumeris* was found in much higher numbers than on the treated plants (Tables 1 and 2). Only low numbers of *A. barkeri* occurred in both plots, with no significant difference.

Table 1. Effect of removing flowers on population density of leaf-inhabiting phytoseiid predators. Pot-grown sweet pepper plants on water table. Listed: total number in sample of 42 leaves.

	With flowers	Flowers removed
Experiment A predator: *Amblyseius cucumeris*		
Predator eggs	25	8
Mobile predators	62	23
Thrips* nymphs	3	5
Experiment B predator: *Amblyseius barkeri*		
Predator eggs	5	0
Mobile predators	6	4
Thrips* nymphs	76	58

* *Frankliniella occidentalis*

Table 2. Effect of removing flowers on population density of *Amblyseius cucumeris* (experiment C). Soil-grown sweet pepper plants, rows 2 and 3 touching. Listed: total numbers in sample of 60 leaves.

	Row 1	Row 2	Row 3	Row 4
Flowers present:	+	-	+	-
Predator eggs	22	4	7	0
Mobile predators	25	5	9	2
Thrips** nymphs	2	0	1	2

** *Thrips tabaci*

The results might explain why *A. cucumeris* is the more suitable species for sweet pepper (Ramakers 1988). Since the host-plant itself provides food for the predators, they can be introduced and settle before thrips occurrence. This 'predator-in-first' technique, contrasting with the 'pest-in-first' method developed for the specialized predator *Phytoseiulus persimilis* (Parr, 1973), makes biocontrol of thrips on this crop relatively reliable. Therefore, most sweet pepper growers have now adopted biocontrol of both spider mites and thrips (Ramakers et al. 1989, M.Y. Steiner, pers. comm.).

3. 'Parking predators' on cucumber

A. barkeri was introduced at different times (starting on February 22) in different parts of a pest-free cucumber house. Predators were monitored until pests (spider mites, thrips) appeared in April. They were collected by washing flowers in ethanol, and mounted for microscopic examination.

Table 3. Composition (%) of *Amblyseius barkeri* population after introduction on prey-free cucumber plants. N = number of predators examined. + = < 0.5 %. Fecundity = % of females with mature egg in abdomen.

	1 week after introduction	3 weeks after introduction	After prey appearance
N	173	63	24
Egg	0	0	17
Larva	+	0	4
Nymph	0	0	13
Adult male	20	0	29
Adult female	80	100	38
Fecundity	1	3	22

As long as prey was absent, predators were seldom observed on leaves, but were found hiding in flowers (feeding on nectar?) and shoot tips. Reproduction ceased immediately, and a gradually decreasing number of survivors - eventually only adult females - was found until about until about a month after introduction.

The absence of immatures and eventually of males (Table 3) strongly suggests that the predators observed were the same individuals that were released earlier. Surviving females isolated from flowers 3 or even 1 week after introduction hardly carried mature eggs (Table 3, last line), but looked well-fed. After being provided with thrips larvae in the laboratory, oviposition was resumed without additional mating being necessary.

From April onwards, the predators colonized the leaves and age distribution became more balanced (Table 3, last column). In summer, when thrips density was fairly high, they were found on the polyethene soil covers as well.

4. Miniature 'open rearing' units

Introduction of *Amblyseius* is usually done by scattering wheat bran with predators on the leaves. The bran will desiccate within a few days, which forces the predators to spread. However, if no predator food is available (cucumbers and eggplants before pest occurrence; very young sweet pepper crops) it is recommended to use a relatively young culture and arrange the bran on the soil or growing substrate around the stem base of the plants. Material applied in this way well not dry up and may serve as an open rearing for some time. Having the bran in plastic bags with little escape holes was found to offer a certain protection against various soil-borne arthropods (springtails, fungus gnats, predatory mites) and even against serial treatments with chemicals.

The 'longevity' of small open rearing units was studied in rockwool-grown sweet peppers. In January, the units were placed on top of the rockwool cubes, in which the plants had been propagated in the nursery. Each unit consisted of 2 cm^2 unprotected bran containing about 30 predators (*A. cucumeris*) and a similar number of storage mites per cm^2. In one plot the number of mites per unit was reduced by 50% by mixing with fresh bran.

As is shown in Table 4 the open rearing units were still quite productive after 24 days, with little difference between standard and diluted material. Even seven weeks after introduction some predators were present. From mid-February onwards predator eggs were found on the plants.

In another sweet pepper house with three identical compartments *A. cucumeris* was introduced on March 10. Each compartment received one third of the same batch of predators. In two compartments the bran was introduced in the usual way on the plant leaves, in the third plot on the rockwool as described above. Oviposition on the plants started immediately in all plots. However, the predator density established on April 4 was highest in the compartment with soil-application (Table 5). Two factors may account for this difference:

- additional production of predators by the open rearing units;
- immediate mortality among (immature) predators after leaf application.

Table 4. Number of *Amblyseius cucumeris* in open rearing units on rockwool. Unit = 2 cm² of wheat bran.

	Plot A	Plot B
Introduction Jan. 20	62	31
January 27	65	44
February 13	26	21
March 10	6	

Table 5. Density of *Amblyseius cucumeris* on sweet pepper after using different introduction methods. Sample: 30 leaves per plot, 25 days after introduction. Incidence: % of leaves with at least one individual (predator egg is counted as individual).

Introduction on:	Plot A leaves	Plot B leaves	Plot C rockwool
Thrips incidence (%)	0	0	0
predator incidence (%)	67	57	93
predator eggs per leaf	0.9	0.6	2.2
mobile predators per leaf	0.6	0.3	1.0

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APPLICATIONS OF *VERTICILLIUM LECANII* IN TOMATOES AND CUCUMBERS TO CONTROL WHITEFLY AND THRIPS

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Summary

The insect-pathogenic fungus *Verticillium lecanii* Viégas (Deuteromycetes: Moniliales) formulated as a wettable powder (MYCOTAL) was used in experiments in cucumber and tomato crops in commercial glasshouses to control whitefly and thrips. Repeated sprayings at weekly intervals reduced whitefly infestations by approximately 90 %, even when relative humidity was as low as 75%. Infection rates as high as 60% of Western Flower Thrips (*Frankliniella occidentalis*) in cucumber were also observed. Integration with other biological control agents and fungicide treatments was proved possible. The potential for commercial use of this fungus as a biological insecticide is discussed.

1. Introduction

V. lecanii is a well-known pathogen of arthropods: it was first described in 1861, and has been collected from numerous species of insects, spiders and mites (Rombach & Gillespie, 1988). Besides that, it is also found as a saprophyte on organic materials, and it is easily isolated from the soil (Domsch et al., 1981). It can also occur as a hyperparasite on rusts (Spencer, 1980; Mendgen, 1981). *V. lecanii* was developed as a microbial insecticide (MYCOTAL) against whitefly (*Trialeurodes vaporariorum*) in the United Kingdom between 1980 and 1985. Trials with this product in the Netherlands in 1984 were not succesfull. Under the normal conditions for growing cucumbers and tomatoes the product did not work well, the humidity had to be elevated to levels which were unacceptable to the grower. In 1988 the development of the product was resumed by Koppert BV in the Netherlands. Improvements in production and formulation resulted in a wettable powder with a dosage of 10^{10} viable conidiospores per gram, a 50-fold increase in comparison with the former product. Subsequent trials on cucumber and tomatoes in glasshouses proved that the product could have a very good effect on whitefly, while the standard operating procedures of the growers could be maintained. New efficacy trials for registration as a pesticide were successful, the approval will probably be granted in 1990. The results of these trials are presented here.

2. Material and methods

The efficacy trials in cucumbers were done in the summer and autumn of 1988 at the premises of five commercial cucumber growers in glasshouses with areas ranging from 4000 till 12,000 m^2. Treated areas ranged from 400 till 2,100 m^2 depending on the area of infestation. This area was divided in four fields.

The efficacy trials in tomatoes were done in the late summer and autumn of 1989 at the premises of five commercial tomato growers in glasshouses with areas ranging from 4,300-30,000 m^2. Treated areas ranged from 900 till 1,300 m^2. This area was divided in three fields.

In each experiment an untreated control area of 400 m^2 was incorporated. Observations were made only in the centre of the fields. All crops were grown on rock wool.

It was very difficult to find growers who had a reasonable but not too extreme whitefly population in their crop. The populations were either very big or very small. The natural whitefly infestation was very low in cucumbers in all cases and in tomatoes in one case. To obtain a whitefly population big enough to perform a trial, about 10 adult whiteflies were introduced per plant and the trial was started when instars were present. The standard operating procedures of the growers were maintained, which meant that the daytime humidities varied from 60 to 80%, the nighttime humidities varied from 70 to 95% and the mean temperature was about 20°C. The only restriction was that fungicides were applied three days before or three days after MYCOTAL applications and that the fungicide tolyl-fluanide could not be used.

MYCOTAL was sprayed at a rate of 3 kg per hectare, in three to four thousand litres of water per hectare. Spraying was always done at the end of the day, between three and eight p.m. depending on the weather. The crop was sprayed in week 0, 1 and 2 after the start of the experiments. In the tomato trials an extra spraying took place in two cases in the fourth week after the start. The first count was performed just before the first spraying. The total number of countings depended on the course of the trial.

To determine the percentage mortality of whitefly caused by *V. lecanii* 50 leaves on which whitefly was occuring, were picked weekly from the untreated area. From the treated area 25 leaves were taken from each of the three different sampling areas. Under the binocular microscope countings were made of numbers of dead (not evidently infected), infected (with *V. lecanii*) and living instars of *T. vaporariorum*.

In tomatoes, killed instars did not show new outside sporulation presumably because humidity conditions were not high enough. Therefore determination of mortality by *V. lecanii* is difficult. To enable good judgement of this, sampled leaves were put in a plastic bag for 24 hours to give 100% relative humidity (temperature 20 °C). Thereafter outside sporulation was easily visible and counting was largely facilitated by this method. Sporulation in 24 hours can only occur on previously infected instars and not from fresh spores wich are accidently on the whitefly instars.

The thrips infestation on cucumbers (*Frankliniella occidentalis*, was a naturally occuring one. Sampling and counting for thrips was done in the same manner as for whitefly.

3. Results

3.1 Results in cucumber trials

Whitefly mortality per cucumber grower is shown in figure 1.

Two weeks after the first treatment the mortality in the treated areas averaged 83 %. In the control areas hardly any infection was found, as is shown in figure 2. It seems that the infection did not spread to the untreated areas untill the last week of the experiment. There are large differences visible in the results between growers, with control varying between 68 an 98 %. Various explanations for this large variablility are discussed below.

Since it is well known that the relative humidity plays an important role in the infection process of *V. lecanii* and other entomopathogenic fungi (Quinlan, 1988; Gillespie, 1988; Milner & Lutton, 1986) the average humidities at the different growers were compared with the percentage mortality of the whitefly larvae. There was no relation between whitefly mortality and average humidity, nor with average daytime humidity or average nighttime humidity.

Another cause of variation could have been the amount of water used during spraying by the various growers. This varied from 3,000 litres till 6,000 litres per hectare. The regression line calculated from the average infection rate of whitefly instars and the amount of water used ($Y=43.3 + 31.6X$, where $Y=$ % mortality and $X=$ litres spraying solution / m^2) had a correlation coefficient of only 0.63, far removed from the significant 5% level of 0.89.

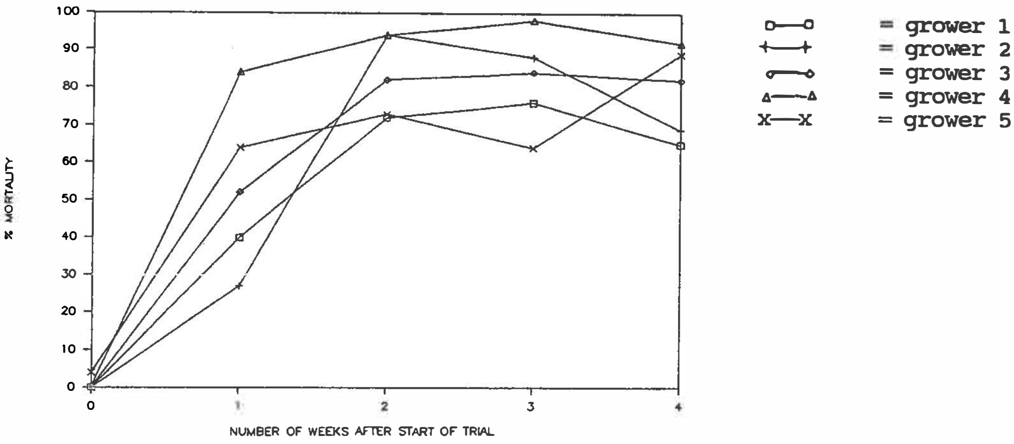

Fig. 1. % Mortality of whitefly instars in treated areas in cucumber: Mean % mortality per grower at weekly intervals.

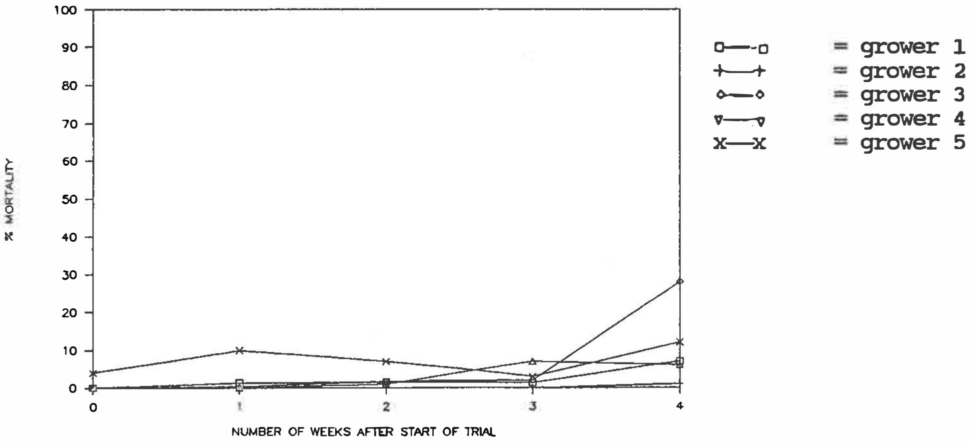

Fig. 2. % Mortality of whitefly instars and pupae in untreated areas: Mean % mortality per grower at weekly intervals.

For Western Flower Thrips the average results are presented in figure 3. The mortality of 20 % at the beginning of the experiments was caused by the simultaneous use of *Amblyseius* predator mites. Since this is another complicating factor, detailed results on thrips are not presented here. *V. lecanii* caused a rise in mortality to about 60 %, in itself not enough to control the population, but high enough to warrant further investigation.

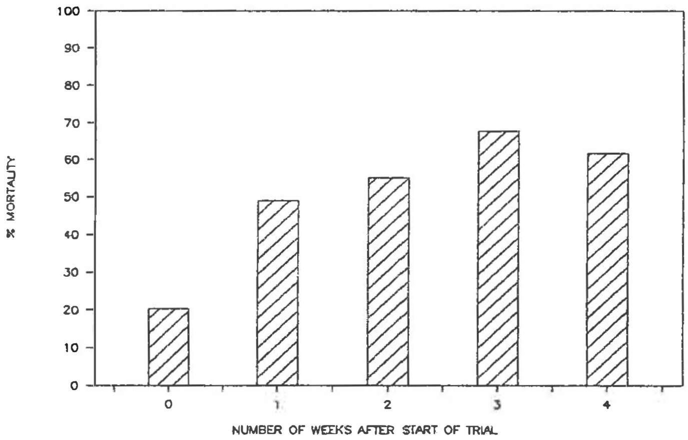

Fig. 3. Mean % mortality of *Frankliniella occidentalis* larvae, pupae and adults for all growers at weekly intervals.

3.2 Results in tomato trials

Whitefly mortality per grower in the treated and untreated areas are shown in figure 4. There are large variations visible in the results between growers with respect to mortality and the periods of time in which control was reached and also in the percentage mortality in the untreated area.

The untreated area of grower No. 2, 3 and 4 showed a high mortality at the end of the trial. For these growers the trials ended at the end of October. In this period the natural mortality of whitefly starts to increase due to changes of the environmental conditions. In the untreated area of grower No. 1 percentage mortality stayed between 10 and 15% including the counting performed before the first spraying. This is due to the use of teflubenzuron against caterpillars two weeks before the trial started. The percentage mortality in the treated areas of grower No. 1 and 4 started to increase reasonably quickly and three weeks after the first spraying mortality is about 90%. The percentage mortality in the treated areas of grower No. 2 and 3 increased very slowly and a fourth spraying was necessary to obtain the desired effect. The situations in trial No. 1 and 4 were different from the situations in trial No. 2 and 3. In trial No. 1 and 4, crops were reasonably dense and the height of the greenhouse was low (3 m., drainhight), while the greenhouses of the other two growers were high (3.75 m, drainhight) and the number of leaves per tomato plant were left low by the grower because of cultivation methods.

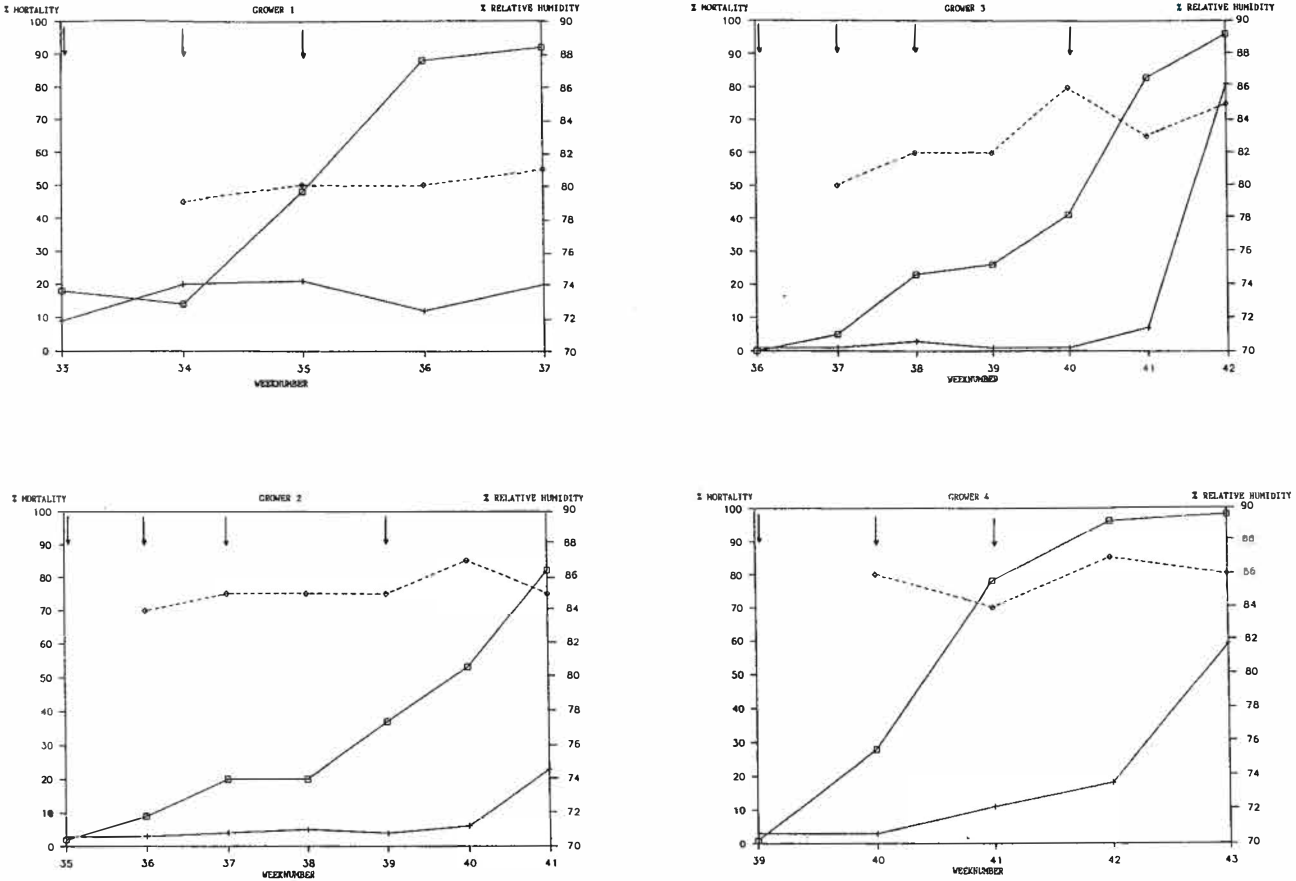

Fig. 4. Mean mortality (%) in treated (□——□) and untreated (+——+) areas and mean relative humidity (%, ◇----◇) in 4 tomato crops treated with *Verticillium lecanii* during several weeks.

↓ = treatment with *V. lecanii*

The average humidities and temperatures at the different growers were compared with the percentage mortality of the whitefly larvae. No relation between whitefly mortality and average humidity (see fig. 4), average daytime humidity, average nighttime humidity, or average temperature was observed.

4. Discussion

It is thought that the microclimate in the phyllosphere largely determines the performance of the fungus. If the humidity is high in this small area germination and infection is improved. The overall greenhouse humidity that is measured by the computer is not necessarily correlated with the phyllosphere humidity. Evaporative transpiration might be a better measure to determine the conditions for *V. lecanii*. A low air movement probably stabilizes the leaf microclimate and therefore spraying should preferably be done on a still day with high humidity if possible.

Spraying equipment was not a source of variation since the same apparatus was used throughout all experiments and was operated by the same man. The amount of water used per grower does not seem to particularly influence results.

Control of *Tetranychus urticae* by the predator mite *Phytoseiulus persimilis* was not affected by the application of *V. lecanii*.

Encarsia formosa still parasitised instars of *T. vaporariorum*, althout the quantity of possible hosts for this parasite were of course reduced by *V. lecanii*. Negative effects of the fungus on *E. formosa* were not observed, nor on *Amblyseius* species. Integration of *V. lecanii* with these biocontrol agents can thus be deemed possible.

It can be concluded that Mycotal can be used to control whitefly in protected cucumber and tomato crops. It is especially valuable in situations where *E. formosa* gives, temporarily or locally, insufficient control. It can also be used in the integrated control programme against *F. occidentalis*, where every added mortality factor is useful.

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POLLEN AVAILABILITY AND ITS EFFECT ON THE MAINTENANCE OF POPULATIONS OF *AMBLYSEIUS CUCUMERIS*, A PREDATOR OF THRIPS

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Summary

The predatory mite *Amblyseius cucumeris* (Oudemans) is used for biological control of thrips in greenhouses. The success in controlling thrips populations varies in relation to the greenhouse crop. This success is correlated with the maintenance of predator populations: while in cucumber populations invariably decline after predator release, in sweet pepper they remain constant or increase, even in absence of thrips as prey. Since sweet pepper produces pollen in large amounts, whereas cucumber does not, we hypothesize that pollen availability is a determinant of predator population size in periods of thrips scarcity. Laboratory experiments showed that a diet of sweet pepper pollen allows for survival, development and egg production. Greenhouse experiments showed that passive dispersal of adult females is reduced by the presence of pollen on the leaves. Even when all dispersal is regarded as emigration out of the crop-inhabiting predator population, the net population growth under pollen supply still appears to be positive.

1. Introduction

Since its accidental introduction around 1983, the Western Flower Thrips, *Frankliniella occidentalis* Pergande 1895, has become a major pest of crops in European greenhouses. Biological control by use of predatory mites (especially *Amblyseius cucumeris* (Oudemans), previously used against another thrips *Thrips tabaci* Lindeman (De Klerk & Ramakers, 1986; Ramakers, 1988)), appeared quite successful (Gillespie, 1989), but its success varied in relation to the greenhouse crop. While successful in sweet pepper, biological control was less effective in cucumber (Ramakers et al, 1989). Observations showed that predator populations on cucumber invariably declined after predator release, whereas on sweet pepper populations remained constant or increased, even in absence of thrips as prey. This conspicuous difference may be explained by the presence of pollen as an alternative food source for predatory mites. Sweet pepper plants produce a considerable amount of pollen, and pollen from several plant species are known to be suitable in that they allow phytoseiid mites to survive, develop and even reproduce (Overmeer, 1985). Cucumber plants, however, are parthenocarp, thus producing virtually no pollen. Hence, we hypothesize that pollen availability is a determinant of predator population size in periods of thrips scarcity.

Pollen may affect population size through:

(1) increased survival, development and oviposition and
(2) decreased rate of emigration out of the crop.

These effects were studied (1) in laboratory experiments to assess life history components of *A. cucumeris* when fed on pollen and (2) in greenhouse experiments to assess the initial population change in numbers of adult predatory mites after their release on plants with/without pollen. In the first experiments life history was analysed by measuring each of its components separately and calculating the intrinsic rate of increase, as a resultant measure of the potential for population growth. In the second experiments population change was assessed as a resultant of adult mortality and adult dispersal. No information is yet available on juvenile dispersal and on realized population growth on a diet of pollen under greenhouse conditions.

2. Materials & Methods

Life history on a diet of pollen

Life history experiments were carried out on rectangular arenas made of black plastic. Wet tissue was wrapped over the edges of the arena, thereby serving both as a barrier and a water source. An additional barrier of tanglefoot on the tissue prevented the mites from escaping. Folded pieces of plastic served as a shelter, where the mites tend to rest and oviposit. Eggs of one day old were placed on the arena then checked daily for survival, for progress in development, and when adult female, for egg deposition. Oviposition rates per day pertained to live females only. The life-time mean oviposition rate was calculated from these daily oviposition rates. To maintain a sufficient supply of pollen an ample amount of pollen (hand collected from flowers, dried at 30°C for 24 hours, sieved and stored in a refrige-rator) was transferred to the arenas every two days. Three species of pollen were tested as a diet for predatory mites: broad bean (Vicia faba), ice plant (*Mesembryanthemum* sp.) and sweet pepper (*Capsicum annuum*).

Life history components were used to calculate r_m, the intrinsic rate of increase, using the life table method described by Lotka (1925) and Birch (1948).

The effect of pollen on adult emigration and mortality

Changes in the number of adult females of *A. cucumeris* were recorded during two weeks after their release in an isolated three-leaf system on a full grown plant. The three leaves were isolated from the rest of the plant by two Tanglefoot® barriers around the stem. Adult female predators were released on the middle leaf and their population size in the three-leaf system was recorded 3 hours after introduction, then daily during the first four days and finally every two days during the remainder of the experimental period (making a total of 9 observations in 13 days).

A negative exponential curve appeared to provide a good fit to the time series of population censuses. We assume that differences between the intercept and the initial number of predators released are accidental, i.e. not related to the treatments of interest, and therefore irrelevant to the interpretation of the experiments. Hence as a summary characteristic of the population experiments only the slope parameters are used. These parameters are further defined as the (relative) rates of population decrease.

The population observations were done on two host plants (cucumber, sweet pepper) and under various treatments of food supply (thrips larvae (*T. tabaci*) or pollen (broad bean or sweet pepper)). In case pollen were supplied, fresh pollen were added every two days (on the middle leaf only, on the two other leaves or on all of the three leaves; see tables for further specification). In case thrips larvae were supplied the plant had been exposed to ovipositing female thrips starting from 6 days prior to the experiment until the end of the experimental period. From the beginning of the experiment, the plants used in the control experiments were placed in the same greenhouse, and thus exposed to ovipositing female thrips. In these experiments all predatory mites had left the plants before the end of the egg incubation period, so non of them have been able to meet thrips larvae. (Since eggs are laid under the leaf surface they are inaccessible to predatory mites.)

Predatory mites were obtained from two distinct sources: (1) the mass rearing unit of Koppert B.V. (Berkel & Rodenrijs, The Netherlands), where bran mites are used as prey (Ramakers & Van Lieburg, 1982), (2) sweet pepper crops in a greenhouse, where predatory mites had been released by Koppert B.V., early in the season (March, April 1989). The effect of the different sources were tested in experimental series additional to the ones discussed above.

To minimize effects of the plant position in the greenhouse, plants were placed in groups with one for each treatment (with/without pollen, source difference of predators).

3. Results & Conclusions

Table 1: Life history components of *Amblyseius cucumeris* fed on a diet of water and pollen of three different species, at 25°C and 75%RH.

Diet	Development Survival (egg- adult) (%)	Development Duration (egg-egg) (days)	Reproduction (life-time) (eggs/day)	r_m (day^{-1})
Pollen of:				
Vicia faba (broad bean)	>80	13	0.5	0.08
Mesembryanthemum sp. (ice plant)	>80	12	1.0	0.11
Capsicum annuum (sweet pepper)	>80	13	0.9	0.10
Thrips prey (for comparison):				
Frankliniella occidentalis 1)	-	12	1.5	0.13
Thrips tabaci 2)	-	9	1.4	0.15

1) Data from Gillespie & Ramey (1988), but r_m is an approximate estimate by the authors.
2) Data from Dosse (1955), but r_m is an approximate estimate by the authors.

Table 2: The effect of prey availability (larvae of *Thrips tabaci*) on the rate of decrease in the number of adult female predators over a 13 days period (in the beginning of September 1989) following release of 32 gravid females on cucumber plants. The predatory mites originated from Koppert's mass rearing unit (thus with bran mites as a food source).

Treatment 1)	Rate of population decrease (day^{-1}) 2)3)
No arthropod prey	0.829 (1) 0.771 (2)
Thrips larvae as prey	0.166 (1)

1) pollen were not available.
2) The (relative) rate of population decrease was calculated from a time series of 9 observations (excluding initial numbers and zeros) on the population size of adult predatory mites taking the slope of an exponential fit as an estimate.
3) Data are given for two replicate experiments.

Table 3: The effect of pollen availability (broad bean) on the rate of decrease in the number of adult female predators over a 13 days period (in the beginning of September 1989) following release of 32 gravid females on cucumber plants. The predatory mites originated from either of two sources:
MRU: Koppert's mass rearing unit (thus with bran mites as a food source),
SPG: sweet pepper crops in a greenhouse, where predatory mites had been released by Koppert B.V. , early in the season (March, April 1989).

Treatment	Rate of population decrease (day^{-1}) 2)	
	MRU 1)	SPG
no pollen	0.218 (1) 0.184 (2)	0.046
pollen on 2nd leaf 1)	0.159 (1) 0.168 (2)	–
pollen on 1st & 3rd leaf 1)	0.117 (1) 0.080 (2)	–

1) The 2nd leaf was the leaf where the predators were released.
2) Data are given for two replicate experiments.

Table 4: The effect of pollen availability (sweet pepper) on the rate of decrease in the number of adult female predators over an 8 days period (in the second half of September 1989) following release of 24 gravid females on sweet pepper plants. The predatory mites originated from either of two sources (MRU and SPG; see table 3). Their respective abiotic mortality over the same period was assessed in the laboratory to estimate its contribution to the population decrease in the greenhouse.

Treatment	Rate of population decrease 1)2) (day^{-1})		Rate of mortality 3) (day^{-1})	
	MRU	SPG	MRU	SPG
no pollen	0.408 (1) 0.442 (2) 0.289 (3)	0.126 (1) 0.180 (2) 0.083 (3)	0.144	0.031
pollen on all three leaves	–	0.063 (1) 0.068 (2)	–	–

1) Data are given for two or three replicates.
2) The (relative) rate of population decrease was calculated from a time series of 6 observations (see Table 2).
3) The mortality was assessed in the laboratory at 25°C (75%RH) using a (sub)sample of 24 mites. The (relative) rate of mortality was calculated from the survival data, using the slope of a negative exponential fit as an estimate.

The experiments led to the following conclusions:

1) A diet of pollen allows for egg-adult survival, development and egg production with little difference due to the pollen types tested. Development rate, oviposition rate and r_m seems somewhat lower than reported for predators fed on thrips.
(Table 1).

2) Decrease in number of adult female predators after release on cucumber plants is reduced by the presence of larvae of *Thrips tabaci.* (Table 2).

3) Decrease in number of adult female predators after release on plants is reduced by the presence of both broad bean pollen (Table 3) and sweet pepper pollen
(Table 4), especially when pollen is not exclusively present on the middle (= release) leaf.
(Table 3).

4) When predatory mites originate from a greenhouse (rather than directly from the mass rearing unit of Koppert B.V.), population decline proceeded at a much lower rate.
(Table 3 and 4).

5) Experiments on adult mortality in the laboratory suggest that this factor contributes less than 30% to the population decline observed in the various experiments. (Table 4). Also, in the greenhouse experiments, no additional mortality occurred due to entrapment in the tanglefoot barriers. Hence, population decline observed under the various treatments seems largely attributable to dispersal from the plants. Dispersal is likely to be of a passive type in that the predators drop themselves from the leaves. Evidently the mites do have control over the decision whether to stay on the leaf or not.

4. **Discussion**

There are now good reasons to suppose that the availability of pollen is a key factor in explaining maintenance of populations of predatory mites in a crop of sweet pepper plants, where pollen supply is guaranteed throughout the growing season. A simple calculation may illustrate this point. If we make the most pessimistic assumption that all mites observed to drop from the plants in our experiments are lost for the crop-inhabiting population as a whole, than we can recalculate r_m on a diet of pollen by including the relative rate of adult dispersal (equal to 0.07 day^{-1}; see table 4) as an mortality factor additional to the one measured in the laboratory life table study. This inclusion of mortality due to dispersal results in a decrease of r_m from 0.10 to 0.08. Hence, the resulting r_m is still positive and we expect the predator population to increase, though at a low rate, under conditions of pollen availability. Long term greenhouse experiments are required to validate this prediction.

The source of the predatory mites appeared to have a significant effect on dispersal rate and mortality rate of the adults. The reasons for this effect are not yet clear. Differences in age distribution of the predators at the moment of release are unlikely to be the cause. The population sampled from the greenhouse had a high proportion of adults, whereas the mass-reared population is likely have a stable age-distribution. Hence one would expect a higher mortality in the population sampled from the greenhouse. However, the reverse was found.

A number of alternative hypotheses remain to be investigated, to explain the lower rate of decrease in the population originating from the greenhouse:

1) Mites from the mass rearing unit can be in a less good condition as result of a dietary deficiency or an infectious disease (e.g. Nosema sp. (Ramakers et al., 1989)).

2) Mites which have experienced plant stimuli can have a reduced tendency to leave a plant. (Dicke et al. (1990) showed that learning of this kind does occur in predatory mites).

3) Mites are obtained from plants in a greenhouse about 6 months after their introduction. Since the average generation time of the predatory mites (at 20°C under pollen supply) is less than one month, selection can have changed average properties over a number

of generations. When dispersal from the plant results in heavy mortality, selection under greenhouse conditions is likely to favour non-dispersal behaviour and capacities to use (non-animal) food on the plant surface.

Laboratory experiments are required to discriminate between the three hypotheses.

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SIMULATION OF THE POPULATION DYNAMICS OF THE GREENHOUSE WHITEFLY, *TRIALEURODES VAPORARIORUM* AND THE PARASITOID *ENCARSIA FORMOSA*

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Summary

Biological control of greenhouse whitefly with the parasitoid *Encarsia formosa* has been very successful on vegetables since 1970. Much experimental research has been published on this pest insect and its parasitoid. These experimental results will be used in a simulation model of the population dynamics of the tritrophic system host plant-pest insect-parasitoid. The present paper summarizes experimental results published after 1983 and describes the development in modelling of this system.

1. Introduction

Research on greenhouse whitefly control with the parasitoid *Encarsia formosa* had already started circa 1920. After a lapse in interest following the second world war, biological control of this pest received more attention again circa 1970, due to problems of resistance and negative side-effects of chemical pesticides. At the moment, around 120 articles have been published on the pest insect, the parasitoid and/or their relationship as influenced by host plant and environmental factors. Data from these articles will be used to develop a simulation model of the population dynamics of the pest insect and its parasitoid, that includes the relationships between host plant, pest insect, parasitoid and the environment. The aim of this study is to increase the explanatory insight into a tritrophic system in order to improve biological control measures.

2. Summary of new research data

Hulspas-Jordaan and van Lenteren (1989) and Yano et al. (1989a, 1989b) developed a simulation model of the population dynamics of the greenhouse whitefly. A simplified, very user friendly version of the model was developed by van Giessen & Mollema (in prep). The main input for the model are autecological parameters, such as longevity, oviposition frequency, immature mortality, development duration from egg to adult and sex ratio. These parameters have been reviewed by, among others, van Lenteren and Hulspas-Jordaan (1983), Hulspas-Jordaan and van Lenteren (1989) and Yano et al. (1989b). A more complete review will be published containing autecological data from 1915-1989 of greenhouse whitefly and *Encarsia formosa* (mean, coefficient of variation, number of replicates, number of individuals per replicate) at different temperatures, host plants (variety) and host insect stages (van Roermund and van Lenteren, in prep). With this more complete data-set the above mentioned autecological parameters will be described as a function of temperature for each host plant (variety) or host insect stage separately. These functions will be the input for the simulation model. Most literature on autecological parameters was published in 1976-1983. New results, if different from information before 1983, are summarized in table 1 and will be discussed below.

Table 1. Summary of new research data if different from publications before 1983. Fecundity in eggs/female/lifetime, oviposition in eggs/female/day, immature mortality in %, development duration from egg to adult in day, temperature in degrees Celcius. Tv= *Trialeurodes vaporariorum*, Bt= *Bemisia tabaci*.

T. vaporariorum

Fecundity	Oviposition	Host	Temperature	Reference
52-83	4.2-4.6	Sweet pepper	23.4	10
157	-	Gerbera	30.0	2
-	2.4-6.8	Gerbera	15.0-30.0	2
-	2.8-3.2	Sweet pepper	24.4	15
-	1.7-7.8	Sweet pepper	20.0	6
Longevity				
8-18		Sweet pepper	23.4	10
59-97		Eggplant	24	12
22-60		Gerbera	15-30	2
Mortality				
59.8		Tomato	22.9	10
1.8-6.5		Tomato	15.0-25.0	1
37-95		Sweet pepper	23	10,15
4.2-20.2		Eggplant	24	12
3.3-16.1		Gerbera	15-25	1
50.5		Gerbera	30	2
Duration				
27.4-26.6		Sweet pepper	22.9	10
27.2-27.4		Sweet pepper	24.4	15
29.1-32.4		Sweet pepper	20	6
57.0-22.1		Gerbera	15-30	2

E. formosa

Fecundity	Oviposition	Host	Temperature	Reference
				9
290	5.6	L1-P Tv/Bean	20	
Longevity				9
52		L1-P Tv/Bean	20	11
18.7		L3L4 Bt/Bean	25	
Mortality				11
10.2		L3L4 Bt/Bean	25	
Duration				11
9.4-13.5		L1-P Bt/Bean	25	

The **oviposition frequency** of greenhouse whitefly on sweet pepper published by van Lenteren et al (1989), Laska et al. (1986), and van Vianen et al. (1987) is higher than published earlier. This could be due to adaptation of the whitefly to the host plant. A difference has been found between Dutch and Hungarian whitefly strains (van Vianen et al., 1987; van Lenteren et al., 1989). New results on tomato and eggplant are the same as those published earlier. On gerbera results are comparable with tomato, except for at high temperatures where oviposition frequency is higher (Dorsman and van de Vrie, 1989). In general, the variation between individuals used in the same experiment is high: in 57 experiments the average CV (coefficient of variation) is 54 % .

The **immature mortality** varies quite a lot among different experiments and seems to be rather sensitive to the host plant variety (as shown for eggplant by Malausa, 1988) and it varies between whitefly strains (van Lenteren et al., 1989). On gerbera mortality was higher than on tomato, although in that experiment mortality on tomato was quite low (Dorsman and van de Vrie, 1987). Van Lenteren et al. (1989) found a much higher mortality on (another variety of) tomato. The CV between individuals is 19 % averaged over 6 experiments.

The **longevity** of greenhouse whitefly on sweet pepper and eggplant is higher than published earlier (van Lenteren et al., 1989; Malausa et al., 1988). On tomato new results do not differ from previously published data. On gerbera the longevity seems to be higher than on tomato (Dorsman and van de Vrie, 1989). The CV between individuals is 50 % averaged over 64 experiments.

The **developmental duration** on sweet pepper is shorter than in earlier publications (Laska et al. 1986; van Vianen et al., 1987; van Lenteren et al.,1989). Again whitefly adaptation could be the cause. On tomato and eggplant it is the same as published earlier. New results were published for gerbera (Dorsman and van de Vrie, 1989). The CV between individuals is low: 7 % averaged over 26 experiments.

New results for *Encarsia formosa*. The **fecundity** of *Encarsia formosa* as observed by van Lenteren (1987) is high compared with data in most other publications. The host stage parasitized seems to be important; fecundity and oviposition frequency are lower when second instead of third or fourth host instars are offered. The CV between individuals is 32 % averaged from 29 experiments.

Also van Lenteren (1987) observed a high **longevity**. The longevity when emerged from *T. vaporariorum* seems to be the same as when *Bemisia tabaci* acts as host (Lopez Avila, 1988). In general, the longevity is higher without hosts, but with honeydew. The CV between individuals is 34 % averaged over 30 experiments.

There are no new results on **immature mortality** on *T. vaporariorum*. It seems to be higher when *Bemisia tabaci* is offered (Lopez Avila, 1988). In general, mortality is influenced by the host stage; it is lowest in the second and third host instar.

New results on **developmental duration** are not different. The developmental duration seems to be the same when *Bemisia tabaci* is used as host (Lopez Avila, 1988). Here also the host stage is important: the developmental duration is shortest on third and fourth instar nymphs. The CV between individuals is 8 % averaged over 68 experiments.

3. Development of simulation model

The simulation model developed by Hulspas-Jordaan and van Lenteren (1989) and Yano (1989a) is the basis for further development. The model for whitefly population dynamics has been rewritten in FORTRAN and structured into different submodels (subroutines). FORTRAN has been chosen because it is the most widely used computer language in mathematical and physical science; libraries with subroutines have been published and are available. This model will be extended by a model of *Encarsia formosa* population dynamics. These two (sub)models will be coupled by a functional response. As a start the functional response as measured experimentally can be taken (Fransen and van Montfoort, 1987; Yano, 1989). Some parameters, like the searching efficiency and the handling time can be related to environmental factors (temperature) or internal state of the parasitoid (number of mature eggs in ovariole). It is also possible to make a separate model to simulate the functional response by integrating behavioural components at the individual level (e.g. walking speed, host acceptance, oviposition, host feeding). Simulation results generated at different host densities but at constant environmental conditions will be used to derive a functional response. Thus these equations derived by simulation at the individual level will be input for the model at the population level. In this way a simulation model for population dynamics of pest insect and parasitoid at the leaf level can be developed. It will only be used to simulate population dynamics within one patch, in which the insect density can be assumed to be constant (one-patch model).

To simulate the population dynamics at the canopy level, total canopy area will be divided into compartments. For every compartment, population dynamics will be calculated separately by using the first model as subroutine (multiple-patch model). If a vertical differentiation is desired, the canopy can be divided into leaf layers. If computation time appears to become too long, population density as simulated by the one-patch model can be used to fit a function (or table) which will be the input for the multiple-patch model. Insects can be divided among the compartments by a statistical distribution as measured experimentally. As this is unknown for the parasitoid, several distribution patterns can be assumed to study their effect.

A next step in the development of the multiple-patch model is the simulation of the dispersion processes to explain the spatial development instead of describing it by a statistical distribution in order to increase the explanatory character of the model. The data of Noldus et al. (1986) can be used for whitefly but experiments need to be done on the dispersion of *Encarsia* adults.

4. Aim of the modelling approach

The advantages of a simulation model approach to biological control is that it indicates shortages in knowledge, gives a better understanding of complex systems, enables distinction between important and less important factors influencing population dynamics, and allows predictions to be made. In our case it will be used to predict whether or not biological control will be feasible in a certain combination of host plant, pest insect, parasitoid and environment, and if not, to understand which factors are responsible for the failure. Additional possibilities are to extend the model with other natural enemies of whitefly, e.g. the fungus *Aschersonia aleyrodis*, or with other host insects, such as *Bemisia tabaci*.

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RECENT DEVELOPMENTS IN THE CONTROL OF APHIDS IN SWEET PEPPERS AND CUCUMBERS

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Summary

In the Netherlands in 1989 the gall-midge *Aphidoletes aphidimyza* has been used against aphids on 50 ha sweet peppers and 3 ha cucumbers. The results on sweet peppers were satisfying, results on cucumbers were until now not very good. In sweet pepper the aphid parasite *Aphidius* sp. was found naturally and made an important contribution to the control of the aphids. The situation of three glasshouse crops were observed weekly in more detail: one sweet pepper on rockwool, one cucumber on rockwool and one cucumber in soil. Results are presented below. In 1990 the area of treated sweet pepper is estimated to be approximately 200 ha. For sweet pepper and cucumber the combination of *Aphididoletes* and *Aphidius* will be investigated.

1. Introduction

The gall-midge *Aphidoletes aphidimyza* is used as a biological control agent against aphids. The gall-midge lays its eggs near aphid colonies. When the eggs hatch the young larvae will search for aphids. For complete development at least 5 aphids are necessary; but the larvae will kill more if the aphid density is high. Full grown larvae pupate in the ground. Almost all aphid species are preyed upon.

Until a few years ago aphid control was not a real problem in Dutch greenhouses. Pirimicarb was widely used on a wide range of aphid species. Recently the cotton aphid (*Aphis gossypi*) has become a big problem in cucumber crops because it is resistent to pirimicarb and reproduces very quickly. To control cotton aphid chemically broad spectrum pesticides e.g. oxamyl,dichlorvos,cyanide, are used.

These pesticides interfere seriously with IPM in cucumbers.
Recently it was found that even pirimicarb is not as safe as was regarded before. Negative side effects on predatory mites are reported. (v/d Staay, unpubl).

Field experiments with *A.aphidimyza* were started in the 70's in Finland (Markkula et al., 1979), later in Russia and Canada. For further information on *A. aphidimyza* see the review by D.Kulp et al., 1989.

In 1988 we started a small mass-rearing of *A.aphidimyza* and we were able to produce 150.000 pupae/week. Introduction rates were : 0.25 pupae/week/m^2 preventively and 0.5-1 pupae/week/m^2 as soon as aphids were found.

The situation in three glasshouse crops were observed weekly in more detail: one sweet pepper on rockwool, one cucumber on rockwool and one cucumber in soil.
At the end of the season a general inquiry was held with 12 sweet pepper growers.

2. Methods

Eighty sweet pepper plants were inspected weekly. The number of aphids, *A.aphidimyza* larvae and parasitized aphids (by *Aphidius*) were counted per plant.
In cucumber, counting of individual aphids was impossible because of the very high densities. Numbers of leaves with exclusively aphids and number of leaves with aphids and *A.aphidimyza* simultaneously were counted from 30 plants.

In all experiments the plants were evenly distributed over the greenhouse. All leaves of a plant were checked.

3. Results

3.1 Sweet pepper (fig.1)

When the experiment started high numbers of naturally parasitized *Myzus persicae* were found. From May until mid-July the aphid number per plant gradually increased from 1 to 160/plant. *M.persicae* was the dominating species but in the end a small form of *Aphis gossypii* and some *Macrosiphum euphorbiae* were found.

A.aphidimyza was found over the whole greenhouse but only in the larger aphid colonies.

Aphidius mummies were found in aphid colonies as well as solitarily.
After mid-July pirimicarb was sprayed locally within the greenhouse.

3.2 *Cucumber on rockwool* (fig.2)

In April an explosion of *A.gossypii* was found. Very few leaves with *A.aphidimyza* larvae were observed. The grower had used several pesticides during that period e.g. cyhexatin against spider mites.

In June the experiment was stopped.

3.3 Cucumber in soil (fig.3)

From the beginning of April *A.gossypii* was present. In all aphid spots *A.aphidimyza* larvae were found. Until May only in very heavily infested spots it was necessary to use a chemical pesticide.

Unfortunately, in the second week of May parathion had been used against thrips just at the time that the adult midge population was very high.

Some interesting observations were made in this experiment. First it turned out that ants protected aphid colonies and we have actually seen them carrying *A.aphidimyza* larvae away.

Secondly we found that *A.aphidimyza* was able to build up a large population because we found an enormous amount of adult midges hanging in cobwebs. After the parathion treatment no adults were observed anymore.

3.4 General observations

All cucumber growers on rockwool failed to have a satisfying result with *A.aphidimyza* In the beginning many larvae were found but the cotton aphid population could explode within a week. From a heavily infested area winged forms very rapidly infest the whole greenhouse.

When large numbers of *A.aphidimyza* larvae were observed within an aphid spot we unfortunately found masses of full grown larvae drowned in drainwater pools on the plastic or in the waterfilm between two plastic sheetings. However, in august one cucumber grower found high numbers of *A.aphidimyza* larvae although he had not introduced A.aphidimyza for 5 weeks. Out of a sample of leaf-litter taken from the plastic several *A.aphidimyza* midges emerged.

In the same crop parasitized cotton aphids were also found, up to ± 40%. In september several other cucumber growers reported high parasitisation rates with an *Aphidius* sp.

An inquiry with 12 sweet pepper growers produced the following result on the use of *A.aphidimyza*: 9 had good results, 2 moderate and one had to stop because of thrips problems.

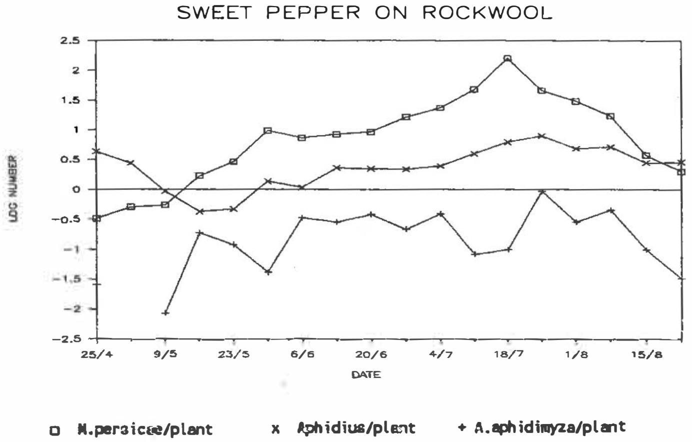

Fig. 1. Mean number of aphids and natural enemies per sweet pepper plant (n=80).

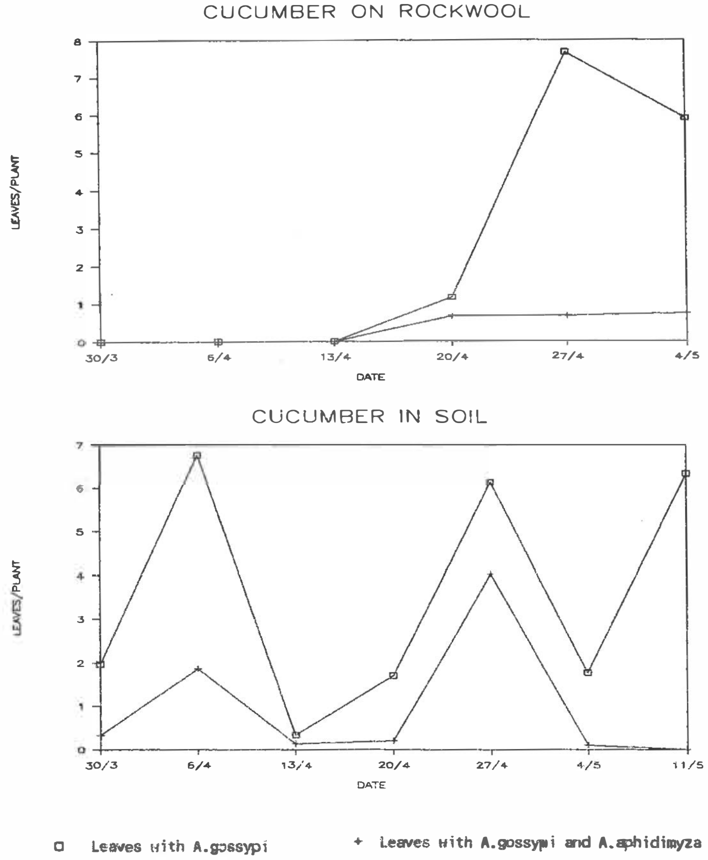

Fig. 2 & 3. Mean number of leaves with exclusively aphids and mean number of leaves with aphids and *A. aphidimyza* simultaneously per cucumber plant (n=30).

4. Discussion and future plans

Aphid control in sweet pepper crops with *A.aphidimyza* gave good results. It seems that the parasite *Aphidius* also plays an important role, especially in parasitizing individual aphids. Attention must be paid to the susceptibility of the adult midges when chemicals are in use.

Compared with *M.persicae* in sweet peppers the reproduction rate of *A.gossypii* in cucumber is much higher. Furthermore no parisites were found at the beginning of the season and in general more chemicals are used in cucumber crops. These three factors are the main reasons that aphid control with *A.aphidimyza* in cucumber crops have failed until now.

For sweet pepper and cucumber crops on rockwool the possibility of providing pupation sites should be investigated. Damp material might be provided along the rockwool mats.

In 1990 we expect to treat at least 200 ha of sweet peppers in the Netherlands with *A.aphidimyza.* At the start of the season introductions with *A.aphidimyza* will be carried out simultaneously with low numbers of parasites. Based upon the 1989 trials we recommend to start preventively with introductions of 0.5 cocoons/m^2 every fortnight, when aphids are found the rate should be doubled.

In cucumbers some *Aphidius* species will be tested on the cotton aphid.

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DEVELOPING A SAMPLING PROGRAM FOR WESTERN FLOWER THRIPS ON GREENHOUSE PEPPERS

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Summary

Five sampling methods were used to investigate the population dynamics of western flower thrips on greenhouse peppers in 2 greenhouses in southern Ontario. The thrips populations were sampled every 2 weeks from May to August in 1989. The inter- and intra-plant distribution patterns for the adult thrips were clumped. The majority of the adults was found on the top third of the plant. The inter-plant distribution pattern for the immature thrips could not be determined from the present analyses. The intra-plant distribution of the immatures, however, was clumped with most immatures also found on the top section of the plant. Among the 4 sampling methods examined for monitoring the population densities of western flower thrips, the plant tapping method was the most consistent in accurately reflecting the changes in the population densities of the adult and immature thrips.

1. Introduction

Greenhouse peppers are a relatively new greenhouse crop for Ontario and in fact, Canada. The western flower thrips (*Frankliniella occidentalis)* is a major pest of this crop in Canada. In Ontario, more growers each year are trying biological control using the predatory mite, *Amblyseius cucumeris,* but chemical control is still the most common control method. Coloured sticky traps, especially blue traps, are the recommended method for sampling western flower thrips on greenhouse peppers (Gillespie & Shipp, in prep.). Leaf samples have also been used to monitor the percent incidence of *Thrips tabaci* and *A. cucumeris* on peppers in the Netherlands (De Klerk & Ramakers, 1986). To our knowledge, however, no sampling methods have been evaluated to determine how accurately these methods reflect the changes in the population densities of thrips on greenhouse peppers throughout the growing season. The present study describes the distribution (population density) pattern of western flower thrips on greenhouse peppers throughout the greenhouse (inter-plant) and on individual pepper plants (intra-plant) in a greenhouse, and determines the accuracy of 4 sampling methods for monitoring the population density of this thrips species on greenhouse peppers throughout the growing season.

2. Materials and Methods

Thrips populations were monitored in 2 commercial growers' greenhouses which were ca. 0.2 ha in size. These greenhouses were located in Leamington, Ontario (42° N latitude). Four sampling methods (blue sticky traps, plant tappings, and blossom and leaf samples) were evaluated every 2 weeks from May to August, 1989. Estimates of the absolute population of the thrips were determined through whole-plant counts. Eight whole plants were removed from each greenhouse each sampling date. Three of these plants were selected as a cluster along a horizontal line that transected 3 rows with 1 plant from each row. The 5 remaining plants making up the sample were randomly chosen throughout the rest of the greenhouse.

All sampling methods were rerandomized for each sampling date. The sticky traps were placed in the greenhouses 24 h prior to sampling. To determine the intra-plant distribution pattern, the individual whole plants were subdivided into 3 sections based on plant height. In the laboratory, the number of adult and immature thrips were counted and recorded by sampling method. Representative samples of adult thrips from each sample were identified to species for 3 sampling dates throughout the season. To determine the inter-plant distribution pattern for thrips on a greenhouse pepper crop, the variability between whole-plant counts of thrips on plants from the 3-plant clusters was compared to that of the other whole plants that were randomly chosen (non-clustered) throughout the greenhouse. Square root and logarithmic transformations were used to stabilize the variance of the whole-plant counts. An one-way random-effect (date) analysis of variance (ANOVA) model was used to determine if the variances were significantly different between plants in the clustered versus the non-clustered plant groups. The intra-plant distribution pattern for the thrips on individual pepper plants was determined by comparing the mean number of thrips found on each of the 3 sections. Percentages for these mean numbers were then calculated based upon the total whole-plant count. To determine how accurately each of the 4 sampling methods monitored the changes in population trends throughout the growing season, the mean number of adult and immature thrips for each sampling method was plotted by date and compared to the mean number of thrips collected from the whole plants. The mean counts for each of the sampling method were then compared to the whole-plant counts over the 8 sampling dates using linear regression analysis.

3. Results and Discussion

Three species of thrips were collected from the 2 commercial greenhouses in 1989. These species were *F. occidentalis, F. tritici* and *T. tabaci* of which over 95% of the identified specimens were the western flower thrips.

To determine the inter-plant distribution pattern for the thrips, the variance components for whole-plant counts of adult and immature thrips within a date in the clustered and non-clustered plants for the 2 greenhouses were compared (Table 1). The within-date variance component was at least 2 times greater for the adults for non-clustered versus clustered plants. This difference was significant at the ($P < 0.001$) for Grower B. Therefore, the inter-plant distribution pattern for the adult thrips was determined to be clumped. More research is necessary, however, before the degree of clumping (i.e., number and density of clumps) can be determined. The variance components for within dates of the whole-plant counts for the immatures did not differ significantly between the clustered and non-clustered plants. For Grower B, the variance component was even larger for the clustered versus non-clustered plants. These results imply that the whole-plant counts for the immatures can vary greatly from plant to plant. It is important to remember that the immatures can only move from one plant to another if the plant parts are in direct contact with each other. Therefore, the 3-plant cluster configuration in the present study may not be the most appropriate cluster configuration to determine the inter-plant distribution pattern for the immature population because 1 plant was always physically separated from the other 2 plants by an aisle-way. On the individual pepper plants, the intra-plant distribution pattern for the adult and immature thrips varied by section (Table 2). The percentage of adults collected from the top section was 2-3 times as great as found on either the middle or bottom sections. The same relationship was also found for the immatures. Therefore, when sampling individual pepper plants the top third of the plant should be included in the sample.

The population trends for the adult and immature thrips as measured by the 4 sampling methods are illustrated in Figure 1 for the 2 growers' greenhouses. For the adult thrips, all sampling methods accurately reflect the population trend that is indicated by the whole-plant counts for both growers. Linear regression analyses for each of the 4 sampling methods against the whole-plant counts provided R^2 values ranging from 0.77 to 0.97 for both greenhouses. The immature thrips were only collected using the plant tapping, and blossom and leaf sampling methods. Of these 3 methods, the population trends as measured by the plant tappings and leaf samples were the most accurate when compared to the whole-plant counts. The R^2 values for the plant tapping and leaf sampling methods ranged from 0.84 to 0.97, while the blossom sampling method had a R^2 of 0.32 in one of the greenhouses.

4. Conclusions

The plant tapping method was determined to be the most accurate of the 4 sampling methods for monitoring the population densities of western flower thrips on greenhouse peppers. The leaf sampling method also accurately monitored the changes in population densities of the western flower thrips throughout the growing season. The major problem with the use of this method is that a large number of samples need to collected because this sampling method seldom collected more than an average of 1 adult thrips per leaf even in peak population counts of 100 thrips per whole plant. The blossom sampling method was satisfactory for monitoring the changes in population densities of the adults, but gave conflicting results for collecting immature western flower thrips. More research needs to be done to determine why the blossom samples only resulted in a R^2 of 0.32 for one of the growers while the R^2 value for the other grower was 0.78. The blue sticky traps were adequate for monitoring the population changes for the adult stage, but this sampling method failed to trap any immatures. The results from the present study will be used to develop a comprehensive sampling program for western flower thrips on greenhouse peppers.

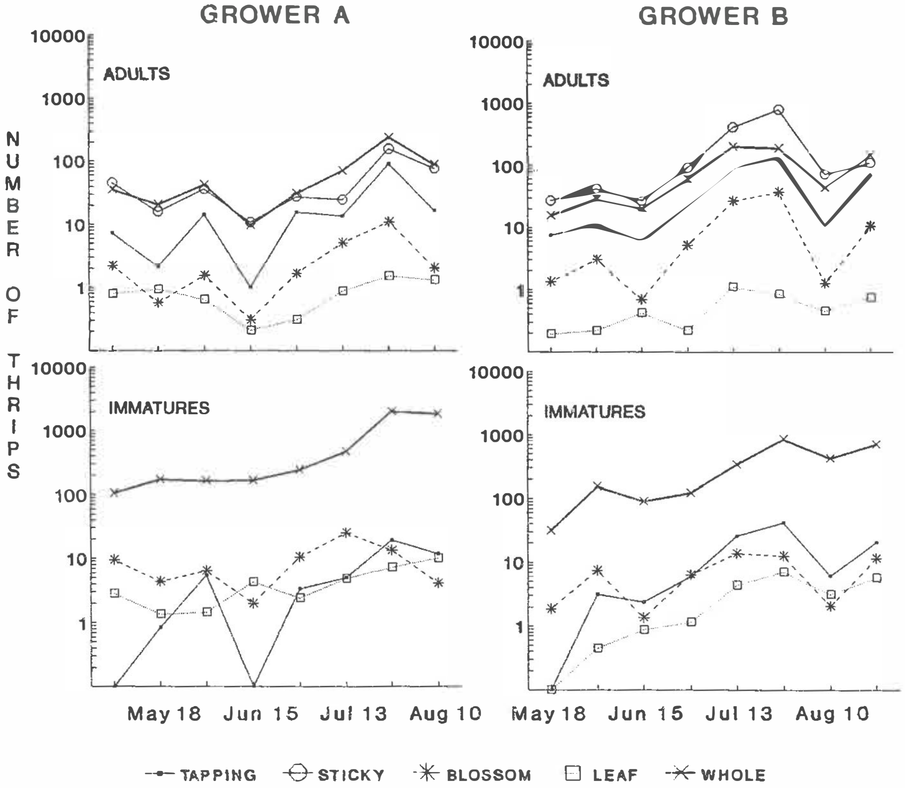

Fig. 1. Population trends of adult and immature thrips determined by 5 sampling methods at 2 greenhouses from May to August, 1989

Table 1. Variance component analysis for the whole-plant counts for adult and immature thrips on greenhouse peppers at 2 growers from May to August, 1989

Grower	Clustered Plants		Non-clustered Plants	
	Adult V.C.[1]	Immature V.C.	Adult V.C.	Immature V.C.
A				
within dates	0.12	19.73	0.22	29.74
between dates	1.02	154.22	0.76	213.60
B				
within dates	1.09[2]	23.28	7.41[2]	18.79
between dates	10.38	51.34	22.54	82.02

[1] V.C. is variance component for whole-plant counts that were stabilized using logarithmic transformation (Grower A adults) or square root transformation (Grower A immatures and Grower B).

[2] V.C. between clustered and non-cluster plants differed significantly; $F_{16,32}=6.82$; $P < 0.001$.

Table 2. Mean number of adult and immature thrips collected from individual greenhouse pepper plants that were subdivided into 3 sections at 2 greenhouses over 8 sampling dates in 1989

	Plant Section					
	Top		Middle		Bottom	
Grower	$\bar{x}$	± SE (%)[1]	$\bar{x}$	± SE (%)	$\bar{x}$	± SE (%)
A Adults	14.08	2.57 (20)	17.26	3.42 (26)	35.62	4.98 (54)
Immatures	99.57	20.78 (15)	193.55	35.33 (31)	337.21	54.98 (54)
B Adults	13.50	2.35 (15)	12.91	1.48 (15)	62.19	9.75 (70)
Immatures	64.53	9.97 (18)	82.41	10.28 (24)	202.84	24.94 (58)

[1] Percentage of the total whole-plant count.

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THE EFFECT OF A PLANT-DERIVED ANTI-FEEDANT ON *TETRANYCHUS URTICAE* AND *PHYTOSEIULUS PERSIMILIS* : "A FIRST LOOK"

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Summary

The beta-acids from hops showed significant anti-feedant and anti-oviposition activity against the two-spotted spider mite *Tetranychus urticae*. Its predator, *Phytoseiulus persimilis*, was relatively unaffected by the beta- acids, showing only a small reduction in the number of eggs laid. The possible use of anti-feedants in pest control is briefly discussed.

1. Introduction

The present trend in pest control is away from traditional agrochemicals and towards the use of less toxic compounds, such as semiochemicals (Pickett, 1988). Although still a minor component of pest control, the use of semiochemicals such as pheromones and allomones, which affect the behaviour of the pest, will undoubtedly increase. Among these chemicals are the anti-feedants, often derived from plants. This preliminary study was carried out to look at the possible effect of an anti-feedant against *Tetranychus urticae* Koch., the two-spotted spider mite and the predatory mite *Phytoseiulus persimilis* Anthias-Henroit. *T. urticae* is often effectively controlled by *P. persimilis* but in some situations the predator is ineffective: e.g. at temperatures above 30°C; on some types of host plant; or where certain cultivation methods are used. This work forms part of a much larger project which is studying the use of semiochemicals against several pests of protected crops.

2. Methods

T. urticae and *P. persimilis* were cultured on French beans in a small glasshouse at a minimum temperature of 20°C. The antifeedant material used comprised the hop (*Humulus lupulus* L.) beta-acids in ethanolic solution. Ethanol was used as the control treatment during this study. No phytotoxic effects were observed at the rates of beta-acids and ethanol used.

2.1 Experiment 1. Anti-feedant and anti-oviposition activity of *T. urticae* in the laboratory.

Perspex rings (30 mm diameter x 20 mm high) were stuck, using low- melting point wax, on to the abaxial surface of severed French bean leaves such that a prominent vein crossed the centre of the ring. Half of the leaf within the ring was painted with 250 μl of beta-acids at one of four concentrations (0.1, 0.032, 0.01 and 0.0032%). The other half was painted with ethanol. Ten adult female *T. urticae*, removed at random from a glasshouse culture, were placed within each ring and a glass coverslide sealed over the top. The leaves were placed on damp cotton wool and kept at 20°C and 16 hr. Light : 8 hr. Dark photoperiod. At daily intervals, for up to 9 days, the number of mites, eggs and damage indix (Hussey & Parr, 1963) on each half of the leaf surface was recorded. Mites on the perspex ring were also recorded. Ten replicates were used for each concentration and the experiment was done twice. Data from both experiments were combined and analysed using a binomial analysis.

2.2 **Experiment** 2. Intrinsic rate of increase of *T. urticae*.

Adult female mites were confined to an ethanol treated bean leaf for 6 hours to obtain eggs of a known age. Immediately after hatching, 15 larvae were transferred to a bean leaf sprayed with 250 µl of 0.1% beta-acids, using a Potter tower (Potter, 1952), or to leaves treated with ethanol. The time taken to develop into adults was recorded and the mites were then left for an identical time period during which the number of eggs produced was recorded. The intrinsic rate of increase (r_m) was then calculated (*cf.* Wyatt & White, 1977). Each treatment was replicated 10 times.

2.3 **Experiment 3.** Anti-feedant, anti-oviposition and dispersal of *T. urticae* in the glasshouse.

French bean plants, at the first two true leaf stage, were arranged in plots of 5 x 5 plants in a small glasshouse. Two plots of plants were sprayed with 1 ml (equivalent to 10 l/ha) of 10% beta-acids using an electrostatic rotary atomiser: the APE-80 (Arnold & Pye, 1980). Two other plots were sprayed with ethanol. 50 adult female *T. urticae* were placed on the centre plant of each plot 1 hour after spraying. The numbers of mites and eggs on each plant were recorded 7 days later. Data were subjected to a square-root transformation before analysis.

2.4 **Experiment 4.** Effect on survival and oviposition of *Phytoseiulus persimilis*.

French bean leaves with known numbers of *T. urticae* eggs were sprayed, using a Potter tower, with 250 µl of 0.1% beta-acids. Fifteen 12 hour old *P. persimilis* and 30 larvae and protonymph *T. urticae* were placed on each leaf. Any *T. urticae* missing were replaced at daily intervals, to maintain a standard predator-prey ratio, and deuteronymph *T. urticae* were replaced to prevent adult emergence and egg laying. The numbers of *P. persimilis* and *T. urticae* mites and eggs were recorded on day 7. Treatments were replicated 4 times and the experiment was done twice. Data from both experiments were combined and subjected to a square-root transformation.

3. Results

3.1 Experiment 1

Significant deterrency of adult mites was seen at all concentrations of beta-acids (Table 1). However, the effects were not consistently related to either the concentration of beta-acids or the time after treatment. Oviposition was significantly reduced on the beta-acids treated surface at all concentrations, particularly during the first two days after treatment (Table 1). Feeding damage was significantly reduced at all concentrations and for at least 6 days (Table 1).

3.2 Experiment 2

The time between hatching and first reproduction was 10 days on beta- acids treated leaf surfaces and 9 days on ethanol treated controls. Total egg production by mites confined to beta-acids treated surfaces was 375 compared to 1213 from those on ethanol treated leaves ($P < 0.001$). The intrinsic rate of increase on the ethanol treatment was 0.257 and on the beta-acids treatment it was 0.193.

3.3 Experiment 3

The number of mites remaining on the beta-acids plots was significantly ($P < 0.05$) lower than on the ethanol treated plots 7 days after treatment (Table 2). Significantly ($P < 0.01$) fewer eggs were also laid on the beta- acids treated plants compared to the ethanol controls (Table 2). On both treatments the mites had only dispersed to two or three other plants.

Table 1. The mean number of mites and eggs and mean damage recorded on beta-acids (B) and ethanol (E) treated leaf surfaces.

Day	Concentration of beta-acids (%)											
	0.1			0.032			0.01			0.0032		
	B	E		B	E		B	E		B	E	
Mites												
1	2.1	3.3	ns	1.3	3.3	***	2.1	3.9	**	1.3	2.9	***
2	2.8	4.1	*	2.0	2.9	*	2.4	4.0	*	2.5	3.0	ns
3	4.4	3.3	ns	1.8	3.1	*	3.2	3.0	ns	2.9	4.3	ns
5	2.6	3.1	ns	2.6	3.6	ns	2.2	3.2	*	3.7	3.4	ns
6	3.0	3.5	ns	1.1	2.9	***	2.9	2.9	ns	2.6	4.2	ns
9	1.1	2.7	**	-	-	-	2.9	4.4	ns	2.7	4.4	ns
Eggs												
1	3	11	***	1	9	***	7	8	ns	2	7	***
2	11	22	***	6	15	***	12	21	*	5	12	***
3	352	410	ns	99	229	***	308	317	ns	147	178	ns
5	251	339	ns	246	252	ns	189	417	***	389	410	ns
6	712	777	ns	203	351	ns	552	514	ns	442	515	ns
9	55	118	ns	-	-	-	65	143	**	359	264	***
Damage index												
1	0.1	2.1	***	0.1	2.2	***	0.1	2.7	***	0.2	1.8	***
2	0.3	3.4	***	0.5	2.9	***	0.4	3.2	***	0.9	2.5	***
3	0.4	4.1	***	0.9	3.6	***	1.2	3.6	***	1.2	3.0	**
5	1.2	4.9	***	2.2	4.6	**	2.3	4.0	**	1.9	3.9	***
6	1.1	5.2	***	2.1	5.4	**	2.4	5.6	**	3.2	4.9	*
9	4.5	6.0	*	-	-	-	4.9	5.8	ns	5.2	5.3	ns

*** P < 0.001, ** P < 0.01, * P < 0.05, ns not significant.

Table 2. The mean number of mites and eggs per plot of bean plants 7 days after treatment with beta-acids or ethanol (Experiment 3).

treatment	adult mites	eggs
control	35.0	700
beta-acids	21.5	215
s.e.d.	8.05	47.9

3.4 Experiment 4

The number of eggs laid by *P. persimilis* was lower on the treated leaves (Table 3), although the difference was not significant. The mortality of *P. persimilis* was zero on the ethanol treated leaves and between 4 and 5 % on the beta-acids treated leaves.

Table 3. The mean number of eggs produced by *Phytoseiulus persimilis* when confined, with *T. urticae*, to beta-acids or ethanol treated leaves. (Experiment 4).

	eggs	s.e.d
control	31.9	5.27
beta-acids	24.1	

4. Discussion

This preliminary study has shown that hop beta-acids have significant deterrent activity against *T. urticae* causing reduction in feeding damage and in the numbers of eggs laid. Mansour, Ascher & Omari (1987) have shown that extracts from Neem seed have similar effects on *T. cinnabarinus*. In some situations the anti-feedant activity could be sufficient to control the mite by itself, but in most cases additional control measures are likely to be necessary. Beta-acids offer the opportunity to significantly reduce the increase rate of the mite and thereby allows more time for control decisions to be made and, more importantly, more time for the chosen control agent to be effective. They are relatively harmless, at least in this short study, to *P. persimilis* and could be used in conjunction with the predator. At temperatures in excess of 30°C, *P. persimilis* moves away from the more exposed apical foliage to areas of shade lower down the plant, enabling the *T. urticae* populations to increase rapidly. A ULV application of beta-acids to these apical areas, such as can be achieved effectively with an electrostatic sprayer, may repel the *T. urticae* down the plant to where the predator is active. Many other potential strategies for manipulating the mite populations to the advantage of the grower are possible.

The use of anti-feedants as practical pest control agents requires considerable experimentation and development. Once active compounds have been found they require economic extraction or synthesis techniques to be established, field trials and full registration clearance. However, the potential for anti-feedants is enormous and many novel strategies for their use with chemical and microbial insecticides and with natural enemies are being developed.

Acknowledgements

We are grateful to Dr. R.J. Wilson (Steiner Hops Ltd.) for supplying the hop beta-acids and to B. Pye (IACR - Rothamsted) for the APE-80 sprayer. We thank John Fenlon for statistical assistance.

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WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* (PERGANDE), IN GREENHOUSE CUCUMBERS IN ALBERTA, CANADA

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Summary

Western flower thrips, *Frankliniella occidentalis* (Pergande), was first reported as a pest of greenhouse cucumbers in Alberta in 1983. It has caused major production losses and jeopardized biological control programs for other greenhouse pests. The predatory mite *Amblyseius cucumeris* (Oudemans) has been investigated in commercial operations since 1986 and shown to be a potentially effective predator for this thrips. Five introductions during late March and throughout April in 1989 were sufficient to maintain acceptable control in most cases, and in an integrated control program with other biologicals gave positive economic returns of >20% compared with a pesticide program. The native pirate bug *Orius tristicolor* (White) has shown initial promise as a supplementary biological control agent and merits further investigation.

1. Introduction

Greenhouse cucumber crops in Alberta traditionally have been subject to the same pests that occur in other parts of the temperate world: primarily two-spotted spider mite, *Tetranychus urticae* Koch, and greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), with occasional outbreaks of fungus gnats, *Bradysia* spp., and mid- to late-season influxes of onion thrips, *Thrips tabaci* Lind. In 1981, most vegetable growers readily adopted a biological pest management program for whitefly and spider mite (Kharbanda 1981), when supplies of *Encarsia formosa* Gahan and *Phytoseiulus persimilis* Athias-Henriot became available through Applied Bio-Nomics, Sidney, British Columbia. In 1983, unusually severe thrips damage to a cucumber crop at the Alberta Horticultural Research Center in Brooks, Alberta drew attention to the presence of a new pest, the western flower thrips, *Frankliniella occidentalis* (Pergande). Although this species is native to Alberta (Heming 1985), it had not been reported previously as a pest in greenhouses. In fact, the color form of the greenhouse-infesting western flower thrips differs from the native type (B.S. Heming, personal communication), suggesting a non-native strain.

In southern Alberta, there is a concentration of over 40 greenhouse operations within the adjoining communities of Redcliff and Medicine Hat. These are mostly small, family operations of approximately 2000 m^2, located in close proximity. In 1984, four of these growers reported difficulty controlling thrips. By March 1985, several growers were unable to control an early thrips outbreak with the standard diazinon ground treatment. By late summer, thrips had spread to nearly all operations, causing both leaf damage and major losses due to scarring and curling of fruit.

In 1984, research trials were initiated in Brooks, testing foliar sprays of *Verticillium lecanii* (Mycotal®) and avermectin (Avid®), and ground sprays of bendiocarb (Ficam®). Further trials with various pesticides were conducted in 1985 and 1988, the results of which are reported elsewhere (Steiner 1984, 1985a, 1985b, 1985c, 1988a, 1988b, 1988c, 1988d; Steiner and Hughes, 1985a, 1985b, 1985c). Although some effective pesticides were identified, none was considered suitable for integration with a biological control program. In any case, resistance to the few pesticides registered developed rapidly and was confirmed in bioassays conducted in 1988 (Steiner 1989), precipitating demand by growers for a biological solution.

During a 1985 study in a northern Alberta greenhouse near Goodrich, two native predators were observed feeding on a mixed-species thrips population. These were identified as the predatory mite, *Amblyseius iroquois* Chant & Hansell, and the pirate bug, *Orius tristicolor* (White). Attempts by Applied Bio-Nomics to rear *A. iroquois* using storage mites as hosts in bran were not very successful, although this predator was found to be as effective as *A. cucumeris* (Oudemans) (S. Johnson, pers. comm.). In 1986, supplies of *A. cucumeris* became available from Applied Bio-Nomics and it was evaluated against western flower thrips in a preliminary trial in a small commercial greenhouse in Morinville, Alberta. Although initial results were not promising, information on distribution characteristics and sampling procedures for thrips and predatory mites was obtained (Steiner 1990, in press). Additional information was collected in several commercial greenhouses in Redcliff in 1987. A fall introduction program in that year was unsuccessful. This was later attributed to *A. cucumeris* entering a non-reproductive diapause. By late August, *A. cucumeris* populations declined substantially, despite the presence of numerous thrips. The program was expanded in 1988 and 1989 to evaluate *A. cucumeris* on a larger commercial scale.

2.1 1988 Research trials

The objectives of the 1988 program were: 1) to assess the effectiveness of *A. cucumeris* against western flower thrips in greenhouse cucumbers, and 2) to establish an economic threshold for western flower thrips in greenhouse cucumbers.

Details of the 1988 trials, which were funded under an Alberta Agriculture Farming for the Future grant, are published elsewhere (Steiner 1989). Sixteen operations were monitored weekly from April to September during the main crop period. Of these, seven used only pesticides and nine primarily biological control agents. *A. cucumeris* were released in bran from February until late May or late June, at rates from 50-100 per plant weekly during the critical period of April to June, and in lesser numbers before this. On average, fifteen introductions were made for a total of 1145 predators per plant.

In general, *A. cucumeris* established well in all greenhouses into which it was introduced, maintaining thrips at low populations or reducing them to acceptable levels when they were high initially. After April, the level of control was comparable to that achieved by frequent pesticide applications. *A. cucumeris* were slow to establish prior to mid-April; this was attributed to diapause and was of some concern since market prices are higher at this time. Powdery mildew was unusually severe; the need to preserve biological control agents interfered with effective mildew control in some cases. Sulphur proved much safer than benomyl:mancozeb mixtures but was less effective against powdery mildew.

Predator distribution is believed very important to the success of control. The mites do not spread rapidly between plants, and rarely across rows. Predators generally need to be as well-distributed as thrips larvae before thrips population reductions will occur. A preliminary economic threshold of 9.5 thrips larvae or 1.7 adults was developed for leaf damage. The damage:yield loss relationship used was based on work by Hussey & Parr (1963) with spider mites, where yield loss occurred when 30 percent or more of the leaf surface was damaged. The relationship between early fruit damage and thrips density was less clear, probably because environmental effects play a significant role in determining severity of damage. Comparison of production figures between growers using primarily biological control agents and those using pesticides indicated significant economic advantages (>20% increase in yield) for the non-pesticide users. To facilitate monitoring, a presence-absence sampling table was developed relating the percentage of leaves infested to numbers of *A. cucumeris* or *F. occidentalis* per leaf. Both thrips and predators were shown to have a clumped distribution (aggregation index was 1.62 for thrips larvae, and 1.31 for both thrips adults and *A. cucumeris*).

2.2 1989 Research trials

Our main objective in 1989, having demonstrated in 1988 that *A. cucumeris* was potentially an effective predator for western flower thrips, was to reduce the number of introductions of *A. cucumeris* to a level growers could afford. Because of the problems with diapause before April, growers were advised to do a good fall clean up and use endosulfan (Thiodan®) if necessary to keep thrips at low levels until April. *A. cucumeris* populations can survive even direct treatments with this pesticide, whereas methomyl (Lannate L®) and deltamethrin (Decis®) eliminate them and leave long-lived, harmful residues (M. Steiner, unpublished data). Five introductions of *A. cucumeris* were made, beginning 22 March and ending 24 April 1989, for a total of 500 per plant. The predators were slow to establish before late April. This may have been weather-related (April was cool and cloudy), or a combination of diapause requirements and the need for an establishment period of about four weeks while the predators adjusted to their new surroundings and food source. The shortened introduction period did not affect the level of thrips control relative to 1988. If thrips populations are low before April (< 1 larva/leaf), and no major disrupting factors such as incompatible pesticides are used, *A. cucumeris* should maintain thrips below economic threshold levels and respond to thrips population increases without needing subsequent routine introductions. In a grower survey conducted in December 1989, 60 percent of growers who used *A. cucumeris* indicated they were reasonably satisfied with the level of thrips control achieved by *A. cucumeris*. Over 90 percent of 22 growers polled indicated they would adopt a biological control program in 1990.

Current recommendations for 1990 in Alberta require a minimum of four introductions of 50-100 predators per plant, two during late February and early March, and the others during late March and early April. All plants should receive predators at each introduction to ensure good distribution throughout the crop. Where thrips populations are already high in April, unacceptable fruit damage and yield loss may occur before the predators can reduce thrips populations to a non-economic level.

2.3 Future Research Plans

As mentioned previously, in 1985 *O. tristicolor* was found feeding actively on thrips in a northern Alberta greenhouse. In 1988, this predator, along with *Nabus* spp., was found commonly from May onwards in some Redcliff greenhouses that were not using pesticides. In 1989, they did not enter greenhouses in appreciable numbers until July, dispelling questions raised in 1988 about whether *A. cucumeris* or *O. tristicolor* were mainly responsible for controlling the thrips. Several releases of field-collected *O. tristicolor* (from alfalfa, *Medicago sativa* L., in bloom) were made into greenhouse cucumbers and one pepper crop in both 1988 and 1989. Thrips populations and fruit damage declined substantially and rapidly in several cases. This was difficult to attribute directly to *O. tristicolor*, since few were retrieved with the sampling procedure employed (primarily visual examination and leaf washing of middle strata leaves). Laboratory-reared *O. tristicolor* are now available in limited quantities from Applied Bio-Nomics. It is our intention to evaluate distribution characteristics, sampling procedures, and efficacy of this predator in commercial cucumber and pepper crops in the 1990 season. From preliminary studies in August 1989, we anticipate that *O. tristicolor* and *A. cucumeris* will be complementary rather than combative.

Acknowledgements

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DISPERSAL OF THE GREENHOUSE WHITEFLY, *TRIALEURODES VAPORARIORUM* (WESTWOOD), ON THE ROSETTE PLANT GERBERA.

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Summary

Development of biological control of the greenhouse whitefly on Gerbera has recently been initiated in the Netherlands. Two factors could complicate biological control on this crop: (a) the large hair densities on leaves of several varieties may impair searching efficiency of *Encarsia formosa*, and (b) a different plant architecture (rosette shape instead of vertical shape) may influence dispersal patterns of whitefly and *E. formosa*. In this paper results on the dispersal and distribution are described of greenhouse whitefly on Gerbera plants. Adult *Trialeurodes vaporariorum* have a clear preference for the young leaves of Gerbera, both for feeding and oviposition. From the site of emergence adult whiteflies move horizontally to the young leaves in the centre of the plant.

1. Introduction

In most of the important vegetable crops grown in glasshouses in The Netherlands biological control of whitefly is used nowadays. Over the last twenty years the usage of *E. formosa* has increased worldwide up to a level of approximately 2500 ha, and it is still increasing (van Lenteren & Woets, 1988). Biological control in ornamentals, however, has yet to be developed. Research in this area has recently started. The total glasshouse surface for ornamentals equals that of vegetables in Holland (van Lenteren & Woets, 1988). Increasing costs of pesticides, pesticide resistance, extensive pesticide use, visible residues on the plants and health risks while applying chemicals are causing the same problems as in vegetable crops and have lead to a desire for alternative means of pest control in ornamentals (van Lenteren, this volume).

Research on biological pest control in ornamentals was started with the model Gerbera-*Trialeurodes vaporariorum-Encarsia formosa. Gerbera jamesonii* was chosen as the target crop, because only the flowers are marketed and no other plant parts are sold. Therefore possible leaf damage or insects still present on the plant does not result in a reduction in quality or price of the flowers. Further, Gerbera is not a very good host plant for *T.vaporariorum*. The development period of whitefly on Gerbera is as long as that on tomato and longer than on cucumber and egg plant. The mortality on Gerbera is higher than on tomato, cucumber and egg plant, but lower than on sweet pepper (Dorsman & van de Vrie, 1987 and van de Merendonk & van Lenteren, 1978). The poor host-plant quality of Gerbera for whiteflies may make biological control relatively easy. Another reason to choose Gerbera is that they are important cutflowers in The Netherlands; they rank in seventh position in economic value (Griffioen, 1990) and are often exported to other countries.

T. vaporariorum is one of the major pests in Gerbera (Dorsman & van de Vrie, 1987). A lot is known about the biology, population dynamics, biological control and distribution of whitefly in glasshouse vegetables (for a review see Noldus & van Lenteren, 1990). The chalcid wasp *E. formosa* was chosen as a biological control agent for *T. vaporariorum*, because of twenty years of experience with this natural enemy and its known capacity for controlling whiteflies in glasshouse vegetables such as tomato and cucumber (van Lenteren & Woets, 1988).

Based on the host-plant quality of Gerbera one might expect control by *E. formosa* to be easy. We envisage at least two complicating factors, however, (a) the large hair densities on leaves of several Gerbera varieties might hamper the searching efficiency of *E. formosa* and (b) the different plant architecture of Gerbera (rosette shape instead of a vertical one) could influence whitefly and *E. formosa* dispersal. In this article we will only discuss aspects related to architecture. All plants on which biological control of T.vaporariorum is succesfully applied currently are vertically structured. The rosette type architecture might influence the distribution of whitefly and *E. formosa* on the host plant in a different way. The within-plant movement of *T. vaporariorum* adults was described for cucumber (Xu Ru-mei et al., 1984), bean (Xu Ru-mei, 1985) and tomato (Noldus et al., 1985): in these three crops movement was directed vertically. Several hours after emergence of the adults a distinct vertical upwards movement to the younger leaves can be seen (Noldus et al., 1985). The choice of these younger leaves is probably adaptive, because of a better nutritional value. If we expect the same choice for nutritionally better leaves of Gerbera, whitefly adults should move horizontally, instead of vertically, to the centre of the plant where the young leaves are situated.

This paper contains the first results of experiments on the dispersal of whitefly in Gerbera. We also present data on the distribution of immature stages of whitefly in Gerbera. Later we will study the dispersal behaviour of *E.formosa* and analyse whether it is related to whitefly distribution patterns.

2. Material and Methods

2.1 Experiments with standardized plants

Ten unsprayed Gerbera plants (cv. Terra Fame), of 10 weeks old were used. Each plant had eight full grown leaves. The leaves could be classified per plant into three well distinguishable groups; young leaves (6 % of the plant leaf surface of the three classes of leaves), full grown leaves (66 %) and old leaves (28 %) (Sütterlin, unpublished data). The plants were placed 25 cm from each other on a table in a small glasshouse (7.5 m^2). At the stem of each plant near the oldest leaves, 25-50 whitefly adults were released from a glass vial. The whiteflies were collected shortly before the experiment from a rearing on Gerbera. The adults were traced immediately after release and afterwards every hour of the release day, and also 23h after release. After 24h all whiteflies were removed from the plants, and 1-2 days later the plants were checked for presence of eggs. This experiment was done thrice between 06.12.89 abd 21.12.89. The temperature in the glasshouse was about 21°C, the humidity 60%, and the photophase 16h.

2.2 Observations in an old crop

A glasshouse of 50 m^2 contained 214 Gerberas (cv. Terra Fame), (age: seven months) and not as uniformly grown as in the previous experiment. The crop became naturally infested 8-10 weeks before our observations with *T. vaporariorum*. We measured the distribution of adults and immature stages. On 50 plants the number of whitefly adults were counted and the number of 4th instar larvae, pupae and eggs were estimated. The counting occurred between 15.01.90 and 29.01.90. The temperature was about 23°C, and the photophase 16h.

3. Results and discussion

In the first three experiments over 40% of the whitefly adults were found back on the plants during the first counts (table 1). The distribution of adult whiteflies over the three categories of leaves 4-6 hours after release is not at random: when we compare the expected number of whiteflies per class of leaves (based on the total surface area of that class of leaves) with the observed distribution, we find a highly significant difference (table 1). We observe (a) more whiteflies than expected on the oldest leaves which is probably an effect of the release of adults at this site, (b) fewer than expected on leaves of medium age, and (c) more flies than expected on the youngest leaves. A preference for the younger leaves occurred. On the young leaves both feeding and oviposition took place. The highest number of eggs per female per 24 hours were laid on the youngest leaves: almost 50 percent of the eggs were found on the two youngest leaves. Detailed data of these experiments will be published elsewhere (Sütterlin in prep.).

The whitefly adults in the older Gerbera crop were also concentrated on the younger leaves. The data in table 2 give the expected percentages of whiteflies based on the surface area of all leaves of a certain age class and the observed percentages. The high percentage observed on old leaves is in this case caused by whiteflies emerging from pupae present on these old leaves.

Table 1. Expected and observed distribution of whiteflies over young, middle and old leaves after 4-6 hours in a relatively young crop; combined data of three experiments. Number of whiteflies released: 1000. Number of whiteflies found back: 450.

leaf class	young	middle	old
number of leaves:	6	12	6
Expected number of indiv. per class:	25.3	295.3	128.4
Observed number of indiv. per class:	64	221	165
Chi-square = 88.9	p< <0.001	df = 2	

Table 2. Expected and observed distribution of whiteflies over young, middle and old leaves in a relatively old crop.

Leaf class:	young	middle	old	total
Number of leaves:	131	494	271	896
Expected % of indiv. per class:	5.7	65.8	28.5	
Observed % of indiv. per class:	28.9	43.4	27.7	
Total number of individuals:	2868	4308	2756	9932

4. Future research

We will continue this research on varieties differing considerably in leaf hairiness to see if hairs influence whitefly distribution. When the whitefly distribution is known, studies on dispersal of *E. formosa* will be done, including experiments to study the effect of leaf-hair density on the searching efficiency of the parasite. Finally, experiments under commercial conditions are planned to develop a practical biological control strategy for greenhouse whitefly in Gerbera.

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CONTROL OF THE WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* (PERGANDE), WITH A NATIVE PREDATOR *ORIUS TRISTICOLOR* (WHITE) IN GREENHOUSE CUCUMBERS AND PEPPERS IN ALBERTA, CANADA

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Summary

Releases of the native pirate bug *Orius tristicolor* (White) into Alberta greenhouse cucumber and pepper crops during 1988 and 1989 resulted in substantial declines in populations of western flower thrips, *Frankliniella occidentalis* (Pergande), and in damage to immature fruit. This predator has potential as an alternative or supplement to the predatory mite *Amblyseius cucumeris* (Oudemans) for western flower thrips control.

1. Introduction

For several years, western flower thrips, *Frankliniella occidentalis* (Pergande), has been a serious pest of Alberta-grown greenhouse cucumbers and peppers. Effective biological management of other pest species was possible until the introduction of this thrips. With the commercial availability of the predatory mite *Amblyseius cucumeris* (Oudemans) in 1986, biological control prospects for western flower thrips looked promising; however, erratic thrips control with *A. cucumeris* observed during a three-year study in commercial crops, prompted a search for a more effective biological control agent. In 1988, preliminary studies using the native pirate bug *Orius tristicolor* (White) were initiated. This insect is a well-known predator of western flower thrips (Salas-Aquilar & Ehler 1977, Stoltz & Stern 1978, Letourneau & Altieri 1983). In Alberta, it occurs in large numbers in flowering alfalfa (*Medicago sativa* L.), and was observed to enter greenhouses and breed during June and July.

2.1 1988 Research trials

O. tristicolor adults and nymphs were collected by sweep net from alfalfa fields in southern Alberta from early May until the end of October. They were introduced into commercial and research greenhouses, where their effectiveness in reducing western flower thrips populations was monitored weekly. The monitoring method used was the model developed by M. Steiner for estimating thrips and *A. cucumeris* densities in greenhouse cucumbers (Steiner 1989, 1990). Four sites were selected with the number of releases varying from two to eight. Introduction rates of *O. tristicolor* ranged from 0.5 to 7.5 per plant over the duration of the summer crop. In three sites where early introductions were made, more than 70 percent of middle-strata leaves were infested initially with thrips. At one site in Brooks, Alberta, 28 percent of immature fruit was scarred by thrips. Two to three weeks after introducing *O. tristicolor* at this site, the percentage of thrips-infested leaves was reduced to <20% and fruit scarring to <5% (Fig. 1). *Orius tristicolor* was observed on 0 to 50 per cent of leaves monitored over the season, but may have been more numerous in flowers or growing points. Similar declines in thrips densities and fruit damage were evident at the other sites. The season-long reduction in fruit scarring is of particular significance, since this thrips often causes unacceptable (>10%) fruit scarring even at very low populations if plant growth is slow (Steiner 1990). The low introduction rates potentially make this a viable commercial proposition.

Overwintering survival of *O. tristicolor* was evaluated by Applied Bio-Nomics, Sidney, British Columbia, Canada, using late-season, field-collected adults. Most specimens were males which did not survive, suggesting that females overwinter and seek hibernation sites early.

2.2 1989 Research trials

In 1989, one pepper and five cucumber crops were monitored. *A. cucumeris* were released at all sites at rates of 18.5 to 676 per plant, beginning in late March and continuing until early June. They established well at four of the six locations. Two introductions of *O. tristicolor* were also made at each site. In two of the cucumber sites *O. tristicolor* adults reared by Applied Bio-Nomics Ltd. were released in early April at rates of six per plant. In the remaining cucumber sites, adults were field-collected in June and July and released at rates of 0.5 to six per plant. Laboratory-reared *O. tristicolor* failed to establish, possibly due to heavy powdery mildew infestations on the leaves. Field-collected *O. tristicolor* established well and thrips populations were reduced below economic thresholds. In the pepper crop, releases of *O. tristicolor* were made 4 and 21 July 1989, for a rate of 0.6 per plant. A substantial decline in the thrips population due to predation by *A. cucumeris* was evident during late May and June (Fig. 2). Thrips densities continued to decline after introductions of *O. tristicolor* adults, with no apparent impact on *A. cucumeris* populations. This suggests the two predators may be compatible and complementary.

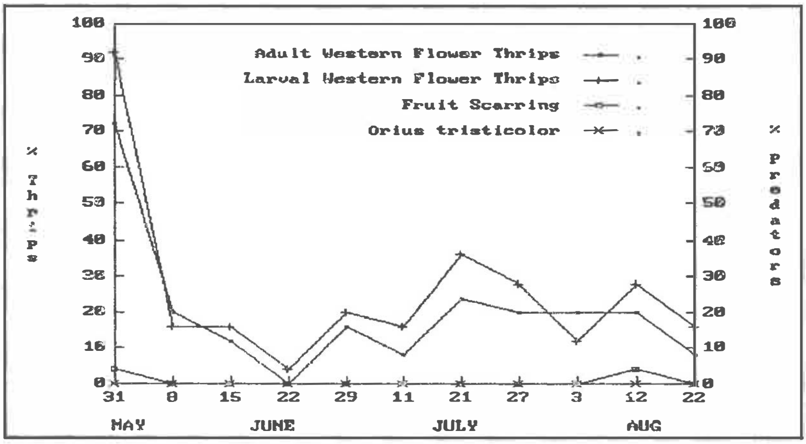

Figure 1. Populations of western flower thrips (*Frankliniella occidentalis*) and minute pirate bugs (*Orius tristicolor*) in relation to percent scarred cucumber fruit in a research greenhouse at Brooks, Alberta, 1988. Pirate bugs were introduced on May 12, 16, 20, 25, 31, June 10, July 4 and July 11 (total - 7.5/plant).

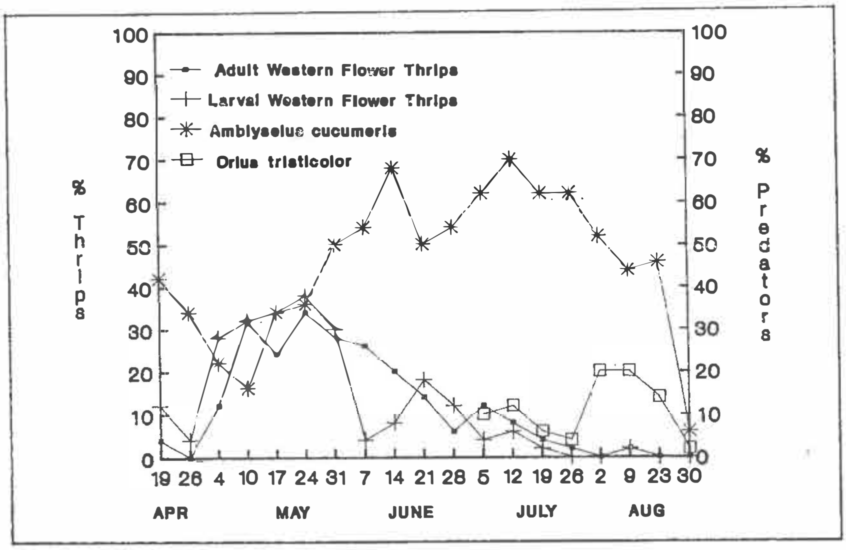

Figure 2. Populations of western flower thrips (*Frankliniella occidentalis*), minute pirate bugs (*Orius tristicolor*), and predatory mites (*Amblyseius cucumeris*) in a commercial greenhouse pepper crop at Brooks, Alberta, 1989. Pirate bugs were introduced on July 4 and 21 (total = 0.6/plant).

2.3 Future Plans

Studies planned during 1990 will determine the distributions of commercially-reared *O. tristicolor* within the greenhouse and within the crop canopy. Distributions and efficacy against thrips will be assessed using scheduled introductions and regular monitoring in commercial vegetable greenhouses.

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A REVIEW OF ATTRACTANTS FOR TRAPPING THRIPS WITH PARTICULAR REFERENCE TO GLASSHOUSES

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Summary

Literature on the use of chemical attractants for trapping thrips is reviewed. The use of chemical attractants with sticky traps for trapping thrips in glasshouses is discussed.

1. Introduction

In the Netherlands methods for thrips control in glasshouses include predatory mites for larvae and "Thripstick®" for pupating instars (Ramakers et al. 1989). Apart from insecticides, which interrupt the biological control of a number of glasshouse pests, there are few effective control methods for adult thrips. Coloured sticky traps catch and kill adult thrips but they appear to contribute little to the overall reduction in thrips populations even when the optimum trap colour is selected. Adult thrips control in glasshouses would be enhanced by improving the efficiency of coloured sticky traps. This paper summarizes research on the use of chemical attractants for trapping thrips and discusses their potential use with sticky traps for thrips control in glasshouse crops.

2. Outside Experiments

The few experiments which concern the use of chemical attractants for trapping thrips have been mostly restricted to simple field bioassays. Howlett (1914) observed that several aldehydes had "a very marked attraction for thrips". However, there were no control comparisons and the thrips were not identified. Morgan and Crumb (1928) listed a number of chemicals to which *Limothrips cerealium* Haliday and *Frankliniella tritici* Fitch were attracted. Although these results were not quantified, a number of aldehydes were said to be particularly strong thrips attractants.

In New Zealand, Penman et al. (1982) discovered the potent attractant, ethyl nicotinate, for the New Zealand flower thrips, *Thrips obscuratus* (Crawford). The number of thrips caught on baited sticky traps often exceeded control catches by a factor of 100 times. Furthermore, the chemical was more attractive than ripe fruit (peaches and apricots), which are hosts to this thrips species. Kirk (1985) investigated a number of chemicals found in flower scents as potential thrips attractants. The scent of anisaldehyde significantly increased the catches of seven species of flower-dwelling thrips by a factor of 3.3 to 8.3, compared to the unscented control. Kirk (1985) did not investigate ethyl nicotinate. Later, Kirk (1987) found that trap size influenced the effect of the chemical attractant. The scent of anisaldehyde increased trap catches of *Thrips imaginis* Bagnall by a factor of 3.3 for small traps, and 1.8 for large traps.

Teulon (1988) compared the attractiveness of several New Zealand thrips species to ethyl nicotinate, benzaldehyde and anisaldehyde. The addition of attractants (including ethyl nicotinate) increased the number of *Thrips tabaci* Lindeman trapped by between 5 to 12 times. However, traps baited with the two aldehydes increased trap catches of *T. obscuratus* by between 20 to 33 times and traps baited with ethyl nicotinate by over 100 times (Teulon 1988). In outdoor experiments in the Netherlands, traps baited with anisaldehyde, benzaldehyde and

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ethyl nicotinate increased the number of *Frankliniella occidentalis* (Pergande) and *T. tabaci* trapped by between 4 to 10 times compared to controls. Benzaldehyde increased the number of *Frankliniella intonsa* (Trybom) by up to 35 times (Teulon and Ramakers 1990).

3. Glasshouse Experiments

The few reports of trapping insects with attractants in glasshouses mostly concern sex pheromones. These suggest that sex pheromones are less effective inside than when used outdoors, possibly due to the lack of air movement inhibiting odour mediated communication (van den Bos 1983), or that they are only useful for monitoring (Foster 1987). However, the mechanisms involved in thrips host selection, including the role of chemicals, are not understood (Kirk 1985, 1987), so the use of attractants for trapping thrips inside should not be overlooked.

In the Netherlands, Teulon and Ramakers (1990) conducted a series of experiments in glasshouses investigating the use of anisaldehyde with coloured sticky traps for trapping thrips. In initial experiments a rectangular hole was cut in the centre of each sticky trap where a vial, containing anisaldehyde or water (control), was secured. There was no significant difference between the number of thrips caught on traps baited with anisaldehyde and controls. In later experiments, however, sticky traps painted with anisaldehyde and alcohol (ratio 2:3) consistently caught significantly more (up to 6 times) female thrips than controls (painted with only alcohol). Differences in male thrips numbers caught on baited and unbaited sticky traps were lower and less significant (Teulon and Ramakers 1990). Furthermore, in these experiments there was some evidence that the presence of an effective anisaldehyde bait in the glasshouse may also have increased the number of female thrips caught on the controls as well. This suggests that an odour-induced visual response is important for host selection with these thrips (Teulon and Ramakers 1990).

4. Discussion

In outdoor experiments the efficiency of thrips traps is known to be influenced by colour (Kirk 1984), size (Kirk 1987), and scent (Penman et al. 1982, Kirk 1985, Teulon 1988, Teulon and Ramakers 1990). Brødsgaard (1989) has shown that colour influences trap catches of thrips in glasshouses and Teulon and Ramakers (1990) have shown that scent is also important. Although Teulon and Ramakers (1990) have clearly shown that the efficiency of coloured sticky traps for thrips in glasshouses can be improved with the addition of chemical attractants, their potential as a method for thrips control was not established. Further experiments are needed to determine the relationship between the number of thrips trapped, the reduction of the total thrips population in the glasshouse, and the reduction of thrips damage to the crop.

There are several other areas where further research may be profitable. It is unlikely that Teulon and Ramakers (1990) established the best method of applying the attractant to the trap or the optimum concentration of the attractant. Alternative methods of application and scent concentrations may improve trapping efficiency. The discovery of new chemical attractants for flower thrips may also increase trap efficiency. Many of the best attractants so far determined are aldehydes, particularly benzaldehyde and anisaldehyde. These chemicals are common constituents of flowers and benzaldehyde of fruits (Kirk 1985, Teulon 1988). It would, therefore, appear that the best chemicals for flower thrips attractants would be constituents of host plant odour, particularly flower scent. However, ethyl nicotinate, by far the strongest thrips attractant so far found is extremely rare in fruit and not recorded from any floral fragrances (Teulon 1988). Furthermore, as a "bouquet" of plant odours is probably involved in thrips host selection, mixtures of chemicals may prove to be more effective baits than single chemicals.

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THE POPULATION GENETICS OF HOST PLANT ADAPTATION OF *TRIALEURODES VAPORARIORUM* (WESTWOOD) ON FOUR DIFFERENT HORTICULTURAL CROPS

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Summary

This paper presents a synopsis of what is already known about host plant adaptation in insects and mites, and summarises the research proposals of Thomas, relating them to the current control situation of *Trialeurodes vaporariorum* Westwood.

1. Introduction

The relative performance of whitefly on several horticultural crops is already known (van Lenteren and Noldus (1990)). Also detailed knowledge is published on the *Encarsia* - *Trialeurodes* relationship from which several ecological models have been constructed. Indeed the control of *T. vaporariorum* by *Encarsia* in glasshouses is currently a very successful practice. However in recent years increasing concern has arisen over the ability of *T. vaporariorum* to adapt to new host plants often at a rapid rate e.g. on paprika (in Hungary), gerbera and chrysanthemum. However the dynamics of this process are unknown and the emperically inferred existence of different whitefly strains has yet to be qualified genetically. Knowledge of this process is of particular importance (especially on ornamentals) as reliance on chemical control decreases and control by plant resistance becomes more important. These experiments have been designed in consideration of the views and work of Via (summarised in her review (Via (1990)) and the experiment of Gould (1979) on *Tetranychus urticae*.

2. Aims of the work

These may be presented as a series of points:

1) Qualification of the existence of different *T.vaporariorum* strains in 'the field' using gel electrophoresis.
2) Laboratory determination of the rate of adaptation of a laboratory strain of *T. vaporariorum* on tomato, cucumber, gerbera and paprika as measured by life history parameters and for a period of ten consecutive generations.
3) From (2) to determine how much of this process is genetic and how much is due to environmental influences.
4) To determine the effect of *Encarsia* on this process.
5) To assess the interaction of this process with insecticide resistance.

3. Methodology

Starch gel electrophoresis will be performed on *T. vaporariorum* samples using a standard methodology and staining for marker isoenzymes.

The main experiment will be done in a climate room using plants that are as standardised as possible. Per host plant two varieties will be used (one for paprika) with two plants of each per generation of whitefly. These will be for tomato; Moneydor and Dimbo, for cucumber; Santa and Corona, for gerbera; Fame and Parade and for paprika Westerlande zoete. The whitefly strain to be used is derived from the stock reared on tomato, variety moneydor/ moneymaker. This strain was used in most of our previous experiments from 1975 onwards.

For tomato, cucumber and gerbera the methodology is as follows. Onto each plant aproximately 30 pairs of adult whiteflies will be clipped (one pair per cage). They will be allowed to lay eggs for 24 hours and then removed. The progress of four randomly chosen families of offspring per plant will then be followed daily. Each day the stage reached by each indivividual will be noted. At the end of the first generation 30 pairs of adults will be collected at random from each treatment and used to infest new plants as before. This will be done for 10 generations. For each generation the fecundity of 10 randomly chosen females may be assessed using the methodology of van Boxtel et al (1978).

Due to the high mortality of whiteflies on paprika a modified method from that given above is required. It is the same as above except that a large stock population will be kept on paprika var. westerlande zoete. Once a month 30 pairs of adults will be taken per plant the progress of their offspring being followed as above. The fecundity of 10 randomly chosen females will be assesed. These results are obviously not directly comparable with those of the other three host plants.

3. Analysis of results

From the 'raw data' we intend to calculate the following parameters per host plant variety per whitefly generation:

(1) 10%, 50% and 90% development times of each stage.
(2) oviposition frequency of adult females
(3) survivorship and mortality of each stage
(4) net reproductive rate
(5) intrinsic rate of increase
(6) an index of adaptation based upon the leslie matrix

Analysis of these parameters will be by ANOVA (within generation analysis) and regression (between generation analysis)

4. Further investigations

At a later stage the effects of *Encarsia* and pesticide resistance on this experimental system will be studied after the data for this first experiment have been analysed

The gel electrophoresis of field populations will yield information on the extent of inbreeding, genetic distance and gene flow in these populations. Electrophoresis will also be done on the experimental populations to assess their genetic variability over time. Thus it is possible to relate the experimental studies to the field situation in the form of some general inferences about the spread of host plant adaptation in the field in relation to the genetic variablility of the populations concerned.

5. Synopsis of the database on host plant adaptation

A database on host plant adaptation reviewing to date 30 published experiments has been produced. From this database several important conclusions may be drawn.

The studies tend to have had the aim of investigating particular aspects of genetic or evolutionary theory, as opposed to investigating a particular pest control problem. The species most commonly studied are mites, leaf miners, aphids and whitefly. Most studies have considered only laboratory or field situations and not a combination of the two. In these studies there tended to be few treatments, few replicates per treatment and few individuals per replicate and hence the experimental designs were often not rigorous in nature. Statistical analysis of the data was predominantly by some form of ANOVA. Very few studies were qualified genetically using any form of biochemical technique. Of all these studies only one (Gould (1979)) was conducted for more than one generation consecutively. Most studies only

assessed adaptation by one parameter which was most commonly net reproductive rate or the overall development time of a generation.

6. Discussion

This study has been designed to provide data that are readily usable and understandable by field workers and the statistical analyses will be kept as simple as possible.

A fundamental knowledge of the population genetics of whitefly is essential to the development of future control strategies, giving a valuable insight into to the process of host plant adaptation (and by inference insecticide resistance). Understanding this process will form the basis for methods of impeding or preventing it.

In view of the proposed freer movement of plants in the EC post 1992, qualification of the existence of whitefly strains is of major importance in relation to plant health and the stringency of its allied inspection procedures.

Finally the data collection and analysis has been specifically designed in consideration of the needs of modellers so that future whitefly-*Encarsia* simulation models may incorporate an evolutionary component thus improving their predictive accuracy.

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GREENHOUSE WHITEFLY, *TRIALEURODES VAPORARIORUM*, AND SPIDER MITE, *TETRANYCHUS URTICAE*, CONTROL IN GREENHOUSE TOMATOES AND CUCUMBERS, WITH SOME EXPERIMENTAL PESTICIDES AND THEIR SIDE EFFECTS ON SOME IMPORTANT NATURAL ENEMIES.

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Summary

The selective pesticides CGA 106630 and DIBeta were tested in greenhouse (tomatoes, cucumbers) and laboratory experiments for their efficacy for whitefly (*Trialeurodes vaporariorum*), spider mite (*Tetranychus urticae*) control, and for their side effects on some beneficial arthropods (*Encarsia formosa*, *Dacnusa sibirica*, *Diglyphus isaea*, *Phytoseiulus persimilis* and *Amblyseius cucumeris*). CGA 106630 demonstrated excellent larvicidal activity to the whitefly and also killed nymphs and adults of *T. urticae*. DIBeta also kills whiteflies to a certain extent,but was very toxic to spider mite nymphs and adults. Survival of *E. formosa* parasites was established in greenhouse tomatoes, while in greenhouse cucumbers, *Aphidoletes aphidimyza* larvae and *P. persimilis* mites were found, despite 2 treatments. Tests to study the side effects of both products on several beneficials revealed no toxicity(mortality). Laboratory and "semi-field" experiments indicate that both products have potentials for use in IPM schemes in greenhouse vegetables.

1. Introduction

The greenhouse whitefly, *T. vaporariorum*, and the two-spotted spider mite, *T. urticae*, may be considered as the main pest organisms in greenhouse tomatoes and cucumbers. Today, the whiteflies can be efficiently controlled with the IGR buprofezin (Applaud)[Van de Veire, M. and Vacante, V. in press] with or without biological control, in tomatoes as well as in cucumbers. In tomatoes the two-spotted spider mite can be controlled with classical acaricides but not with the predatory mite *P. persimilis*. In contrast, *P. persimilis* is very efficient for spider mite control in cucumbers. Next to the aforementioned pests, other pests can occur at damage level. Leafminers, *Liriomyza bryoniae* as well as *L. trifolii*, may severely damage greenhouse tomatoes. The former can be controlled with oxamyl (spray or drench), but L.trifolii has become resistant and is very difficult to control. Biological control with the endoparasite, *D.sibirica*, has great prospects under certain conditions. We have tested the IGR cyromazine for leafminer control and found that the product is very efficient as a spray or drench at low dosages.

Aphids can also occur at pest level: *Myzus persicae* is still easily controlled with pirimor, but *Aphis gossypii* is resistant to the product, and biological control is still in the research stage. Noctuid larvae often cause severe damage in tomatoes and can be controlled with *Bacillus thuringiensis*, but some species are resistant (eg. *Spodoptera exigua*), and cause great problems. From the foregoing, it appears that IPM has progressed considerably,but we are facing new pests now (*Bemisia tabaci*, *Frankliniella occidentalis*, *Liriomyza huidobrensis*), or older ones that have become resistant. Therefore, any means,including chemicals, to improve biological or integrated control, should be considered. Agrochemical industries have recently been developing more specific pesticides, and we have tested the efficacy of some of these for whitefly and spider mite control, and their compatibility with natural enemies.

2. Materials and methods

The candidate pesticides were CGA 106630 (3-(2,6-diisopropyl-4-phenoxyphenyl)-1-tert.butyl-thiourea)(500 SC) from Ciba-Geigy Cie) [Streibert et al., 1988] and DIBeta(1.5% w/w) (ABG-6162A) a bacteriological fermentation product, from Abbott Cie.

2.1 Experiment in glasshouse tomatoes

Young tomato plants (variety: Vision) were transplanted on February 20th, 1989 in grow bags and placed in an isolated commercial greenhouse compartment, in which the temperature was rather high (20-25°C) and R.H. was low (40%). The total number of plants was 32. The plants were attached to wires and grown according to normal cultural practices (irrigation,fertilization, etc.). On February 21st, ca. 250 adult whiteflies, *T. vaporariorum*, were introduced among the plants; this number corresponds to a high infestation level.Spider mite, *T. urticae*, infestation occurred spontaneously; they came from an adjacent greenhouse in which tomato plants were heavily infested. At regular time intervals spider mites(adults, nymphs, eggs) were introduced artificially by spreading infested tomato or bean leaves between the plants(April 4th, 19th, and 26th, and May 16th and 29th). On April 19th, predatory mites, *P. persimilis,* (ca.200) were introduced among the plants, to study the side effects of the pesticide on this natural enemy. The treatments (dose and dates) of the compound are given in table 1. Treatments were carried out on 8 plants. They were sprayed to run-off, using a hand-driven knapsack sprayer (10 liter). The underside of the leaves was also sprayed. Eight plants were not treated. On April 18th, the grower needed to use cyhexatin for spider mite control in an adjacent house; this caused severe mortality of *T. urticae* in our control plot, but this could be corrected by introducing spider mites at regular times. To evaluate the efficiency of the compound, weekly 10-20 leaflets were collected and checked for numbers of whitefly larvae, pupae and parasitized pupae (black pupae) and for nymphs and adults of *T. urticae* and *P. persimilis*.

2.2 Side effects of CGA 106630 and DIBeta on some beneficial arthropods: initial contact toxicity

CGA 106630 (dosage: 0.4 ml A.I./liter water) and DIBeta(0.6 g A.I./liter water) were applied to tomato or bean leaves by dipping the latter in the aforementioned spray solution. After drying, leaflets (diameter: 3cm) were placed in small petri dishes with ventilation gauze in the lid.The insecticide/acaricide bifenthrin (0.02 g A.I./liter) and the acaricide amitraz (0.38 g A.I./liter) were used as reference products. Adult parasites or predators: *D.sibirica*, *E. formosa*, *D. isaea*, *P. persimilis* and *A.cucumeris* were put on the fresh deposits of the compounds and checked for mortality 24 hr later. Control insects were put on leaves treated with water.

3. Results and discussion.

3.1 Experiments in greenhouse tomatoes.

Mortality of whitefly larvae (%), *E. formosa* parasitization, *T. urticae* nymph and adult mortality (%) are given in table 1.

CGA 106630 provided excellent control of the greenhouse whitefly. Mortality of larvae is very high (78%) during the entire growing period, except on May 24th and May 30th, probably due to the limited residual activity of the compound.The compound appears to be compatible with *E. formosa* since black scales were found over a long period;however, further experiments should be carried out to learn about the compatibility, since in this experiment, untreated plants became highly parasitized, and parasites could easily migrate towards the treated plants, in numbers which may exceed the normal number which occur in greenhouses. DIBeta also kills the greenhouse whitefly (larval mortality 51%). Mortality in the control was

24%, due to predation by the *E. formosa* wasps. CGA 106630 and DIBeta gave excellent control of the two-spotted spider mite. DIBeta was so efficient, that only few mites were found on the leaves from April 11th until May 11th. CGA 106630 gave similar results. Both products gave sufficient protection during 3 to 4 weeks.

Table 1. Whitefly and spider mite mortality, *E. formosa* parasitization on different dates in greenhouse tomatoes.

Date	Whitefly larval mortality	Par.(%)	*T.urticae* mortality (%) nymphs	adults
Treatment DIBeta on April 4th and 14th and May 31st (each 0.6g A.I./10 l water)				
April 11th	83.3	0	-	0
April 19th	57.1	5.2	-	-
April 25th	0	25	100	-
May 2nd	10.4	0	-	-
May 11th	82.1	14.3	-	-
May 24th	0	59.1	18.3	0
May 30th	58.3	73.7	1.1	9.6
June 6th	100	80.1	29.6	90.9
Treatment CGA 106630 on April 4th and 14th and May 31st (each 4g A.I./10 l water)				
April 11th	95.2	0	-	-
April 25th	79.4	0	19.1	0
May 2nd	100	0	95.1	100
May 11th	75.0	42.8	100	-
May 24th	41.1	74.6	11.6	13.6
May 30th	21.3	45.8	27.6	7.6
June 6th	94.7	50.0	78.7	78.1
June 9th	100	16.7	75.7	100
Untreated control				
April 11th	8.6	0	-	0
April 25th	66.1	8.5	20.0	85.9
May 2nd	0	39.6	65.3	100
May 11th	22.6	11.5	76.3	22.7
May 24th	5.3	100	36	0
May 30th	56.4	83.3	14.3	0
June 6th	35	79.8	24.2	0

3.2 Experiment in greenhouse cucumbers

Similar experiments were done with CGA 106630 and DIBeta in a cucumber crop. DIBeta did not have a great ovicidal effect on *T. urticae* eggs, while CGA 106630 was toxic to the eggs. DIBeta and CGA 106630 both gave excellent control for nymphs and adults of *T. urticae*.

A. aphidimyza larvae and dead *A. gossypii* were found 2 weeks after the last treatment with CGA 106630 and DIBeta indicating a possible compatibility with the two compounds. Also *P. persimilis* eggs, nymphs and adults were found in the CGA 106630 treatment on many leaves indicating a compatibility of CGA 106630 with *P. persimilis*.

3.3 Side effects of CGA 106630 and DIBeta on some beneficial arthropods

Table 2. Mortality (%) of different beneficials after exposure to CGA 106630 and DIBeta.

Product	*D.sibirica*	*E.formosa*	*D.isaea*	*P.persimilis*	*A.cucum.*
CGA 106630	0	0	20	60	75
DIBeta	17	13	30	85	77
Bifenthrin	100	100	100	-	-
Amitraz	23	64	55	100	95

Although the results in table 2 do not give information on the parasitization or predatory capacity of the beneficials,it can be considered as a fast procedure with an indicative function. It is clear that CGA 106630 and DIBeta do not kill *E. formosa*, *D. sibirica* and *D. isaea*, in contrast to bifenthrin which is harmful. However, for the predatory mites, CGA 106630 and DIBeta exert toxicity, as well asamitraz. According to the toxicity classes as agreed by the IOBC working group "Pesticides and Beneficial Organisms", the products may be considered as moderately harmful, and thus probably compatible with *P. persimilis*, or useful for IPM in greenhouses. However, further experiments, the so-called sequential tests (semi-field, and field tests) should be carried out, to know the harmfulness more accurately.

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INTEGRATED PEST MANAGEMENT IN PROTECTED ORNAMENTAL CROPS

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Summary

The present situation of IPM in ornamentals grown in the United Kingdom is summarised. IPM is expanding mainly because of growers' interest, influenced by pest resistance and the 'green trend' in public life. Expansion of IPM will continue so long as adequate supplies of high quality natural enemies are maintained and expanded. There is scope for better collaboration between distributor/breeder companies and potential for commercial support of the research and development that is needed to develop and publicise the technique. The training of growers and their staff and the development of better introduction and monitoring techniques will help to make IPM work well. IOBC should increase public awareness of IPM and educate retailers that IPM has advantages when selling their products.

1. Introduction

Expansion of IPM into protected ornamentals was forecast at the IOBC workshop at Aalsmeer in 1987 (Wardlow, 1989) and this has indeed occurred in the United Kingdom especially during 1989. Exact data is difficult to obtain but 10-20 ha of various ornamental species were grown under an IPM regime in that year. There are probably a number of reasons for this expansion:

o Some of the major pests are highly resistant to pesticides
o The threat of western flower thrips (*Frankliniella occidentalis* (Perg)) necessitates frequent treatment with insecticides that may harm the crop.
o Breeders of natural enemies are expanding the range of their products and improving their support in the field.
o Retailers of plants are becoming interested in the market potential of products raised with minimum pesticide input.

2. Method of IPM expansion

The Agricultural Development and Advisory Service (ADAS) has begun to create a reservoir of information on the use of IPM in ornamentals in the belief that should there be found an effective natural enemy for western flower thrips, then many growers would be keen to use the technique. However, because information is still limited ADAS entomologists have not promoted IPM. Nevertheless, certain growers have decided that IPM must be made to work effectively and have gone ahead with the technique using whatever information is available. ADAS is closely involved with most of these growers but some liaise solely with the distributors and breeders of natural enemies.

3. Implementing IPM on ornamentals

Growers usually express interest in IPM by seeking programmes for specific crops. Advice on these is sometimes easy to give, eg. poinsettias for which only whiteflies and fungus gnats need be considered. Following success in such specific cases, growers and their staff quickly appreciate the benefits of IPM and begin to consider using it on other crops. The development of *Amblyseius* spp for cucumbers and sweet peppers has helped enormously in designing programmes for ornamentals; these predators are cheap and readily available so that they can be applied liberally especially for the control of western flower thrips. Although there is considerable risk working with these new predators, growers are aware of the risks of failure and their expectations are not too high.

It is apparent that each crop has its own requirements and there is much to learn about introduction rates of the various natural enemies within the package. In most cases ADAS advice hinges on the idea of regular introduction (preferably weekly) of natural enemies in numbers that give 'economic overkill'. Integration of pesticides is always strictly controlled.

4. Design of IPM packages for ornamentals

Knowing the range of pests LIKELY to occur on the crops, ADAS entomologists can list the range of natural enemies and integratable pesticides required. 'Economic overkill' by these components of the IPM programme is then a flexible calculation depending entirely on how much money the grower is prepared to spend on each crops. Initially the wise adviser assumes that there can never be too many natural enemies and advises that the grower should purchase the maximum number possible. Although information is lacking, some provisional rates of introduction of natural enemies have been accepted and these can be used as a working guide. It is important that the grower seeks independent advice on how many to buy until more experience has been gained. Following the schedule it is a simple matter to tabulate each crop's weekly requirements. Some distributors have designed appropriate order forms for this purpose.

5. Limitations to the IPM package

Until recently, the limited range and inconsistency of supply of natural enemies caused problems with IPM. Supplies have improved dramatically but they may be affected by some unpredicted circumstance at any time. Distributors/breeders should be more open about informing growers of such problems when they occur, even if they think that their competitors might gain a temporary advantage. It is most important that IPM retains a good image and distributors/breeders should collaborate more to ensure that the experience is gained.

As IPM develops, it will become evident that the technique will not work satisfactorily on some crops, eg. western flower thrips breeds between the calyx and the base of the flower in *Streptocarpus* so that natural enemies are unlikely to find their prey. In such cases, other techniques such as using bait-plants to attract the pest off that crop will need to be incorporated in the IPM package.

6. Techniques in IPM on ornamentals

Many techniques that can enhance the performance of natural enemies wait to be discovered, but considerable experience has been gained in recent years. The following points are worth consideration by the grower even if he has to change his cultural practice:

- Plant propagators must be encouraged to reveal what pesticides have been applied to stock plants.
- predatory mites must be given every opportunity to find their prey, plants should not be spaced apart without 'bridges' for them to spread.
- Devices should be designed for the correct storage of inactive stages of natural enemies to ensure their successful emergence and distribution.
- Where temperature in the glasshouse are borderline for activity of natural enemies, introduced animals must be placed in the warmest area.
- Monitoring of pests and natural enemies must be done on a regular basis (weekly

minimum), using additional aids such as sticky traps.

- Growers and their staff should be trained in the identification and habits of natural enemies and monitoring techniques. The more scouts the merrier where IPM is used!
- Growers should learn which crops and cultivars are susceptible to the various pests. These can be then given special consideration (ie. more generous treatment) that can enhance the IPM programme. These crops also act as useful indicators of pests during monitoring. Sometimes they can be used to manipulate the pest movement.
- The 'Banker' plant systems should be used wherever relevant.

7. Distributors/breeders of natural enemies for IPM

In the United Kingdom, there are too many companies competing for the small vegetable market though some are expanding IPM in other countries as they search for new business. IPM on ornamentals is therefore a useful market for expanding sales in the United Kingdom. Researchers and advisers must be heeded by the companies if IPM in ornamentals is to succeed and flourish. Full cooperation is this venture should increase business for all companies.

At present, companies compete heavily on price of natural enemies (something the grower likes) but high quality and the consistency of supply is far more important. Cost cutting should not be taken to extremes.

Some companies collaborate in specific circumstances such as in the supply of the more exotic natural enemies or when production facilities break down for some reason. It is hoped that this can be improved eventually, to the point where companies specialise more. It is important however, that variety in the stocks of our natural enemies is maintained including replenishment from the wild to prevent any genetic breakdown in the future.

8. Training in IPM in ornamentals

In the United Kingdom, individual natural enemies have been well publicised so growers are generally aware of what is presently available. There is however, a great need to train nursery managers and staff. During 1990, ADAS will carry out much of this training. The next phase however, is to educate retailers and the general public which is probably best done by IOBC.

9. Prospects for IPM in ornamentals

In 1988 and 1989 IPM was successful on poinsettias (whiteflies), cyclamen (western flower thrips), saintpaulia (tarsonemid mites), *Gerbera* and hibiscus (several pests), begonia (melon-cotton aphid), marguerite (leaf miner) and chrysanthemums (western flower thrips) and a range of plants used in amenity horticulture. Programmes for these crops and others such as fuchsia, geranium, *Impatiens* and bedding plants are proposed for 1990. The use of IPM will continue to expand in spite of the lack of precise information. It is hoped that members of IOBC can find the resources to record their experiences in detail so that firm recommendations can be made in the future.

10. References

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POTENTIAL NEW ADDITIONS TO THE ARMOURY OF NATURAL ENEMIES FOR PROTECTED TOMATOES

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Summary

The predatory midge, *Therodiplosis persicae* (Kieffer) worked well against the spider mites *Tetranychus urticae* (Koch) and *Tetranychus cinnabarinus* (Boisduval) infesting tomatoes, but sprays of fenbutatin-oxide have to be integrated with the natural enemy to reduce the hypertoxic damage caused by *Tetranychus cinnabarinus*. The midge completed its life cycle within two weeks in summer producing as many as 14 cocoons per leaflet on mite-infested plants. The predators spread rapidly and established widely in crops within three weeks. Introduction of such a mobile predator is attractive to growers because it saves labour. It therefore has commercial value although until problems with winter diapause are overcome it may be useful only in the summer months.

The egg-parasitoid *Anagrus atomus* (L) occurred naturally (Magill, 1934) in tomatoes infested with glasshouse leafhopper, *Hauptidia maroccana* (Melichar) and parasitized almost 80 per cent of eggs; consequently, the pest never caused serious damage. The market for commercialising this parasite is limited but the pest can be persistently serious of affected nurseries.

Both natural enemies would be useful to growers of tomatoes because they now use bumble bees to pollinate crops and have to be careful using insecticides.

1. Introduction

In the United Kingdom, two recent major developments have altered attitudes towards pest control in protected tomatoes. Firstly, the recent withdrawal of cyhexatin from the market created difficulties with the control of spider mites (*Tetranychus urticae* (Koch) and *Tetranychus cinnabarinus* (Boisduval) against which this acaricide worked so well without harming other natural enemies. Secondly, the advent and expansion of the use of bumblebees to pollinate tomatoes dictate that pesticides should be used only as a last resort and that natural enemies should be used as widely as possible. Two natural enemies that have been known for many years were recently found in glasshouses in southern England and showed that they are potential candidates for mass-rearing. Initial observations on them are described here so that workers in biological pest control can exploit them further should the opportunity arise.

2. The candidates

2.1 The predatory midge, *Therodiplosis persicae*

Extensive observations on this predator were carried out by Roberti (1954). In 1988, a natural immigration of this midge from outdoors was fully effective against an extensive infestation of *Tetranychus cinnabarinus* on tomatoes at the nursery of Mr C Roger in Kent. At the ADAS laboratory in Wye this midge was cultured on *Tetranychus urticae* infesting dwarf French beans for release to a few commercial crops of tomatoes during 1988.

2.2 The egg parasitoid, *Anagrus atomus* (L)

For some years, the tomato crops of Mr D Stapley, a grower in Kent, had been consistently plagued by glasshouse leafhopper, *Hauptidia maroccana* (Melichar) that was usually controlled by heptenophos, an insecticide that harms natural enemies. When bumble bees were introduced for pollination in 1988, heptenophos was not used, yet infestations of leafhopper did not reach to damaging levels. The parasitoid was found to be responsible and was briefly examined to asses its potential.

3. Observations on the candidates

3.1 *Therodiplosis persicae*

From May to September 1988, weekly batches of midge cocoons from the laboratory culture were placed at the rate of 200 per ha into one 0.2 ha tomato crop infested with *T. cinnabarinus* and another 0.2 ha crop infested with *T. urticae*. On one occasion in July and another in August, a sample of 50 leaflets showing symptoms of spider mite feeding were collected from both crops and were examined under a binocular microscope in the laboratory. Because *T. cinnabarinus* damages the crop severely, a spray of fenbutatin-oxide was applied at that site on 6 July, a few days prior to the first assessment.

3.2 *Anagrus atomus*

Adult parasites were accidentally first seen during routine scouting of the crop during July. This prompted closer examination of the undersides of leaves revealing the red parasitized eggs of the leafhoppers. Assessments of the levels of parasitism were done once in July and again during August on 50 leaflets that showed symptoms of leafhopper feeding.

4. Effectiveness of the candidates

4.1 *Therodiplosis persicae*

Results of the assessments are given in Table 1.

Table 1. spider mite infestation and predation by *T. persicae* on tomatoes, 1989-

Site	*Tretranychus urticae*		*Tetranychus cinnabarinus*	
Date of assessment	30 July	22 August	10 July	3 August
Per cent leaflets with spider mites	80.0	28.0	94.0	100
Live mites per leaflet	15.4	0.5	5.4	3.7
Mite eggs per leaflet		0.7	10.4	7.5
Per cent damaged leaflets with midge present	64.8	78.0	34.0	60.0
Numbers of midge larvae or cocoons per leaflet	2.5	2.7	0.4	1.0
Numbers of midge larvae or cocoons on those leaflets with midge	2.7	3.4	1.3	1.7

It was noticeable at both sites that released midges spread rapidly (within three weeks) throughout the crop. At around 21 degrees C eggs hatched within three days. Larvae fed on eggs as well as the active stages and developed into cocoons after one week. Adults emerged from cocoons after a further 7-10 days but they seemed to live only a few days in the crop. The highest numbers of cocoons recorded per leaflet were 14 with *T. urticae* and six with *T. cinnabarinus*.

At both sites, the midge suppressed the spider mites infestation to acceptable levels, though the hypertoxic damage caused by *T. cinnabarinus* was unacceptable in some areas of that crop.

4.2 *Anagrus atomus*

Results of the assessments are given in Table 2.

Table 2. Parasitism of eggs of *Hauptidia maroccana* by *Anagrus atomus*, 1989

Date of assessment	30 July	22 August
Number of non-parasitized leafhopper eggs/leaflet	0.7	0.4
Number of parasitized leafhopper eggs/ leaflet	2.6	0.9
Per cent parasitism	79.0	70.6
Maximum number of parasitized eggs/ leaflet	6	2

The parasite was very effective and restricted the leafhopper infestation to one half of the glasshouse throughout the season.

5. The future of the candidates

5.1 *Therodiplosis persicae*

Breeding the predator proved difficult especially during the winter, this was due to a diapause similar to that experienced with the predatory midge of aphids, *Aphidoletes aphidimyza*. However, on those nurseries where spider mites are a consistent problem, growers would welcome any additional weapon even if it were available only during the summer months. It can be assumed that spider mites will become an increasing problem in tomatoes now bumble bees are used more widely. To be able to release a predator that flies to its prey would be more convenient than having to introduce less mobile species such as *Phytoseiulus persimilis* that have to be placed on infested plants. The predatory midge may also be most useful in ornamental crops where it can be released with no risk of introducing spider mite.

5.2 *Anagrus atomus*

The market for this parasite is small at present although it is of considerable value to those growers suffering the ravages of leafhoppers. Presumably in future, problems with this pest will increase as less pesticides are used ? Leafhoppers can be a considerable nuisance to ornamental crops for which IPM programmes re being developed in several countries.

6. References

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