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PREFACE

This volume contains the precedings of the 8th full meeting of our working group. The idea to publish pre- instead of proceedings developed in the 1980s when the number of participants of our working group increased so fast that it was hard to have all papers read and have useful discussions during the meeting. The meetings are now mainly used for evaluation of recent work and for development of new ideas for research and implementation of integrated control of pests and diseases in protected cultures.

Most of the meetings have been held in West and South Europe, except for one conference which was organized with our colleagues in Central and East Europe: the 1987 Budapest meeting. During that meeting it became clear how important it was to have more intensive contacts with researchers outside the initial greenhouse nucleus in Europe. We were, therefore, very happy that our North American colleagues were willing to arrange a workshop in California, an area with an active greenhouse industry.

This bulletin contains 48 papers and some important shifts in attention can be observed. Some pests are apparently under good biological control without demanding intensive research support after initial studies (e.g. leafminers, some aphid species, spider mites and greenhouse whitefly). Several "old" pests are not yet under reliable biological control and receive a lot of attention (e.g. western flower thrips) and there are a few "newcomers" (e.g. cotton aphid and sweet potato whitefly). It is satisfying to see many papers on integrated pest control, and some on integrated pest and disease control. Accidental importation of pest insects remains one of the main causes for new problems in many areas. Such unintentional imports often lead to panic actions with very frequent chemical treatments. Biological and integrated control programmes are regularly interrupted and it takes considerable time to restore a carefully developed IPM programme. Pro-active measures with the aim to design well balanced action programmes in the case of an unintentional introduction might provide an alternative.

One of the recent developments in inundative and seasonal inoculative release programmes concerns the development of quality control tests for natural enemies. The market for biological control expands fast. The reasons for expansion are diverse, the main ones being a lack of effective pesticides for the control of several key pests and an increased international awareness that the usage of pesticides has to be reduced drastically. Several papers relate to these topics. Producers of natural enemies, scientists and policy makers in Europe and North America are working on the development and implementation of quality tests.

Some papers had to be shortened considerably which was usually done by the authors. In several instances I had to summarize very long papers because time constraints made communication with the authors not possible. I these cases I am responsible for the mistakes.

I am very thankful to M. Parrella, J. Nelson and coworkers (Davis, California) for local arrangements and coordination of the meeting, and to J. Sanderson (Cornell, New York) for organizing this meeting under the shared responsibility of IOBC/NRS and WPRS. Mrs. Otteline Crommelin retyped a number of articles, and my companion Marianne Bergeman is thanked for help with editing, reretyping and keeping me awake during the month of January.

J.C. van Lenteren,
Convenor IOBC/WPRS Working Group
"Integrated Control in Glasshouses"
31 January 1993

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IPM FOR GREENHOUSE CROPS IN NEW ZEALAND: GROWER ACCEPTANCE

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Abstract
Grower perception of the benefits of Integrated Pest Management (IPM) programmes has dramatically improved in the recent past due to increasing grower and public awareness of the hazards of indiscriminate pesticide use. In 1991, a selective insecticide for whitefly control, buprofezin, was registered for use in New Zealand, and this made the utilisation of *Encarsia formosa* in greenhouse vegetables commercially viable. Grower uptake of IPM programmes in these crops has been rapid since this registration and since bumble bees have become available for pollination in greenhouse vegetables. The activities of an Advisory Officer who can teach growers how to use the biological control agents and the availability of simple IPM manuals for each crop have also contributed to the successful adoption of greenhouse IPM.

Introduction
In the 1970s, the New Zealand Ministry of Agriculture & Fisheries established colonies of *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae), a parasitoid of greenhouse whitefly (*Trialeurodes vaporariorum* (Westwood)) (Homoptera: Aleyrodidae) and *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae), a predator of two-spotted mite (*Tetranychus urticae* Koch) (Acari: Tetranychidae). These natural enemies were supplied to growers of greenhouse crops (Martin, 1989a; Thomas & Walker, 1989) but regular use soon ceased. In 1981, research was initiated to develop Integrated Pest Management (IPM) programmes for greenhouse flower, fruit and vegetable crops. A key element was the biological control of whitefly and two-spotted mite. Implementation of the programmes for tomatoes, cucumbers, capsicums, and beans was delayed until the registration of a selective pesticide for whitefly control. Growers of export *Cymbidium* orchids had to overcome their fear of predator and pest mites being found on flowers. A major potential problem was the disappearance of a Government advisory service to assist growers in learning the new technology. This difficulty was overcome by appointing a specialist greenhouse IPM Advisor for three years and developing grower IPM manuals for each crop.

Recent changes in grower practices and attitudes
In 1991, a survey of attitudes to IPM indicated that a high proportion of growers were concerned about pesticide use - 82% were aware of a need to reduce personal, employee and family exposure to pesticides. More than 80% of growers were interested in using IPM techniques. Growers are increasingly conscious of the quality of produce destined for both local and export market; they are interested in exploring alternatives.

Most Cymbidium orchid producers grew orchids as a part-time money-making hobby. They tended to have inadequate greenhouses, unsuitable cultivars, and poor cultural and chemical practices. The current trend among orchid growers is towards professionalism. Larger areas with modern greenhouses, computerised systems for water, fertiliser, and heating/cooling inputs, and fewer cultivars have decreased many of the pest and disease problems experienced in the past. Proper timing of control options has further decreased pest and disease problems.

Although many greenhouse vegetable growers still plant directly in the soil, an increasing number are using hydroponic techniques. This change in growing methods has forced many growers to learn basics of such things as plant nutrition, pH, and CF readings.

In the past, tomato growers packed their own fruit, resulting in variable grading standards. Many Auckland growers now belong to one of four packhouses; the competitive edge this gives these growers is slowly forcing other urban areas around New Zealand to consider developing packhouses. Although primarily a domestic crop, some packhouses now export tomatoes.

A recent extensive survey of the local fresh market vegetables showed some misuse of pesticides and caused concern among growers. This finding added impetus to a land-based industry initiative to start the New Zealand Agrichemical Education Trust which will train and certify growers and other people handling pesticides in their safe and proper use.

Finally, the greatest change for tomato growers has been the commercial availability of bumble bees for crop pollination. Grower uptake of this technology has been extremely rapid. Because bumble bees are very susceptible to most pesticides, growers are demanding alternative pest and disease control options that are compatible with bumble bees.

Education of growers

One key factor in the successful implementation of IPM is an advisory service which can transfer information to growers (van Lenteren, 1987). The lack of a government advisory service created a challenge. Martin (1989b) found that traditional sources of information for New Zealand tomato growers (in descending order of importance) were from other growers, grower journals, overseas trips, and consultants. We have therefore aggressively marketed IPM programmes through industry magazines, grower meetings and demonstration crops, coupled with simple manuals.

A full-time Advisory Officer has been appointed to assist greenhouse growers throughout New Zealand in learning IPM techniques. Group meetings are used to acquaint growers with details of basic biology of the pests and their biological control agents, plant diseases, and control options. Key growers in each region are supervised regularly; these growers can then dispense their new knowledge to other growers in their areas. The Advisory Officer also provides feedback on the IPM programmes so that they can be altered or improved as circumstances change. The Advisory Officer is funded by the Agricultural and Marketing Research and Development Trust therefore consultation time is free, an important consideration for New Zealand growers with small properties. The travel expenses of the Advisory Officer are met by vegetable industry levy funds which is an inducement for growers to attend meetings and listen. IPM manuals have been written for each crop. They cover all aspects of pest and disease control, including pesticide resistance management for diseases and environmental manipulations to reduce disease incidence. Local grower associations were asked to assess the tomato manual after a year's trial, and their comments have been used to update the manual (Martin 1992). The new manual provides additional information and will be published with replaceable sections in a ring binder.

Acceptance by growers

Some 10% of New Zealand Cymbidium orchid growers are currently using *P. persimilis* to control two-spotted mite (Beck, *et al.*, in press) even though the major importer, Japan, has stringent quality control, and biological control is more expensive than conventional control (Martin & Workman, 1988). Our programme uses calendar introductions of *P. persimilis* and relies on pesticides for controlling other pests (Beck, *et al.*, in press). Similar programmes are being developed for roses and carnations. An unexpected impetus for uptake by these ornamental producers is that the demand by florists for reduced residues is increasing.

Peak demand for *E. formosa* increased four-fold from 1991 to 1992. Grower acceptance is primarily due to bumble bee availability. The increased use of *P. persimilis* by vegetable growers can be attributed to the paucity of miticides registered for these crops. Growers of several high-value, specialty export crops, such as Japanese melons, are now requesting predators. A pool of experienced, major producers is developing as growers become more sophisticated in the use of natural enemies. Up until 1 December 1992, sole responsibility for natural enemy production and management has rested with Crop & Food Research (formerly DSIR Plant Protection); on 1 December, however, retailing duties have been taken over by several commercial horticultural supply companies who will act as over-the-counter consultants to growers. The consultants will assist with proper application of the natural enemies, timing of introductions, use of compatible pesticides, and retailing of the IPM manuals.

Discussion

Primary produce forms a high proportion of New Zealand's exports. The image of New Zealand as a "clean, green" country is heavily marketed. The use of biological control agents in flower and vegetable crops fits both this image and the move to sustainable production. Reduction in insecticide use by growers involved in our IPM programmes can be high; for tomato growers, a decrease of 80% is possible. Growers perceive the main benefit of IPM to be reduced use of pesticides. However, because many combine applications of pesticides for insect/mite control with those for disease control, the full cost savings are realised only if fungicide use is also reduced. For this reason, the IPM manuals provide detailed recommendations on how to manipulate the greenhouse environment to reduce the risk of disease. Because growers usually need to apply some pesticides, guidance on effective spraying is given. Continuing education of these growers in the use of natural enemies, proper pesticide application, and the biology of the pest organisms is necessary. In general, growers are eager to understand the biology of the pests and their natural enemies, and realise such knowledge gives them a ability to manage their crops better. In situations where the use of natural enemies has not been effective, the majority of growers are willing to try again; they realise that the fault lay not with the natural enemy but in its improper use.

Concerns for the future

Active marketing of the natural enemies by retailers who also sell pesticides is one area of concern. The simple marketing of a natural enemy by over-the-counter consultation will not give the grower enough information to utilise it successfully. However, the majority of field consultants for these companies have tertiary educations during which they have been exposed to IPM techniques and principles; this is being supplemented by the Advisory Officer who is holding training sessions on the use of biological control agents. These consultants seem eager to help implement IPM techniques. As sales from the natural enemies increase and retail companies develop more revenue from those sales, retail company staff will become more aware of grower's need for good advice.

Another concern is the scarcity in New Zealand of private consultants who have a background in entomology or IPM techniques. However, this scarcity will also be counterbalanced by increasing grower interest in reduced chemical programmes; consultants who want to maintain their clientele will be forced to update their own knowledge. As more natural enemies become commercially available (we are currently testing the release of *Amblyseius cucumeris* in greenhouse cucumbers), the adoption of subsequent biological control agents should become easier. Indeed, we frequently receive requests from growers for biological control agents for other pests.

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BIOLOGICAL CONTROL OF APHIDS ON CUCUMBERS: FURTHER DEVELOPMENT OF OPEN REARING UNITS OR "BANKER PLANTS" TO AID ESTABLISHMENT OF APHID NATURAL ENEMIES

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Abstract
Trials were carried out during 1992 in both experimental glasshouses and on a commercial cucumber nursery, to further investigate the practical application of open rearing units (banker plants) in order to aid establishment of aphid natural enemies, for the control of *Aphis gossypii* within an IPM programme. The trials demonstrated that *A. gossypii* can be controlled biologically on cucumbers on a commercial scale. Banker plants, comprising wheat or barley seedlings infested with bird-cherry aphids, *Rhopalosiphum padi*, enhanced the early establishment of *Aphidius colemani* and *Aphidoletes aphidimyza*, enabling rapid and prolonged control of *A. gossypii*. Further development work is necessary to improve and simplify the banker plant technique, and to evaluate lower rates of natural enemies, to make the system more attractive for commercial use.

Introduction
Aphid natural enemies can be difficult to establish and often do not give adequate control, particularly of *Aphis gossypii* which multiplies very quickly on cucumbers. In trials during 1991, a range of aphid biological control agents was evaluated on cucumbers. The only successful treatment was the use of open rearing units or banker plants to establish *Aphidius matricariae* and Aphidoletes aphidimyza in advance of infestation of the cucumbers with *A. gossypii* (Bennison, 1992). The system, using one banker plant seed tray per 25 cucumber plants, gave effective and prolonged control of *A. gossypii*. Trials during 1992 evaluated lower rates of banker plant units, to make the system more practical for commercial use.

Materials and Methods
The trials were located at two sites:

1. Horticultural Research International (HRI) Stockbridge House, North Yorkshire, UK.
2. DTN Stubbins Nursery, Essex, UK.

Similar treatments were evaluated at both sites, with Site 2 used to investigate whether the techniques developed at Site 1 would be effective and practical on a commercial scale. Due to limitations on space, this paper will mainly describe the trial at Site 2, with results given at Site 1 discussed where appropriate. Full details are available from the first author.

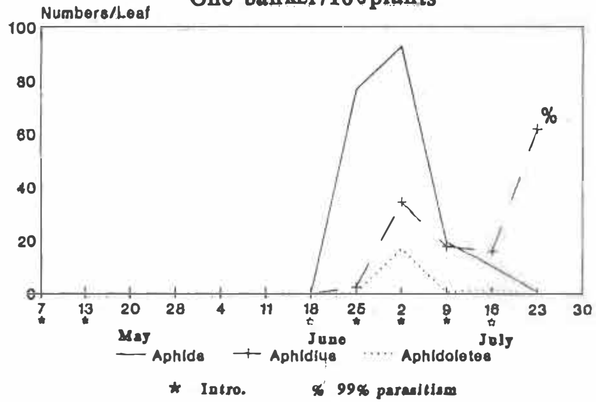
Treatments, Early Season Crop

1. One banker plant unit per 100 plants - reduced rates of natural enemies.
2. One banker plant unit per 200 plants - reduced rates of natural enemies.
3. No banker plants - higher rates of natural enemies.
4. Untreated - nicotine if and when necessary.

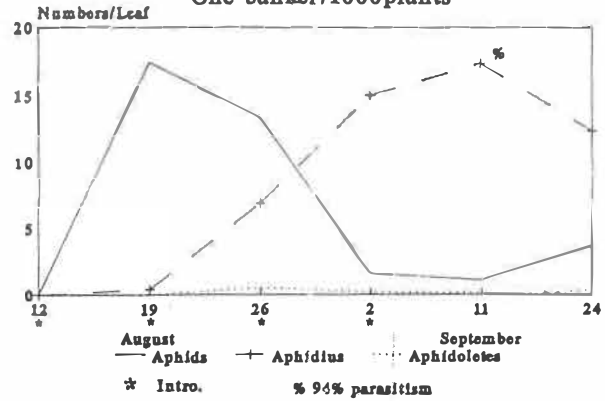
Treatments, Replanted Crop

1. One banker plant unit per 1,000 plants - reduced rates of natural enemies.
2. No banker plants - higher rates of natural enemies.
3. Untreated - nicotine if and when necessary.

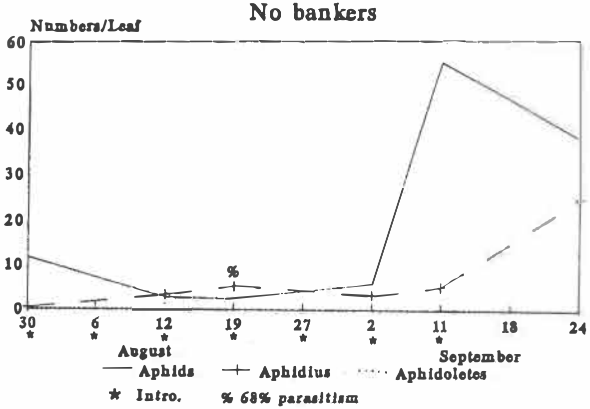
Graph 1: Early Season Crop Cucumber Assessments One banker/100plants



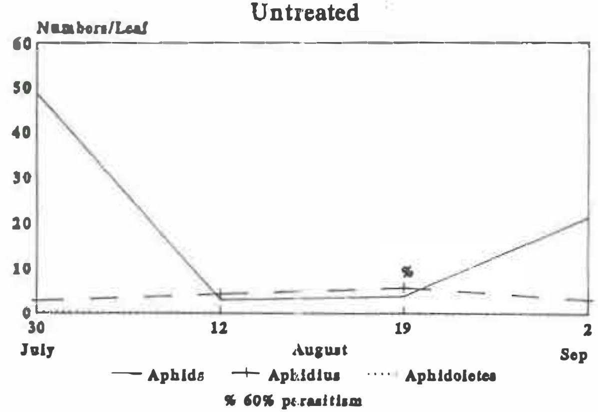
Graph 2: Replanted Crop Cucumber Assessments One banker/1000plants



Graph 3: Replanted Crop Cucumber Assessments No bankers



Graph 4: Replanted Crop Cucumber Assessments Untreated



Separate glasshouse blocks of 2,500-4,000 m^2 were used for each treatment, containing 3,000-4,800 plants. Banker plants were produced in the grower's propagation house and transferred to the cucumber glasshouses from April, one month before the estimated arrival of *A. gossypii*.

Rates of natural enemies: Where banker plants were used, mean weekly rates were *A. colemani* at $0.1/m^2$ and *A. aphidimyza* at $0.6/m^2$. Where banker plants were not used, the commercial programme recommended by Koppert was evaluated; this included two rates. A low weekly rate of *A. colemani* at $0.1/m^2$ and *A. aphidimyza* at $1/m^2$ was used from mid-April when an *A. gossypii* infestation was expected. Once *A. gossypii* was seen on the crop, the weekly rates were increased to *A. colemani* at $0.5/m^2$ and *A. aphidimyza* at $2/m^2$.

N.B. *A. colemani* was used at both sites rather than *A. matricariae* as in previous trials. *A. colemani* has now been demonstrated to be a very efficient parasitoid against *A. gossypii* due to its high rate of increase, being equal to that of the pest on cucumbers (Van Steenis, 1992).

Results and Discussion

A. gossypii Invasion: The pest was not introduced at Site 2 as this was a commercial nursery. Migration was later than expected, in late June. In the early season crops, migration to Treatment 2 was too late to fully evaluate control and no migration occurred to the blocks used for Treatments 3 and 4. In the replanted crops, *A. gossypii* infested plants in all treatment blocks shortly after planting, so all treatments could be evaluated.

Control of A. gossypii: In the early season crops, effective aphid control was given by Treatment 1; one banker unit per 100 plants. Control was mainly given by *A. colemani*, with *A. aphidimyza* contributing on any heavily infested leaves. Within three weeks of infestation, 50% parasitism had occurred and within a further three weeks, "overkill" was achieved with 99% parasitism (graph 1). In the replanted crops, the most effective treatment was Treatment 1, one banker unit per 1,000 plants. *A. colemani* achieved 90% parasitism within three weeks of *A. gossypii* arrival (graph 2). *A. aphidimyza* contributed to control on the occasional leaf with an aphid colony. Outstanding control of aphids was maintained until the end of the season.

In the replanted block evaluating Treatment 2, using higher rates of natural enemies without banker plants, aphids were adequately controlled but the level of parasitism reached only 68% and very few *A. aphidimyza* larvae were recorded (graph 3). During the final month of the trial, aphid numbers began to increase, but pesticides were not required. In the untreated replanted block, aphids were also adequately controlled, by natural enemies migrating from the other blocks. Most of the control was given by *A. colemani*, with the level of parasitism reaching a maximum of 60% (graph 4). Aphid numbers began to increase towards the end of the season, but nicotine treatment was not required.

The results at Site 1 were similar to those described for Site 2; all banker plant treatments gave effective and prolonged aphid control, as long as healthy banker plants and cereal aphids were maintained. Where higher rates of natural enemies were used without the aid of banker plants, temporary control was given but not maintained throughout the life of the crop.

Banker plant maintenance: In the early season crops, the banker plants had to be maintained for two months until *A. gossypii* arrived. Despite using mildew-resistant cereal varieties, severe mildew developed and the plants had to be replaced every two to three weeks.

***Production of natural enemies on the banker plants*:** Banker plants produced up to seven times as many *A. colemani* and four times as many *A. aphidimyza* as those introduced, depending on the rates of banker units used. Aphid control was excellent even at the lowest rate of banker plant production. Similar results were given at Site 1, where the number of banker plants or stations used seemed less critical than the maintenance of a healthy source of natural enemies in the crop at the time of aphid invasion, to supplement those introduced.

In the replanted crop, the weekly numbers of natural enemies introduced to Treatment 2 were similar to those produced on banker plants in Treatment 1. The improved aphid control with banker plants could have been due to the provision of a constant source of more viable natural enemies e.g. pupal survival of *A. aphidimyza* was probably improved when the vermiculite carrier was applied to the trays of cereal plants rather than to the rockwool blocks.

Future Work Planned

The banker plant technique enabled effective and economic biological control of aphids on cucumbers. However, the system needs improving and simplifying for commercial use. Trials in 1993 will evaluate alternative plant hosts and growing techniques for banker plants, to improve longevity and natural enemy production. More economic introduction rates for natural enemies will also be evaluated to make biological control of aphids more acceptable commercially.

Acknowledgements

The Ministry of Agriculture, Fisheries and Food (MAFF) and the Horticultural Development Council (HDC) are thanked for funding the work at Sites 1 and 2 respectively. HRI Stockbridge House Staff for assistance with trial management and assessments at Site 1. DTN Stubbins Nursery for providing the trial site and help at Site 2. Bunting Biological Control Ltd and Koppert, for providing the natural enemies free of charge for Sites 1 and 2 respectively and for technical collaboration. Grodan for providing the rockwool matting free of charge, for banker plant production. MAFF Central Science Laboratory, Harpenden for providing the aphid cultures. Development Centre staff at ADAS Cambridge for assistance with graphics production.

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OUTLOOK FOR IPM IN PROTECTED CROPS IN ITALY

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Abstract
The greenhouse acreage in Italy is about 24,000 ha, yet seasonal inoculative and/or inundative releases of beneficials were applied on only 300 ha in 1992. The main factors limiting IPM for the principal crops are surveyed and discussed, with emphasis on the most important pests, the status of biological control and the beneficial species employed.

Introduction

In Italy, the greenhouse acreage for vegetables is 19,826 hectares, and the most important crops are tomato (29.6%), strawberry (16.8%), sweet pepper (10.7%), melon (10.0%), eggplant (6.9%), zucchini (6.6%) and lettuce (6.0%) (ISTAT, 1991a). Non-potted flowers and green plants account for 4,269 hectares, whereas 216 million potted plants are produced yearly (ISTAT, 1991b). As in the other Mediterranean countries, greenhouses feature a wood and/or metal support framework that is covered by plastic film, climate-conditioning facilities being seldom employed, normally used only for ornamentals. Italy can be divided into two broad areas: the Po valley in the north with a continental climate and the rest of the peninsula along with the main islands (Sicily and Sardinia), where greenhouses are concentrated close to sea coasts. As the low temperatures in northern Italy make winter vegetable growing impossible without heating systems, protected crops are commonly restricted to spring and summer. In southern Italy, crops are grown in unheated plastic tunnels even in winter while it is very common to leave greenhouses empty during July and August. These differences influence pest outbreaks: red spider mite, whiteflies and Noctuids are more dangerous in the South than in the North, while other pests are less important or absent in the South, such as the European corn borer, *Ostrinia nubilalis* (Hb.) and the Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Table 1).

IPM Strategies

Nucifora (1989) and Celli et al. (1991) reviewed possibilities for IPM in protected crops in Italy. Inundative and seasonal inoculative releases of beneficials are increasingly more common in vegetable crops, whereas the limited experience in ornamentals has to date focused on biological control on gerbera, poinsettia and potted plants (Table 2).

Tomato. The main arthropod pests in northern Italy are the greenhouse whitefly, *Trialeurodes vaporariorum* (Westw.) and the aphid *Macrosiphum euphorbiae* (Thom.). Releases of the parasitoid *Encarsia formosa* Gahan against *T. vaporariorum* and sprays of selective insecticides, if needed, make it possible to apply IPM.

In southern Italy, the tomato yellow leaf curl virus (TYLCV) transmitted by the cotton whitefly *Bemisia tabaci* (Genn.) recently occurred (Credi et al., 1989; Rapisarda, 1990), severely limiting IPM. Especially when the tomato cycle begins during the summer, screens have to be set up to prevent the entrance of *B. tabaci* adults (Berlinger et al., 1991). Releases of *E. formosa* against *T. vaporariorum* are often unreliable during winter and early spring. Nevertheless, wild populations of some zoo-phytophagous myrid bugs limit whiteflies and other pests, their action being combined with that of *E. formosa*. The most common species are *Macrolophus caliginosus* Wagn., *Dicyphus errans* (Wolff) and *Nesidiocoris tenuis* (Reut.) (Arzone et al., 1990; Costanzi & Pini, 1991; Delrio et al., 1991; Petacchi & Rossi, 1991).

The release of the parasitoid *Diglyphus isaea* (Walk.) is very satisfactory in controlling leafminers, i.e. *Liriomyza trifolii* (Burg.), moreover the wild natural enemies are often sufficient to keep these pests at low densities.

While the use of bumblebees, *Bombus terrestris* L., for pollinating tomato will also contribute to the spread of biological control, further studies are needed on the influence that climate and greenhouse facilities can have on the colony life and pollination efficiency.

Strawberry. An IPM strategy has been set up in northern Italy where *Chrysoperla carnea* (Steph.) larvae are released against aphids and the predatory mite *Phytoseiulus persimilis* Athias-Henriot against the red spider mite *Tetranychus urticae* Koch and spraying inorganic fungicides to control diseases (Benuzzi et al., 1992).

In southern Italy, the western flower thrips *Frankliniella occidentalis* (Perg.) has become the major pest since its introduction (Arzone et al., 1989), thereby encouraging the use of wide-spectrum insecticides that have disrupted the biological control of *T. urticae* without offering satisfactory control of the new resistant pest. Yet this failure of pesticides has encouraged a return to IPM: the

Table 1: Main pests of the protected crops in Italy
(-: harmless; +: occasionally harmful; ++: often harmful; +++: generally harmful).

CROPS	PESTS *									
	WFT	GWF	CWF	APH	MBS	ECB	LEP	CPB	LFM	RSM
					NORTHERN ITALY					
Cucumber	++	++	-	+++	-	-	-	-	-	+++
Eggplant	++	+++	-	+++	-	-	-	+++	-	+++
Lettuce	-	-	-	+++	-	-	++	-	-	-
Melon	-	+	-	+++	-	-	-	-	-	++
Strawberry	+	-	-	++	-	-	+	-	-	+++
Sweet pepper	++	-	-	++	-	+++	+	-	-	++
Tomato	+	++	-	++	-	-	+	+	-	+
Zucchini	-	+	-	+++	-	-	-	-	-	+
Gerbera	+++	+++	-	+	-	-	+	-	+++	++
Poinsettia	+	++	+++	-	-	-	-	-	-	+
Potted plants	+++	++	+	++	++	-	-	-	+	+++
					SOUTHERN ITALY					
Cucumber	+++	++	+	+++	-	-	+	-	+	+++
Eggplant	+++	+++	+	+++	-	-	++	-/+++	+++	+++
Lettuce	-	-	-	+++	-	-	++	-	-	-
Melon	++	+++	+	+++	-	-	+	-	+	+++
Strawberry	+++	+	-	+	-	-	++	-	-	+++
Sweet pepper	+++	-	+	+++	-	+	+++	-	+	+++
Tomato	+	+++	+++	++	-	-	++	-/+	+++	++
Zucchini	+	+++	+	+++	-	-	+	-	++	++
Gerbera	+++	+++	+++	+	-	-	++	-	+++	+++
Poinsettia	+	++	+++	-	-	-	-	-	-	+
Potted plants	+++	+++	+	++	+++	-	+	-	+	+++

* : WFT = *Frankliniella occidentalis;* GWF = *Trialeurodes vaporariorum;* CWF = *Bemisia tabaci;* APH = Aphids; MLB = *Planococcus citri* and other mealybugs; ECB = *Ostrinia nubilalis;* LEP = other Lepidoptera; CPB = *Leptinotarsa decemlineata;* LFM = *Liriomyza* spp.; RSM = *Tetranychus urticae.*

Table 2: Protected crops in Italy under control of released beneficials, 1992
(-: not released; +: occasionally released; ++: often released; +++: generally released).

CROPS	SURFACE (hectares)	BENEFICIALS *							
		Pp	Ef	Cc	Di	Or	Cm&Ld	Btk	Bb
Strawberry	100	+++	-	+++	-	++	-	+	+
Sweet pepper	20	+++	-	++	-	++	-	++	+
Tomato	80	-	++	-	++	-	-	-	+++
Other vegetables	20	+++	++	-	-	++	-	-	+
Gerbera	15	+	++	-	+++	++	-	-	-
Poinsettia	15	-	+++	-	-	-	-	-	-
Potted plants	10	++	++	+	+	+++	++	-	-

* : Pp = *Phytoseiulus persimilis;* Ef = *Encarsia formosa;* Cc = *Chrysoperla carnea;* Di = *Diglyphus isaea;* Or = *Orius* spp.; Cm&Ld = *Cryptolaemus montrouzieri* and *Leptomastix dactylopii;* Btk = *Bacillus thuringiensis ssp.kurstaki;* Bb = *Bombus terrestris.*

release of *Orius* spp. seems to be effective against *F. occidentalis*, as do wild natural enemies when selective techniques are applied. Outbreaks of aphids are common in the Po valley but rare in southern Italy. *T. urticae* is more dangerous in the south, where a higher release rate of *P. persimilis* is needed to control it (12-15 predators/m^2 vs. 4-6/m^2); otherwise a selective acaricide is sprayed before the release of the predatory mite.

Sweet Pepper. Its main pest in northern Italy is *O. nubilalis*. In greenhouses, good results are recorded using screens to prevent the entrance of moths. This technique makes it possible to release *C. carnea* larvae, inducing a peculiar 'seasonal inoculative' effect due to the reproduction of the predator inside the greenhouse.

In southern Italy, *F. occidentalis* has disrupted IPM in this crop too. While *Amblyseius cucumeris* (Oud.) appears ineffective, the release of *Orius* spp. is very promising. *P. persimilis* provides good control of *T. urticae* and powdery sulphur can limit the broad mite *Polyphagotarsonemus latus* (Banks) (Vacante, pers. comm.). The control of Noctuids is difficult, especially of *Spodoptera littoralis* (Boisd.), as in many other crops (Inserra & Calabretta, 1985).

Eggplant. *L. decemlineata* is one of the main pests in Italy except in Sicily and Sardinia, being rare in the former and absent in the latter. Releases of the exotic egg-parasitoid *Edovum puttleri* Grissell have proved to be effective (Maini et al., 1990), although the high cost of mass-rearing severely limits its application. While microbial control could solve the problem, *Bacillus thuringiensis* Berl. ssp. *tenebrionis* is not yet registered, and hence the use of selective insecticides (i.e. teflubenzuron) offers the only real option for IPM.

Several other pests attack this crop (Table 1), so it is generally difficult and expensive, to release 3-4 beneficials at the same time. Nevertheless, the biological control of *T. vaporariorum* and *T. urticae* in northern Italy is reliable, although once again *F. occidentalis* is limiting IPM in the south.

Cucurbits. *A. gossypii* is the key pest of these crops in Italy, and neither the available beneficials nor selective insecticides can control it. *Aphidoletes aphidimyza* (Rond.) has proved to be ineffective; *Verticillium lecanii* (Zimm.) is not registered in Italy, moreover the activity of microbial products available in northern Europe is limited by the low humidity in the South. Field trials are being carried out to evaluate the parasitoid *Aphidius matricariae* Hal. Wild predators, mainly Coccinellids, are the principal natural enemies of *A. gossypii* in the open field, but they limit the pest only when the agro-ecological conditions are favourable.

Ornamentals. The first experiences on gerbera were done by Nucifora & Vacante (1981). The release of *D. isaea* combined with the action of wild natural enemies is fully effective in the control of *L. trifolii* (Calabretta & Campo, 1989), although *F. occidentalis* now limits IPM. Moreover *B. tabaci* is replacing *T. vaporariorum* in large areas of Italy, creating many problems for chemical control too and making IPM very problematic.

In poinsettia IPM is rapidly expanding, mainly because of the few pests that attack this crop and the resistance to insecticides of *B. tabaci*, which here too is replacing *T. vaporariorum* (Benuzzi et al., 1990). In 1992, *E. formosa* was released in about one million plants (ca. 8.0% of the total). Some problems have emerged only when the initial infestation of *B. tabaci* was high; on the other hand, chemical control is very difficult as *B. tabaci* shows resistance even to buprofezine. New options may emerge from specific natural enemies of *B. tabaci*, such as *Eretmocerus mundus* Mercet.

Zero-tolerance of pests is a severe limit to IPM in potted plants, even though biological control is increasing, especially for plants distributed in the national market. The parasitoid *Leptomastix dactylopii* (How.) and the predator *Cryptolaemus montrouzieri* Muls. have proven to be effective against *Planococcus citri* (Risso); *P. persimilis* controls *T. urticae*, while *F. occidentalis* is only slightly harmful to several green potted plants.

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THE EFFECT OF TYPES OF GREENHOUSE SCREENS ON THE PRESENCE OF WESTERN FLOWER THRIPS: A PRELIMINARY STUDY

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Abstract
The thrips population prevailed on the flowers outdoors year round, with a clear peak during April-June and a smaller one in autumn. A general positive correlation was found between thrips population density outdoors and indoors. In laboratory tests, the thrips freely penetrated the commercially used whitefly-proof screens. In the field, the thrips population was reduced considerably when traps were covered by the same screens. In high 'walk-in' tunnels covered by various types of screens, the commercial woven screens reduced thrips penetration considerably, compared with the outside population, in the traps and on the flowers. A loose shading net of aluminium color through which whiteflies penetrated freely in the laboratory, reduced thrips penetration very much in the high tunnels but, under an identical shading net of white color, WFT populations were much higher than outside. Blue sticky traps caught significantly fewer WFT when placed outdoors on a background made of the aluminium-colored shading net, or of whitefly-proof screen, than in control traps placed on bare soil. In traps placed on a white-colored shading net background, catches were higher than in the control. The WFT is strongly affected by color, and its appearance can be reduced considerably by using a proper screen.

Introduction
The WFT is an economically important pest. It was introduced into Israel accidentally, most likely on imported ornamentals. It was first found on chrysanthemums and on ornamentals in a greenhouse near Tel Aviv in 1988 (Brosh, 1989). It has since spread throughout the country, attacking vegetable crops, flowers, ornamentals and wild plants. Covering tomato greenhouses with screens was found to be a very efficient whitefly control measure (Berlinger et al., 1991). Thus a series of experiments was performed to investigate the possibilities of using screens also against the WFT, especially since the color of the screen may affect - attract or repel - the thrips (Brown and Brown, 1992). The purpose of this work was to investigate the possibilities and potentials of using screens to control the WFT.

Materials and Methods
Thrips monitoring by traps. The appearance of WFT populations was studied at Gilat with blue sticky traps, and at Besor also on *Ageratum* flowers. The traps were arranged vertically, approximately 50 cm above the ground. In some cases yellow sticky traps were used despite the fact that they catch fewer WFT than did blue traps. Still, in practice they have some advantages: it is easier to count thrips on yellow traps, and they also trap whiteflies, aphids, leaf miners, etc.
Monitoring thrips by removal from flowers. Thrips prevailing in the flowers were monitored by sampling flower inflorescences. They were placed in a funnel which was closed tightly. Two or three drops of turpentine were applied to a small piece of cotton. The thrips, repelled by the turpentine, were collected in attached glass tubes containing 70% ethanol.
The screen mesh. The mesh of woven screens is indicated by the number of holes/inch in the length and the breadth. The size of the hole (mm^2) was calculated.

Thrips penetration through screens. Two types of screens were tested: woven screens, and unwoven shading nets. Thrips penetration was tested in the laboratory using two halves of a petri dish (90 mm in diameter). The tested screen was stretched between them as a barrier. Approximately 50 thrips were introduced into one compartment. After 24 hours the thrips were counted in both compartments.

Semi-laboratory tests were performed in the field. The bottom of a petri dish was smeared with insect-glue (Rimi-, or Tangle-foot). A piece of the tested screen was then stretched tightly over the opening of the dish, which was placed on a thrips-attracting background.

Field tests were performed by covering both sides of a 'walk-in' tunnel, at a height of 2 m, with the tested screen. The roof was covered with a greenhouse-plastic cover. *Ageratum* flowers were planted in the tunnel in September and two to four blue sticky traps were placed among them. The experimental layout consisted of 36 high tunnels, each 6 m long by 6 m wide, and 2.5m at the highest point. The treatments were arranged in a randomized block design. Two experiments were carried out, one in 1991/92 and one in 1992/93.

Effect of background colors. Blue sticky traps were placed in the center of squares (1.5 x 1.5 m each) representing various backgrounds: a shading net of aluminium color, a screen with the same texture but colored white (identified as 1.5% or 2.5% white), a piece of a used and a piece of a new commercial screen; and a transparent plastic sheet. Each background was tested in four replicates, which were arranged on a clean field in randomized blocks. The traps were renewed four times between 20 September and 11 October.

Results and Discussion

Phenology. At both sites, Besor and Gilat, a clear peak of the WFT population was detected by trapping, from the end of April to mid June; from late June to late September the catches were very low. A second, smaller peak was in October- November. During winter the numbers of thrips were again at a very low level.

On the flowers at Besor the thrips population prevailed outdoors all year round, and its presence was similar to that in the traps. After winter, during March-June, it rose to a clear peak. From August to late December the population level was low, 3-4 thrips/flower.

The effect of screening on thrips presence.

Laboratory and semi-laboratory tests. In the field 21.0% of the control penetrated through a screen the hole size of which was 2.18 mm^2 (Table 1, Expt. 1). Commercial 'whitefly-proof' screens, with smaller holes (0.17-0.23 mm^2) reduced thrips penetration only to 11.8-19.7% of the control. In the laboratory, over 90% of the thrips penetrated through the commercial screen No. 1. The penetration rates were somewhat smaller (68.4-88.0%) when the hole size was further reduced (Table 1, Expt. 2). Whereas, in the field only 3.2-6.5% of the thrips penetrated through the same screens. The screen holes differed in their general size but also in their XxY mesh and both characters seem to be important in thrips penetration. On the upper sticky surface of a screened yellow trap 47% of the control were caught *i.e.* although the thrips could detect the yellow trap through the screen, still about half of tits population was repelled visually by the screen. Hence, the screens may have a combined mechanical/visual effect.

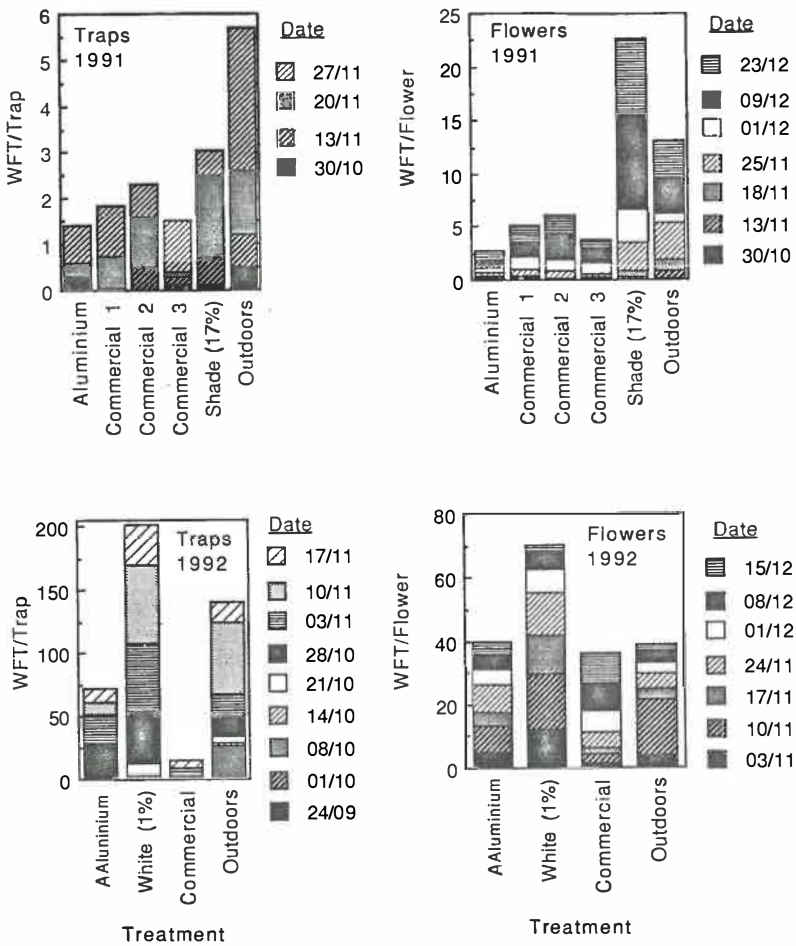
WFT in screened high tunnels. In 1991, there were fewer WFT in traps in all screened tunnels than in the unscreened outdoor control (Fig. 1). Comparing among the screens, more thrips were trapped under the screen with the bigger holes (2.18 mm^2) than under the commercial screens or even under the aluminium-colored shading net. A similar trend was found on the flowers, with the exception that under the screen with hole of 2.18 mm^2, more thrips were found than in any other treatment.

Table 1. **Thrips penetration (% of control) through various screens in the laboratory and in the field**

Treatment	Screen Mesh (X x Y)	Hole size mm²	Thrips - % of control, Testing site: Laboratory	Field
Experiment 1:				
Shade screen (17% shade)	14x16	2.18	-	21.0
Commercial screen No. 1	28x58	0.17	-	19.7
Commercial screen No. 2	25x50	0.23	-	15.8
Commercial screen No. 3	25x54	0.20	-	11.8
Commercial screen No. 1+Glue			-	47/0*
Unscreened Yellow Control	---	--	-	100
Experiment 2:				
Commercial screen	28x58	0.17	93.7	5.7
Experimental screen 1	66x66	0.15	68.4	4.3
Experimental screen 2	46x61	0.14	88.0	6.5
Experimental screen 3	36x76	0.07	69.1	3.2
Unscreened control	-----	---	100	100

* thrips were found sticking to the glue on the external surface of the screen, and none passed through it into the trap.

Fig. 1. Appearance of the western flower thrips in screened tunnels at Besor



In 1992 the experiment lasted almost 2 months (24/9-17/11) compared with less than a month (30/10-27/11) in 1991 (Fig. 1). Accordingly, the total number of trapped WFT was higher in 1992. Nevertheless, the trapped thrips population was remarkably lower under the aluminium and commercial screens than in the unscreened control. The highest numbers of WFT were trapped under the white shading net. Accordingly were the numbers of WFT in the flowers also lower under the aluminium and commercial screens than under the white shading net. The low numbers found in outdoor flowers were probably due to the unprotected, less favorable conditions. In general, screens may reduce the WFT populations, not only in traps but also in the crop, but by themselves they are not a sufficiently effective control measure. Nevertheless, the reduction in WFT pressure on the crop may increase the efficiency of complementary control measures, like biocontrol.

Effect of the trap background color on trapping.
The number of trapped WFT was strongly influenced by the background (Table 2). When the traps were placed on a shading net of aluminium color, on a piece of commercial screen, or on a transparent plastic sheet, significantly fewer thrips were caught (3.3-5.0%), compared with traps placed on the bare soil (control), and on a piece of 1.5% or 2.5% white shading net. Hence, some backgrounds reduced WFT trapping. These results may explain the relatively scarce appearance of WFT in the high tunnels covered by the commercial whitefly-proof screens and aluminium colored shading net compared with the relatively high population under the white-colored shading net cover (Fig. 1).

Table 2. Mean number of trapped WFT in blue traps placed on various backgrounds or on bare soil (control).

Treatment	Mean WFT/Trap
Aluminium (shading net)	3.3 a
Commercial screen	4.3 a
Transparent plastic sheet	5.0 a
Control (bare soil)	17.3 b
White (1.5%) shading net	18.5 b
White (2.5%) shading net	22.5 b

Figures followed by different letters differ significantly at p=0.05.

Conclusion
The WFT is affected by the screen mesh but it is also strongly affected by colors. Thus the population can be reduced very much by using a proper screen. A reduction in population density will obviously contribute to the control of this pest and will make complementary control measures, like biocontrol, more efficient.

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BIOLOGICAL AND INTEGRATED METHODS IN THE CONTROL OF THE WHITEFLY *TRIALEURODES VAPORARIORUM* ON GREENHOUSE TOMATO.

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The greenhouse whitefly *Trialeurodes vaporariorum* (Westwood) has been the most harmful insect of greenhouse crops. Many years ago it was controlled by chemicals, the period in which the problems of resistance appeared. Other means of control were subsequently developed, based on the use of the parasite *Encarsia formosa* Gahan, and the integrated programs in which chemical, biotechnical and biological treatments are combined, such as the integration of traps with *E. formosa* which were demonstrated to be highly efficient in controlling whitefly populations (Ekbom, 1980; van de Veire & Vacante 1984). In Crete, the application of biological control of *T. vaporariorum* by *E. formosa* alone or combined with other methods in integrated programs started in 1981 (Michelakis, 1983). In the present study, different methods were combined to test their efficiency in controlling whitefly populations and production of high quality products.

Four different treatments for the control of the glasshouse whitefly were tested on tomato: biotechnical combined with chemical (traps and Quinomethionate: Morestan), bioligical and chemical (*E. formosa* and Quinomethionate), biotechnical with biological (traps followed by parasite release) and combined chemicals (Applaud and Actellic).

All treatments were satisfactory in controlling whitefly populations efficiently. The fastest acting treatments were those with traps. The second those with Applaud and Actellic, in which a rapid reduction of the whitefly population occurred immediately after spraying (fig. 1).

Sticky yellow traps are promising because of their simplicity and effectiveness. When installed in the early stages of planting, traps were efficient in monitoring the whitefly population; they trapped great numbers of whiteflies and kept the population low. They were insufficient for control of rapidly increasing whitefly populations, and other means of control were required, such as Quinomethionate.

This chemical was effective when combined with traps of *Encarsia* treatments (fig. 2) and it did not harm the parasite. Plots treeated with this chemical were clean, and the plants were healthy and free of red spider mite and oidium disease, which were found in other treatments and in the controls.

Parasites introduced after installation of traps were more effective than when used alone. In both treatments, three introductions at intervals of 2-3 weeks were sufficient. Plants and fruits harvested from the plots with traps combined with *E. formosa* were the cleanest; those harvested from the plots with *E. formosa* and Quuinomethionate, traps with Quinomethionate, and those treated with Applaud plus Actellis were less so. The least healthy plants and fruits were the controls, in which whitefly developed rapidly. Foliage and fruits were covered by honeydew on which sooty mould developed, after which the plants were attacked by *Cladosporium herbarum*.
(*summarized by the editor from a 12-page manuscript*)

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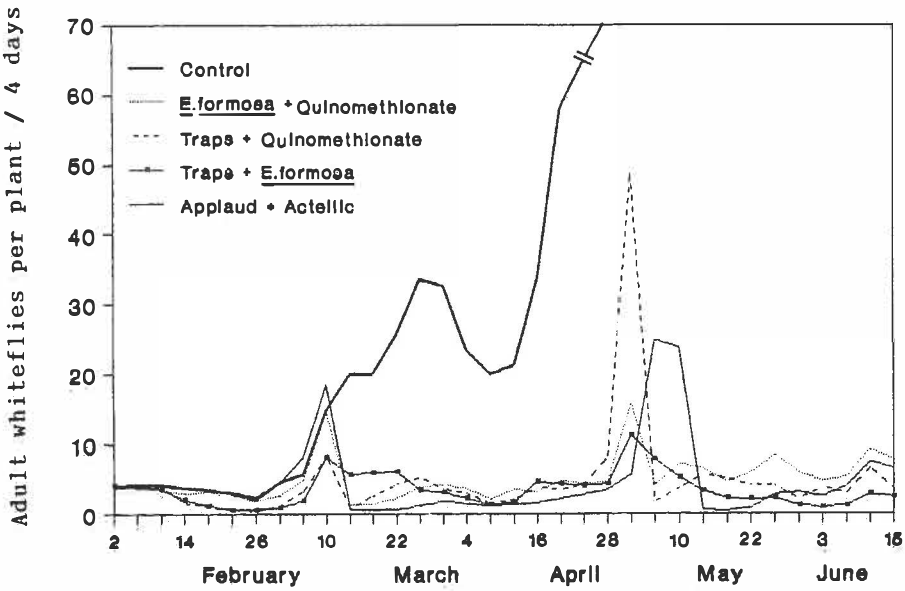

Fig. 1. Evolution of whitefly populations in 4 treatments and the control

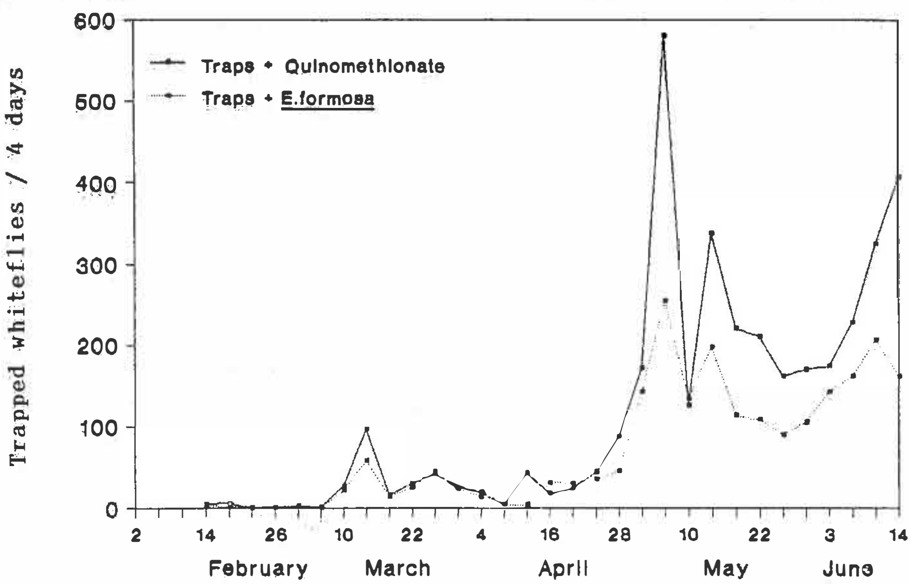

Fig. 2. Whiteflies trapped per 4 days in treatment of trap with Quinomethionate or *E. formosa*

COLOURED STICKY TRAPS FOR THRIPS (THYSANOPTERA: THRIPIDAE) MONITORING ON GLASSHOUSE CUCUMBERS.

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Introduction

In most countries in the northern temperate region, the two most important thrips pests on glasshouse crops are the onion thrips (*Thrips tabaci* (Lindeman)) and the western flower thrips (*Frankliniella occidentalis* (Pergande)) (Brødsgaard 1991). Due to the small size and often secluded habitats of these thrips, the responsiveness of the thrips to coloured surfaces has been used to develop coloured traps as sampling means for registration of attacks. Traditionally, yellow sticky traps have been used for monitoring glasshouse thrips (e.g. Elliott et al., 1987). The choice of colour has been based on the fact that yellow is the optimum colour for a wide range of herbivorous insects rather than experimental evidence of the colour preference of the thrips species in glasshouses. However, *T. tabaci* has been found to prefer white without UV to yellow and blue in an outdoor experiment (Kirk, 1984). In another outdoor experiment Czencz (1987) found these three colours to be equally attractive but found that responsiveness of *T. tabaci* to the various colours was affected by the crop and especially the colours of the crops - these being different background colours to the trap colours. Blue sticky traps of certain specific hues have proven to be effective in catching *F. occidentalis* (Brødsgaard, 1989, 1992; Gillespie & Vernon, 1990), *Frankliniella intonsa* (Trybom) (Murai, 1988) and *Thrips palmi* Karny (Kawai, 1986) in glasshouse crops.

In the present study, experiments were conducted in order to find the colour preference of *T. tabaci* in glasshouse cucumber crops and of *F. occidentalis* at low light intensities. Furthermore, experiments were conducted in order to find a correlation between blue trap catches of *F. occidentalis* and the actual population size on glasshouse cucumbers. Finally, the optimum height of placement of blue traps mature cucumber crops was investigated.

Materials and methods

Colour preference

The *T. tabaci* experiment (exp. 1) was conducted in an experimental glasshouse with three double rows of 16 cucumber plants aligned in an east-west direction from 1st June to 24th June. The cucumber plants were infested with *T. tabaci* on 21 March and during the experimental period the thrips density was five to ten thrips per leaf. The traps were made of 20 x 6 x 0.2 cm acrylic plates coated on both sides with Tangletrap®. The colours tested were white, blue and yellow (Riacryl nos. 080, 257 and 360) (Brødsgaard, 1989). The traps were suspended on vertical strings in the centre of the two walkways between the rows of cucumber plants. One trap of each colour was suspended above one another in a randomized way. Traps were situated vertically at heights of 130-150, 155-175, 180-200 cm, respectively. Six sets of three traps were used. The traps were counted daily and substituted by new traps in a re-randomized pattern.

The *F. occidentalis* experiment (exp. 2) was conducted from 7-21 December on a heavily infested flowering pot chrysanthemum crop without provision of supplementary light. Blue and yellow traps (Riacryl 257 & 360) were suspended 5 cm above the flowers with a distance between traps of 50 cm. The traps were counted and substituted daily.

Relationship between trap catches and number of F. occidentalis on leaves and in flowers

This experiment was conducted in the period from 11 May to 2 June on cucumber in an experimental glasshouse. The temperature and relative humidity were measured using two thermo-hygrographs and the global influx (MJ/m^2) was measured at an automatic weather station 20 km away. Thrips on plants were counted daily *in situ* and daily mean numbers of thrips, larvae and adults (during the experiment a fairly stable age distribution was seen), per leaf ($n = 150$) and of adult thrips per flower ($n = 50$) were calculated. Six blue sticky traps (Riacryl 257) were suspended vertically in a height of 2.3 m in the centre of the walkways, three traps 2 m apart in each of two walkways. The traps were counted daily.

The relationship between trap catches of *F. occidentalis* and number of thrips on leaves or in flowers were examined by regression models. The number of *F. occidentalis* on traps (independent variable) at sampling dates after leaf and flower sampling dates was tested as a predictor of number of *F. occidentalis* on leaves or in flowers (dependent variable) in a straight line model $Y = \alpha + \beta X$. However, trap catches are not only a function of population size but also of thrips flight activity and this in turn is a function of air temperature and light intensity and probably many other factors. To test whether the predictive value of the model could be improved, noon air temperature in the glasshouse and daily global influx were incorporated into the model making it a multiple regression model ($Y = \alpha + \beta_1 X + \beta_2 Z + \beta_3 Q + \beta_4 [Z*Q]$, where Y=Thrips density on leaves or in flowers at day_d; X=Daily thrips catch on blue sticky traps at day_{d+1}; Z=Noon air temperature at day_d; Q=Daily global influx at day_d).

Influence of trap height on catches of F. occidentalis.

Blue sticky traps (Riacryl 257) were suspended in different heights in mature glasshouse cucumber crops in order to investigate the influence of trap placement on trap catch of *F. occidentalis*. The experiment was replicated in three glasshouses, two commercial (exp. 1 & 2) and one experimental (exp. 3).

Results and Discussion

Colour preference

The results of the colour preference experiments are shown in table 1. In contrast to Kirk (1984) it was found that white without UV was inferior to the tested hues of blue and yellow. The results showed that the best hue for *F. occidentalis* (Riacryl 257) is as good as yellow for *T. tabaci* monitoring; i.e. it is demonstrated that only one trap type is needed for monitoring economically important glasshouse thrips. Furthermore, it was shown that Riacryl 257 is an optimal hue for *F. occidentalis* monitoring even at very low light intensities.

Table 1: Mean daily coloured sticky trap catch response of glasshouse thrips.

		Thrips tabaci (exp. 1)		*Frankliniella occidentalis* (exp.2)	
Visible colour	Trap type	*n*	Mean [ln (x+1)] (±S.E.)§	*n*	Mean [ln (x)] (±S.E.)
Blue	Riacryl 257	144	1.20a (±0.07)	56	4.08* (±0.18)
Yellow	Riacryl 360	144	1.05a (±0.06)	56	3.38* (±0.12)
White	Riacryl 080	144	0.44b (±0.04)	-	-

§) Means followed by the same letter are not significantly different ($P < 0.05$) according to Duncan's new multiple range test.

*) Means are significantly different ($P < 0.05$) according to a *t*-test.

The sex ratios of *F. occidentalis* caught was 10.7% ♂♂ and 10.1% ♂♂ on blue and yellow traps, respectively. This is in agreement with Matteson and Terry (1992) who did not find significant differences in sex ratios between blue and yellow sticky trap catches during non-swarming periods in cotton and more or less with Gillespie and Vernon (1990) who found sex rations of 11.7% ♂♂ and 21.6% ♂♂ on blue and yellow sticky traps, respectively, in a summer experiment on glasshouse cucumber.

Relationship between trap catches and number of F. occidentalis on leaves and in flowers

The results of the sampling experiments showed that the straight line model, where blue trap catch was a predictor of numbers on leaves, had a moderate correlation (r^2=0.47) with the best fit parameter estimates: Y= 1.727 + 2.646X (F=33.19; P=0.0001; n=138). Incorporating air temperature and global influx only slightly improved the correlation with the best fit of Y= -27.20 + 2.965X + 1.253Z + 0.286Q - 0.023(Z*Q) (r^2=0.55; F=9.11; P=0.0001; n=138).

Trap catches did not give a proper estimate of adult thrips population in flowers. Best model fit: Y= 1.423 + 0.003X (F=4.93; P=0.0281; r^2=0.04; n=130). Incorporating climatic parameters into this model did not increase the correlation. The bad correlation between number of thrips adults in flowers and trap catches may be due to the facts that cucumber flowers are; (i) very attractive to *F. occidentalis* and (ii) short lived, resulting in very contagious distributions of the adults between the flowers. On sweet pepper, however, Shipp and Zariffa (1991) found good, but inconsistent correlations (r^2 = 0.68 & 0.92) between blue sticky trap catches and whole plant counts. Incorporating climatic parameters may increase correlation consistency in this crop. However the present results shows that until key factors (other than trap hue) affecting trap catches of thrips in cucumber crops have been identified only rough trends in population developments can be monitored by means of blue sticky traps only.

Influence of trap height on catches of F. occidentalis.

The results of the placement experiments with blue sticky traps in mature cucumber crops are shown in table 2.

Table 2: Trap catch of *F. occidentalis* at different heights in mature cucumber crops.

Trap height cm from floor to traps (bottom-top)	Mean daily catch per trap (±S.E.)[§]		
	Experiment 1 n = 56	Experiment 2 n = 56	Experiment 3 n = 208
210-230	70.18b (±3.26)	12.84a (±2.15)	49.56a (±4.72)
180-200		5.50b (±0.67)	27.17b (±1.53)
150-170			15.52bc (±1.84)
120-140	24.57c (±0.85)	1.75c (±0.15)	7.44c (±0.54)
90-110			8.00c (±0.77)
60-80			11.71bc (±1.50)
30-50	91.29a (±5.55)	6.50b (±0.60)	22.46b (±2.26)
0-20			34,42b (±3.57)

§) Means followed by the same letter within each column are not significantly different (P < 0.05) according to Duncan's new multiple range test.

The trap catches of *F. occidentalis* were affected by placement of the traps. The largest catches were obtained with traps placed just above the canopy and only minor catches were seen in the middle strata of the canopy. This is in agreement with an earlier experiment of Gillespie and Vernon (1990), who measured the influence of trap placement in cucumber crops at heights between 60 and 300 cm. However, in the present experiments large trap catches were obtained just above ground level (0-50 cm). The large catches obtained at this height may be due to the fact that the vast majority of larvae pupate on the ground in secluded places and, thus, the thrips caught on sticky traps just above ground level are newly hatched adults at their first 'take off'. If sticky traps are to be used as a mass trapping tool in an IPM program in cucumbers, as suggested by Kawai (1986) and Murai (1988) for other crops, the largest effect of the mass trapping will be obtained by suspending the traps near ground level, because at this height, not only large numbers of thrips will be caught, but the thrips will be caught before they will get the opportunity to reproduce in the crop.

Acknowledgement

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CONTROL OF SCIARID FLY WITH PARASITIC NEMATODES

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Abstract
The insect parasitic nematode *Steinernema feltiae* was evaluated as a control agent for the glasshouse sciarid fly *Bradysia paupera* in a replicated trial at Bridgemere Nurseries, Cheshire, England. Rates of 1 x 10^6 and 1.5 x 10^6 nematodes per m^2 were used on propagation benches kept moist and heated to a constant 20°C, and containing a range of HONS subjects including rhododendrons, azaleas and viburnums. Nematodes were applied twice, with three weeks between applications, while other plots were not treated. Numbers of adult sciarid flies were monitored by weekly counts of flies on yellow sticky traps hung over each bench just above the plants.

Both rates of *Steinernema feltiae* worked within two weeks and on some assessment dates significantly ($P = 0.05$) reduced the number of flies compared to untreated plots. However, the fly numbers on untreated plots showed a decrease during the period of the trial, indicating that sticky traps alone contributed towards the control of this pest.Differences in control between the two rates of nematode were small, counts showed that nematode persistence in this situation was approximately 6 weeks.

It is concluded that *Steinernema feltiae* is an effective control agent for sciarid fly in propagation areas, and has the advantage of being safe to the crop, and integrating well with other biological control agents. However, at present prices, nematodes are still more expensive than chemical control agents and it is recommended that work with lower rates of nematodes (0.25-0.5 million/m^2) is carried out, as these rates would be more economic for the grower.

Introduction
Sciarid flies (*Bradysia* spp) are a major pest of HONS subjects during propagation. The larvae thrive in the warm, moist compost environment, and feed on the roots and stems of cuttings. In addition there is evidence that they can spread pathogens such as *Pythium* sp, both through larval feeding and via adult flies dispersing pathogen spores. Chemical control of the pest is possible, but there are often problems with phytotoxicity on 'soft' cuttings material. In addition, biological agents such as the predatory mite *Phytoseiulus persimilis* are often used in the HONS situation, and chemical applications may adversely affect them.

Therefore, there was a need for a biological agent to control sciarids, which would integrate safety into the overall biological control programme. *S. feltiae* is now commercially available in the UK and is recommended primarily for control of vine weevil (*Otiorhynhus sulcatus*) in HONS and pot plants. however, as the nematode was originally isolated from dipterous larvae, it was expected to have activity against larvae of the fly *Bradysia* spp (Gouge and Hague, 1991).

The objective of this study was to determine whether the insect parasitic nematod *Steinernema feltiae* controls glasshouse sciarid fly in HONS propagation.

Materials and methods
The trial was carried out in a greenhouse at Bridgemere Nurseries, Cheshire on heated propagation benches kept at a constant 20°C and misted frequently to maintain high humidity. A range of HONS subjects including rhododendrons, azaleas, viburnum, cistus, mahonia and conifers were treated. The compost consisted of a 50/50 peat/perlite mix with added slow-release fertiliser in standard seed trays. Benches were covered over with clear polythene to maintain high humidity. Each bench was 18 metres long by 1 metre wide, and was divided into three plots 6m x 1m by

plastic partitions. There were three replicates of each treatment in a randomised block design.

Nematodes (Nemasys[R] - AGC microbio) were applied on 21 November and 11 December at either 1 x 10^6 /m² or 1.5 x 10^6 /m², using a watering can to evenly distribute nematodes over the compost. Approximately 2.5 litres of nematode solution was applied per m² of compost.

Yellow sticky traps (Trappit (R) brand - Agralan Limited) measuring 16.5 x 7.5cm were hung just above crop level at a density of 1 trap per 3 m² of bench area. Numbers of adult sciarid flies were counted weekly, and then the traps were changed.

Treatments

1. Untreated
2. Nemasys at 1.0 x 10^6/m²
3. Nemasys at 1.5 x 10^6/m²

Because benches were covered completely with polythene, and partitions separated each plot, it was hoped that movement of adult flies between plots would be minimised.

Results and discussion

Nemasys(R) was an easy formulation to apply: the nematodes were in a "gel" which dissolved in water, but tended to settle out. Therefore constant agitation of the nematode solution during application was very important.

Counts of adult sciarid flies before the trial started and at approximately weekly intervals thereafter, are shown in Table 1.

One week after the first application of nematodes, there was no relationship between treatments and number of flies (assessment on 28.11). In fact, numbers on the Nemasys single rate plots were much hhigher than on the untreated plots. However, by the following week both treatments had considerably less flies than the untreated plots, although the differences were not significant. This is consistent with the mode of action of parasitic nematodes; as only sciarid larvae are infected, it takes about two weeks for this to be reflected in subsequent counts of adults.

Differences between nematode treated plots and untreated plots were significant ($P = 0.05$) on 12.12, 19.12 and 16.1. However, there were no significant differences between the two rates of nematodes at any assessment date. Previous work (Nedstam and Burman, 1990) showed good control of sciarids using 20 x 10^6 nematodes per m², a rate totally uneconomic to use in the UK at present prices.

Conclusions

1. Nemasys at rates of 1.0 x 10^6 or 1.5 x 10^6 per m² gave acceptable control of sciarid flies when two applications were made about 3 weeks apart to propagation benches.
2. Lower rates may give equally good control at a more economic cost; but further work is needed to establish this.

Acknowledgements

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Table 1. Mean number of adult sciarid flies on yellow sticky traps. Nematodes applied on 21/11 and 11/12/91. Means followed by the same letter are not significnatly different (P = 0.05; Duncan's test). A square root transformation was used for statistical analysis of the data.

	Date							
Treatment	28.11	5.12	12.12	19.12	2.1*	9.1	16.1	23.1
Untreated	48.4a	30.3a	19.5a	31.6a	51.4a	28.6a	19.6a	15.0a
Nemasys $1.0x10^6/m^2$	98.4a	22.5a	12.9ab	19.8b	26.9a	12.2a	9.4a	16.1a
Nemasys $1.5x10^6/m^2$	42.3a	15.8a	10.5b	19.5b	29.6a	14.3a	12.0ab	16.1a
SED	30.0	7.2	3.5	4.6	13.2	7.4	3.6	5.09

* two week count; traps not assessed over Christmas week.

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BIONOMICS OF *ORIUS ALBIDIPENNIS* AND *ORIUS LIMBATUS*

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Abstract
For the purpose of controlling *Frankliniella occidentalis* in the Canary Islands we studied some biological features of the most abundant *Orius* species in the Canaries, which are associated with the Californian thrips. A study was carried out of the developmental and adult periods, as well as of oviposition and survival rate at 15, 20, 23, and 27°C of *Orius albidipennis*, with a basic diet of *Cadra kuehniella* (Lep. Phyticidae) eggs. Preliminary data are also given concerning *Orius limbatus* at 25°C, with a diet of *Cadra cautella* eggs. In both cases RH was 60-70% and the photoperiod used 16L:8D.

Introduction
Frankliniella occidentalis Pergande was detected in the Canary Islands for the first time in April 1987. Since then it has caused widespread damage in horticultural and ornamental plants, cut flowers and some fruit trees. In addition it is a vector of the so-called TSWV (tomato spotted wilt virus), which affects many plants and is particularly damaging to peppers, lettuce and tomatoes. Chemical control methods have proved less efficient than hoped for, and residue problems are not uncommon. For these reasons we decided to seek alternative control measures, including the use of species of *Orius* which are autochtonous to or present in the Canary Islands. This was the primary objective of our project, which was supported financially by the Fundacion Ramon Areces.

Our first step was to carry out a field search for *Orius* species associated with populations of *Frankliniella occidentalis* (Table 1). Subsequent analysis showed that the most abundant species were *Orius albidipennis* and *Orius limbatus*. We then proceeded to study the parameters of the biological cycle of both species, and implemented a mass rearing method prior to releasing them in plants. *O. albidipennis* has been studied already by other authors (Tawfik y Ata, 1973a,b, and Awadallah et al., 1977), who have focused primarily on different types of diets and hosts. In this work we analyse the results obtained using different constant temperatures (15, 20, 23 and 27°C) and a diet based on *Cadra (Ephestia) kuehniella* eggs, which the above-mentioned authors did not use. *O. limbatus* is an endemic species of the Canary Islands and Madeira, although little information has been available to date concerning aspects of its biological cycle. The preliminary data contained in the present work, therefore, may be considered as being a new contribution.

We have also developed a rearing method, which is currently being perfected in order to allow a mass rearing system to be achieved. The current method is being used for releases of *O. albidipennis* in open air strawberry plants and greenhouse peppers. The results of these latest experiments will be given in future publications.

Description and natural cycle of *Orius albidipennis* (Reuter, 1884)
An allotype, based on the Wagner collection, has been described for the Canary Islands. It was cited for the first time in the Islands by Wagner in 1952 and later by Lindberg in 1953, Gómez-Menor in 1958 and Pericart in 1972. (Heiss, E. and Baez, M. 1990). The species is also known in southern Spain and Cape Verde.

Adults are dark to black in colour and long-bodied. Females are larger than males. The morphology of the larvae remains similar throughout development, varying in size and thickness.

Table 1. ***Orius* species associated with *Frankliniella occidentalis* in the Canary Islands on different plant hosts (* Endemic species).**

ORIUS SPECIES	HOSTS IN TENERIFE	IN GRAN CANARIA
O. albidipennis	*Allium sativum* *Capsicum annun* *Zea mays* *Solanum lycopersicum* *Bituminaria bituminosa* *Ploclama pendula* *Nerium oleander*	*Heliotropum erosum* *Tagetes sp.* *Irschfeldia incana* *Tamarix canariensis* *Echium auberianum* Cucumber greenhouse weeds
O. laevigatus	*Menta sp.*	*Adenocarpus viscosus* *Castanea sativa* Cucumber greenhouse weeds
*O. limbatus**	*Menta sp.* *Zea mays* *Allium sativum*	*Ploclama pendula* *Tagetes sp.* *Irschfeldia incana* *Euphorbia regis-jubae*
*O. lindbergi**	*Menta sp.*	---

Table 2. **Measurements of *O. albidipennis***

STAGE	LENGTH (mm)	WIDTH (mm)	N
EGG	0.44 ±0.04	0.11 ±0.01 Diameter operculum	N=38-Length N=30-Diamet
NYMPH I	0.58 ±0.06	0.2 ±0.03	32
NYMPH II	0.73 ±0.07	0.28 ±0.03	22
NYMPH III	0.94 ±0.08	0.35 ±0.04	30
NYMPH IV	1.23 ±0.11	0.48 ±0.06	30
NYMPH V	1.51 ±0.11	0.6 ±0.05	31
♂	1.54 ±0.16	0.54 ±0.07	30
♀	1.85 ±0.14	0.7 ±0.09	35

Measurements of the specimens reared by us are given in Table 2.

In the field, we observed that eggs were usually placed on the upper side or borders of corn leaves, near the prey, on the leaves closest to the cob. Laboratory observations confirmed that eggs are generally placed in groups in a specific, and preferably upper, area of the vegetable substrate. However, isolated individual eggs are by no means uncommon.

The species was captured by Lindberg on compound leaves near the coast in *Zolikoferia spinosa* Boiss and *Schizogyne sericea* D.C. and on *Tamarix* (Pericart, J. 1972). To date, we have managed to capture only *O. albidipennis* in Tamarix on the island of Gran Canaria. Specimens were collected on other vegetable hosts not mentioned in the literature consulted by us (Table 1).

In the field *O. albidipennis* feeds on several preys. In corn we have found populations of this anthochorid on plants where there were no thrips but an abundance of *Rhopalosiphum maidis* and *Rhopalosiphum padi* aphids. Adults tended to be found close to the youngest leaves, feeding also on the pollen that fell from the panicle. They tended to conceal themselves in the leaf-stem joint. In northern Tenerife *O. albidipennis* is abundant from February-March until the end of the year. During the colder months, on clear sunny days relatively large populations can be found on spontaneous vegetation. In southern Tenerife the species can be captured all year round.

Data on the biology of *O. albidipennis.*

Experiments. All experiments were carried out at constant temperatures (15, 20, 23 and 27°C) in climatic chambers with a photoperiod of 16L:8D and an RH between 60-70%.

Results. No complete development of *O. albidipennis* takes place at 15°C. The total pre-imaginal development takes 22.9 days at 20°C, 20.7 at 23°C and at 27°C it takes 14.5 days. The fecundity is 50.8 at 20°C, 82.0 at 23°C and 52.5 at 27°C. Preoviposition period decreases from 5.5 days at 20°C, via 3.2 at 23°C to 2.4 at 27°C. Female longevity is 29.5, 25.1 and 21.1 at the three temperatures, respectively.

Preliminary data on the biology of *O. limbatus.*

This species which is endemic to the Canaries and Madeira has never been studied from the point of view of its biological cycle. The data provided here, therefore, represent a new contribution to science and are of interest for general knowledge of the *Orius* genus. It is a species frequently associated with *F. occidentalis* in the Canaries (Table 1), and thus could fulfil a complementary control role along with *O. albidipennis*. *O. limbatus* differs from other *Orius* s.str. in that it is rather longer and its pronotum is less pointed behind. Moreover, it has a clear hemelytron membrane and different paramers (sic, Pericart, 1972). The flagella of the male's paramers have a small spike on the external edge and a tooth in the extremely small vestigial lamella. It is found in both low and high altitude zones (up to 2,000 m above sea level in Tenerife). Specimens can be caught along the coast throughout the year. It shows a particular preference for *Ploclama pendula* (Rubiacea), endemic to and extremely plentiful in the Canary Islands. We have found it also on other host plants (Table 1).

Experiments. We used a climatic chamber at 25±2°C, 70+10% R.H. and 16 hours of daylight. Cabbage leaves served as substrate for oviposition and food for the mobile stadia was provided in the form of eggs of *Cadra cautella* (Walker). Specimens of *O. limbatus* were caught in Los Moriscos in eastern Gran Canaria, on *Plocama pendula*. Specimens were determined by us using the Pericart codes (1972) and those of Gómez-Menor, Ortega (1958), together with other comparison material determined for us by Dr Pericart.

Results and discussion. An important finding was that the life-span of males is much shorter (roughly one half) than that of females. Fecundity was extremely high, with an average of 82 eggs. Egg-laying distribution is irregular, although in general most are laid during the first two weeks after which time there is a sharp fall. This, in conjunction with the fact that half of the females die by 15 days, would make it advisable not to use the population in mass rearing experiments for the present time.

Comparison of our results with those obtained by other authors (Table 3) with other species shows that *O. limbatus* is a good biological control candidate although it is necessary to complement the present work with studies of the mortality of the different life stadia, of the species' predacious capacity and the search for alternative oviposition surfaces.

Table 3. Comparison of life cycle parameters of *Orius limbatus* at 25 °C, according to different authors.

	27 °C *Orius albidipennis.* *C. kuehniella* eggs	FISCHER et al 25 °C *Orius majusculus.* *C. kuehniella* eggs	25 °C *O. limbatus.* *C. cautella* eggs
EGG	3.41	4.02	4.59
NYMPHAL PERIOD	11.04	11.4	11.81
PREOVIPOS. DAYS	2.37	4.1	3.73
OVIPOS. DAYS	21.11	52	16.35
DAILY FECUNDITY	2.06	6.31	4.90
TOTAL FECUNDITY	52.48	328	81.78

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(*summarized by the editor from a 14-page manuscript*)

THE PEPPER WEEVIL, *ANTHONOMUS EUGENII* CANO AS A GREENHOUSE PEST IN CANADA

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Abstract

The pepper weevil, *Anthonumus eugenii* Cano (Coleoptera: Curculionidae) was found infesting greenhouse peppers in Canada. Control and eradication strategies were developed for this sub-tropical pest. Results of a trial on the effects of temperature on longevity of adult weevils suggest that maintaining growing temperatures between crops is important to the eradication of this pest. This approach may be effective for other pests. Possible mechanisms for immigration of this pest into Canada include movement in imported fruit, on shipping palettes, and in weed hosts.

Introduction

The pepper weevil, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) was discovered damaging a pepper crop in a greenhouse in Langely, B.C. in the summer of 1992. The native distribution of the pepper weevil is restricted to northern Mexico (Essig 1958). It occurs in the pepper-growing regions of California, New Mexico, Texas, Louisiana and Florida where it survives only during mild winters (Essig 1958, Riley 1992). The biology of the pepper weevil has been summarized by Essig (1958) and Riley (1992). Adult pepper weevils feed on leaves and blossoms, and bore into fruit pods of pepper and other solanaceous plants. Eggs are laid in punctures made by the adults on flower buds and young fruit pods, and larvae feed on the seeds and other tissue in the developing fruit pod. Fruit are usually aborted after attack. The adults fly readily, and may be monitored by yellow sticky traps (Riley 1992).

Anthonomus eugenii has not been previously reported as a pest in Canada, although it has been recorded in imported pepper fruits in retail outlets in eastern Canada (Garland 1990). The circumstances surrounding its occurrence as a pest and our experiences in developing a control and eradication strategy may help others deal with this pest in greenhouses, and may ultimately suggest some general strategies for dealing with new and unexpected pests.

History

The pepper weevil was first discovered in late July, 1992. The numbers present at this time indicate that there likely had been at least two generations prior to this, requiring about seven weeks. Early signs of infestation were small holes in fallen immature fruit. These were initially attibuted to slugs or to cutworm caterpillars, particularly *Trichopusia ni* (Hübner) (Lepidoptera: Noctuidae). Small, circular, or oval holes (2 to 5 mm) in leaves were also attributed to caterpillar feeding. These are, however, quite characteristic of feeding by pepper weevil adults, and are quite unlike the wounds produced by caterpillars. Specimens were sent to the Agriculture Canada Biosystematics Research Centre in Ottawa and our preliminary identification was confirmed within a week.

Few insecticides are registered for use on greenhouse peppers in Canada. A literature search suggested that none of those would be effective against this pest. After considering efficacy, crop safety, and residue concerns, a submission was made to Agriculture Canada for emergency registration of the pyrethroid, permethrin, which was granted 18 days after the submission.

Initial control efforts were centred on removal of weevil-infested peppers. Oviposition scars were the best indicator of infestation. About 70% of the peppers in the greenhouse were culled and destroyed. The greenhouse managers estimated peppers valued at about $400,000.00 Canadian were removed. After permethrin applications began, infestation levels quickly dropped to less than 5% of the peppers in the crop. Within 8 weeks, fewer than 1% of peppers contained weevils. One of the side-effects of permethrin applications was the collapse of biological control of the twospotted spider mite, *Tetranychus urticae*, and the green peach aphid, *Myzus persicae*. Both of these pests were peristant problems in the crop for the remainder of the season. Damage caused by these additional pests, and the costs of their management added to the overall losses.

Eradication

A simple experiment on the effects of temperature on the survival of adult pepper weevils emphasized the importance of the management of the greenhouse environment between crops to eradication of this pest. Freshly emerged pepper weevil adults were collected from infested bell peppers and placed in groups of 5 in 32 plastic petri dishes. The bottom of the dishes was lined with 3 sheets of Whatman #1 filter paper. Half of the dishes were supplied with a slice of fresh pepper, which provided both food and water for the weevils. No food or water was provided to the other 16 dishes. Four dishes from each group were placed at each of 2, 5, 10 and 27°C, in incubators, without lights. The dishes were brought to room temperature for 1 hour every day to determine mortality. Weevils were considered to be dead if there was no leg reflex after 1 hour at room temperature. Pepper slices and filter paper were replaced as required.

In general, pepper weevil adults survived best at temperatures of 5 to 10°C (Table 1) with food. More than 50% of adults were still alive after 100 days at 10°C. Without food, 50% of adults were dead by 13 days, and 100% of adults by 28 days at 2, 5 and 10°C All adults were dead after 7 days at 27°C without food. Adults exposed to freezing temperatures (~-10°C) were dead in 15 minutes. Adults at 2 and 5°C were motionless during storage, and required about 0.5 h to recover after being returned to room temperature. The legs were generally curled under the body. Adults at 10°C were generally found in a standing position, although significant movement was not seen until the dishes had warmed slightly at room temperature.

Table 1. LT_{50} and LT_{100} in Days for adult pepper weevils held with and without food at 2, 5, 10 and 27°C.

Temperature	With Food		Without Food	
	LT_{50}	Lt_{100}	LT_{50}	LT_{100}
2°C	31	48	11	24
5°C	92	>100	13	27
10°C	>100	>100	12	28
27°C	40	88	4	7

We concluded that the pepper weevil could not be eradicated by chilling the greenhouse. Although severe freezing temperatures do occur in south coastal British Columbia, the timing is not reliable enough to guarantee eradication of adult weevils in an unheated greenhouse. Chilling the greenhouse to 2 to 5°C would require an extended shut-down of the greenhouse and food, either pepper fruit, leaves or stems, would greatly prolong the survival of adults. At high temperatures, adults died very quickly without food, presumably through dehydration. This was considered a practical approach, although costs of maintaining even 25°C for 10 days were prohibitive. Based on these results, and published information on the pepper weevil, the following eradication strategy was developed as a compromise.

All crop residue was removed carefully and thoroughly, and the plastic sheet covering the floor was rolled up and disposed. The entire greenhouse floor was sprayed with hydrated lime and sources of free water in the greenhouse were eliminated. The greenhouse was maintained at more than 20°C for more than 10 days and a high density of yellow traps was placed throughout the greenhouse to intercept flying adults, and to monitor the progress of the eradication program. Finally, the greenhouse was fumigated with several products. To date, no pepper weevils have been noted in the greenhouse.

Importation

As this is the first report of *Anthonomus eugenii* as a pest in greenhouse-grown pepper in temperate zones, some consideration should be given to how this insect invaded a greenhouse almost 3000 km from its closest native range. *Anthonomus eugenii* have been recorded infesting green pepper fruits in a retail outlet in eastern Canada (Garland 1990). Adult pepper weevils may have invaded from discarded fruits originating from nearby household waste, or from produce brought into the greenhouse by employees. The wooden palettes on which containers of produce are moved about in trucks and warehouses are transient items, and are not the property of any particular greenhouse operation or shipper. Some of the palettes discovered in the greenhouse in question originated in produce warehouses in southern California. These could have carried pepper weevil adults emerged from infested fruit. The palettes could have been maintained at about 10°C in warehouses and refrigerated trucks until their arrival at the greenhouse.

Finally, the fruit of a number of common North American weeds are important alternate and overwintering hosts. Most important among these are the nightshades, *Solanum* spp., and buffalo bur, *Solanum rostratum* Dunal (Patrock and Schuster 1992). Fruit of these plants could have been moved from the southern United States to Canada in any number of agricultural containers or shipments, and been deposited at nearby horticulture operations.

Throughout most of the spring, temperatures in southern B.C. do not allow development of pepper weevils. However, they are not lethal to pepper weevil adults either. Our results suggest that prolonged survival of adults in suitable situations, for example, inside fruit of alternate hosts, is entirely possible.

Conclusions

The occurrence of the pepper weevil in a northern temperate greenhouse, and the frequent occurrence of many other mediterranean and subtropical pests, for example, sweetpotato whitefly, tomato russett mite and melon aphid, suggests almost any pest insect or mite from these regions could occur in a greenhouse in northern temperate climates. Therefore it is appropriate to advise growers to determine a cause for all damage symptoms, and to arrange for routine identification of even familiar-looking pests.

As a general rule, shutting down a greenhouse seems to be a poor strategy for control of insect pests during the winter due to increased longevity and decreased metabolic activity at temperatures below 10°C. It may be more appropriate to take advantage of most insects' need for water, and their increased metabolic activity at temperatures above 20°C. Despite the cost, 7 to 10 days of temperatures above 20°C following a very careful clean-out of the greenhouse may be a far more effective clean-up procedure that prolonged periods of shut-down with temperatures below 10°C.

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INTEGRATED PEST MANAGEMENT IN GLASSHOUSE ORNAMENTALS IN THE NETHERLANDS: A STEP BY STEP POLICY

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Abstract
The governmental "multi-year-crop-protection program" has stimulated research, extension and practice to look for ways to become less dependent on the use of chemical pesticides. To implement IPM, close cooperation between the three organisations is needed. Research on population dynamics, selection of natural enemies and host plant resistance is carried out simultaneously with the introduction of IPM on different crops. Floriculture is characterized by its wide range of products. Experimental IPM is already in use on several cut flower crops (21.55 ha), and on a number of pot plant species (26.27 ha). IPM in Bouvardia, Chrysanthemum, rose, Gerbera, Ficus, and Poinsettia are of de highest priority.

Introduction
Protected cultivation of ornamentals in the Netherlands takes place on about 5278 ha (Anonymous, 1991a). One characteristic of Dutch floriculture is the wide range of products. About 110 species of cut flowers and 300 species of pot plants are being grown in a range of cultivars. Use of integrated pest management (IPM) has been lagging behind compared with IPM in fruit vegetables which started some 25 years ago. Three important reasons explain this. (i) More chemicals were available for ornamentals than for fruit vegetables because of safety regulations for vegetables. The first natural enemies for pest control were developed for control of acaricide resistance in spider mites. (ii) In fruit vegetables only the fruits are harvested, which allows for a certain level of the pest population and leaf damage can be tolerated. In contrast most ornamentals are being sold with flowers and leaves and thus, also leaves should be free of damage or presence of insects. (iii) Additionally, the criterion of the so-called "zero tolerance", only needed as an export requirement for a few countries, has been used generally as a "standard" for all products. The "multi-year-crop-protection program" of the Dutch government has initiated a policy to become less dependent of pesticides. (Anonymous, 1991b, van Lenteren, 1990). This has generated new actions in research, extension and industry among which biological control of pests and diseases in floriculture. (Fransen, 1993). The approach of IPM in Dutch floriculture is summarized below.

Research
Several new pest insects have recenltly infested ornamental crops. Beet army worm, *Spodoptera exigua*, western flower thrips, *Frankliniella occidentalis*, serpentine leafminer, *Liriomyza huidobrensis*, cotton aphid, *Aphis gossypii,* and sweet potato whitefly, *Bemisia tabaci,* have complicated the biological-control programs. Western flower thrips is considered to be the major pest, because of its feeding habits on flowers, flower buds and growing points. Whitefly can only be tolerated in low numbers because already low amounts of honeydew contaminate the plants. Both insect species form a potential risk by their ability to vector plant viruses. Besides, *Bemisia tabaci* by itself causes fytotoxicity in Gerbera (yellowing of flower stems) and Bouvardia (yellowing of young leaves) (van der Meer *et al.*, 1992). Several aphid species are infesting ornamentals. Predominantly cotton aphid and the endemic potato aphid, *Macrosiphum euphorbiae*, are a threat because of their high rate of increase. They can cause damage by the production of honeydew and the deformation of growing points and young leaves. Research at universities, research institutes, research stations and biological-control companies focusses on the following topics.

Population dynamics: Still a lot of information needs to be collected on the population development of pest insects. Life table parameters have to be established on different crops for pests like western flower thrips, leafminers, aphids and whitefly. For instance, for greenhouse whitefly extensive information has been collected on various fruit vegetable crops (van Roermund & van Lenteren, 1992), but related to ornamentals until recently only Gerbera has been considered (Dorsman & van de Vrie, 1987). Additionally, the relation between pest numbers and damage levels and ways of monitoring populations on ornamentals need to be studied. This kind of information is essential for the assessment of damage threshold levels which can be used for decisions on the use and timing of chemicals and/or natural enemies. In Chrysanthemum and rose where often chemicals are used in strict schedules, studies are being carried out to find a monitoring system and define threshold levels.

Natural enemies: Research is aimed at the selection of natural enemies. Information on life-table parameters, searching behaviour, preference and mass production are necessary to develop introduction strategies. Next to the approach of seasonal inoculative releases which may work well for greenhouse whitefly control by *Encarsia formosa* and for leafminer control by *Diglyphus isaea* and *Dacnusa siberica*, other approaches are considered. For control of western flower thrips releases of *Amblyseius* species can be combined with releases of *Orius* species. The predatory mites attack the first instar thrips larvae, whereas the pirate bugs prey on thrips of all stages except the eggs. The latter may control high density spots with thrips more easily. Banker plants may be used for a continuous supply of natural enemies. Possibilities are being considered for the pirate bugs and aphid parasitoids and already the rearing bags for *Amblyseius cucumeris* are widely used. On the tritrophic level there is not only an interaction between prey and predator to be considered but also an interaction between predator and host plant. *Orius insidiosus* has been observed to prefer Gerbera and Chrysanthemum to rose for egg laying which agrees with the negative results of introduction of the pirate bug on roses (Fransen, Boogaard & Tolsma, 1993). Therefore, another natural enemy, the parasitoid *Ceranisus menes* will be tested for control of western flower thrips in roses. Also other *Amblyseius* species being less dependent on high relative humidity are being tested (van Houten *et al.*, 1993). The results of aphid control have been positive since the differentiation of releases of *Aphidius colemani* against cotton aphid and of *A. matricariae* against *Myzus persicae*, and the use of *Aphidoletes aphidimyza*. As the damage threshold levels in ornamentals are generally low also inundative releases of natural enemies are considered to obtain an "overkill" of the pest.

Host plant resistance: An important contribution to the success of biological control can be use of resistant cultivars. The plant influence on survival and rate of increase in the pest population can be crucial. Differentiation in host plant resistance against leafminers and western flower thrips has been found in cultivars of Chrysanthemum (De Jong & Van de Vrie, 1987, Fransen & Tolsma, 1992). Plant breeders should take these factors into account for the development of new cultivars.

Extension

Regular support and information from extension officers is needed to motivate the grower with regard to relatively common methods for reduction of chemicals like good sanitation and the use of well-maintained spraying equipment. Reporting of the applied pesticides by the growers themselves also contributes to good horticultural practice. Courses on recognition of pests and diseases in the different crops are being organised and often fully booked. Information is published in special leaflets, posters, and articles in the grower's magazines. Improvement of knowledge on pests and diseases will make the grower more confident and stimulate a change of mentality from spraying schedules to supervised control.

Over 50% of the growers seem to use sticky traps in their glasshouses. However, it is not clear whether these play a role in their control strategy. Scouting for pests is offered to the grower as a service from the extension organisations. Although damage threshold levels are not yet well established growers may consider omitting regular sprays when low numbers of pests are found on the sticky traps. The amount of chemicals used even fluctuates for growers with the same crop and much can be gained by a more uniform approach. This is illustrated by a survey on insecticide and fungicide use at 15 chrysanthemum growers and at 7 Gerbera growers. The total amount of active ingredients per ha for one year varied from 23.4 to 71.0 kg for chrysanthemum and from 11.6 to 41.3 kg for Gerbera (Vernooy, 1992).

An interaction and dialogue between the growers and extension service and the researchers is essential for a good implementation of IPM.

Industry

In fruit vegetables the use of IPM expanded from tomato to cucumber to sweet pepper and recently also to egg plant (van Lenteren & Woets, 1988). In ornamentals the first efforts are carried out for different crops (Table 1). Already in 1992 on a total of 21.55 ha of cut flowers and 26.27 ha of pot plants experimental releases of natural enemies have been carried out. Additionally on 17.5 ha of pot plants and cut flowers insect-parasitic nematodes, *Steinernema* spp., have been applied against sciaridae. Additionally IPM is carried out in more than 5 ha glasshouses of institutes, botanical and zoological gardens. IPM has been introduced on a large scale in interior landscapes in office buildings. More than 20 different species of natural enemies are offered for pest control by various companies. Implementation supervised by the advisors of the companies producing the natural enemies. To prevent too much diversification of efforts and thus the danger of coming to a dead end, attention should be focussed on a range of priority crops being chosen on aspects of production area, acceptibility of damage, pests and availibilty of natural enemies. At the moment cooperation in research, extension and commercial releases takes place on Gerbera, Chrysanthemum, Bouvardia, Poinsettia and Ficus. In future, also rose and Saintpaulia may be included. A careful selection of growers is needed who are supported by an intensive extension program and to whom a continuous feed back from research is given. Experience will be built up step by step in the different crops over time, which may convince the grower that a good quality product can be offered at the auction by means of IPM.

As was concluded at the IOBC meeting in Veldhoven in 1991, realization of an environmentally safer crop protection necessitates a higher input in research and extension activities, particularly in the developmental and introduction phase to obtain the goals as presented in the Dutch "multi-year-crop-protection program".

Table 1. Area of commercial glasshouses in which natural enemies for control of pests have been released in 1992.

cut flowers	ha	pot plants	ha
Anthurium	2.80	Bromelia	2.00
Bouvardia	3.45	Dracaena	1.00
Chrysanthemum	3.15	Ficus	3.25
Cymbidium	3.00	Palms	7.70
Gerbera	5.55	Pelargonium	2.00
Rose	1.10	Poinsettia	4.00
		Schefflera	2.20
Others	2.50	Others	4.12
Total	21.55		26.27

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BIOLOGY OF *DELPHASTUS PUSILLUS*: THE INFLUENCE OF DENSITY ON FITNESS

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Abstract
We examined the influence of prey density on oviposition of the coccinellid predator *Delphastus pusillus*, of predator density on its emergence, and fitness parameters. Above 100 eggs/cm^2, on 23-25 cm^2 leaves, are needed for optimal oviposition. Food shortage for beetle larvae of the same age will result in mortality of all individuals; food shortage of beetle larvae of different ages will result in cannibalism and some adult beetle emergence. Larvae grown under crowding conditions have a tendency to develop faster and yield smaller adults that die younger.

Introduction

Recently, new thrips and whitefly species have become prominent in greenhouses (Van de Veire 1991). These can often be controlled through seasonal inoculative releases of beneficial insects (van Lenteren 1986), thus abstaining from insecticidal treatments while maintaining an acceptable crop quality. In order to attain this goal, it is neccessary to be familiar with numerous biological and physiological characteristics, which will facilitate economical mass rearing and efficient manipulation of the beneficial organism.

The coccinellid *Delphastus pusillus* has been observed in Florida as a predator of whiteflies. It was introduced into Israel in order to combat *Bemisia tabaci* (Gennadius) in 1990. Recently, *D. pusillus* was studied by Hoelmer et al. (1992) who provided information on its reproduction and feeding behavior as a predator of *B. tabaci*. We further examined its autecology and behavior in order to facilitate future utilization for whitefly control in confined environments.

Predators often require relatively high prey densities in order to locate their prey, and their immatures, often the most voracious phase of the life cycle, may have only restricted mobility (Gerling 1992). Therefore, it is essential to determine the density of *B. tabaci* at which *D. pusillus* adults will remain on prey-bearing leaves, when they will oviposit, and what the fate of the predacious larvae will be under different predator density and age regimes. The following experiments were designed to answer some of these questions, and to allow for better mass rearing and utlization of *D. pusillus*.

General Materials and Methods

All experiments were carried out at 26$\pm$2^{0}C and under a 14:10 L:D light regime. Potted cotton (Acala SJ2) plants were used as hosts for *B. tabaci*. Plants were infested by confining them with whiteflies at different densities as required. The culture of *D. pusillus* was obtained from Florida through the courtesy of Drs. L. Osborne and K. Hoelmer during 1990, and maintained ever since in our laboratory on *B. tabaci*. Beetles were released on whitefly-infested cotton plants. Approximately 18-20 days thereafter, we started to collect the new generation of beetles using an aspirator. The beetles for the experiments were taken from a cage containing whitefly infested plants. For many experiments we used plants from which all but one or two leaves had been removed. Statistical significance was determined using an SPSSPC program.

The experiments

Influence of prey density on oviposition and predator arrestment

Methods: Increasing numbers of whiteflies were released upon a one-leaf (about 24 cm^2) cotton plant, so that different egg densities were obtained. Thereafter, we counted the density of eggs on 15 leaf halves. We also counted the number of eggs on 1cm^2 for each half leaf and ran a correlation analysis. The results ($y=4.5x+151.8$ $R^2=0.83$ $P<0.001$) indicated that 1 cm^2. gives a good measure of egg density upon the leaf. Therefore, we used an average of three cm^2/leaf as a measure of egg density. The experiment was conducted by releasing a pair of beetles upon a one-leaf-plant and leaving them there for three days. The number of *D. pusillus* eggs was then counted, calculated as average daily oviposition, and correlated with that of prey eggs which were grouped at intervals of 30 eggs/cm^2.

Results: A significant ($R^2=0.98$) positive correlation between prey and predator egg densities was observed (Fig. 1). The curve shows a response of diminishing returns indicating the importance of handling time and physiological parameters at higher prey densities. Prey egg density upon leaves with more than 100 eggs per cm^2, was also typified by adult arrestment responses (table 1), where after three days significantly more beetles were found on the leaf than on the surrounding cage walls.

Fig 1. Relationship between whitefly egg density and average beetle oviposition

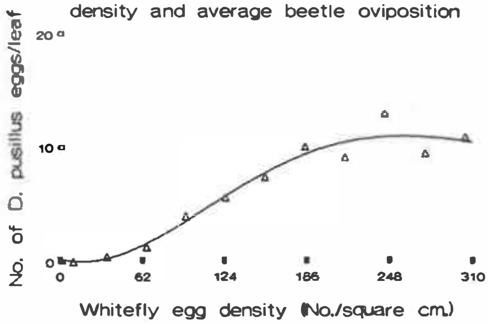


Fig.2 Relationship between No. eggs laid and adults emerging – Same age

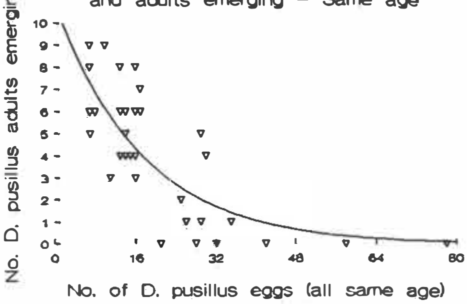
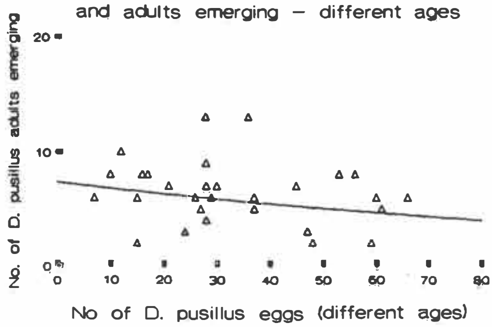


Fig.3 Relationship between No. eggs laid and adults emerging – different ages



Effect of larval density of D. pusillus on emergence

Methods: Increasing predator densities were introduced upon two heavily infested cotton leaves with a total area of 45 cm^2. Density was manipulated in two ways: 1. Predators of the same age. Pairs of beetles were placed upon the leaves and removed after 24 hours; 2. Predators of different ages. One pair of beetles was placed on the leaves and removed after either 2,3,4,6 or 8 days. The eggs and/or larvae of *D. pusillus* were counted upon removal of the beetles, and the number of F1 adult beetles was counted at the end of each experiment, approximately 20 days following oviposition.

Results: A most significant difference was observed between the two experiments. Whereas the 'equal aged' introduction resulted in a sharp decline leading to very low, or zero, emergence when more than 20 eggs were found on the leaves, the mixed age distribution showed a slow and insignificant decline (Figs 2 and 3).

Table 1. Location of adult *D. pusillus* females, in relation to initial prey egg density.

No. prey eggs/ cm2	No. *D. pusillus* adults on leaf	not on leaf	X2	significance
50>	14	15	0.0345	NS
50-100	19	14	0.7576	NS
100-200	20	5	9	$P<0.01$
200+	11	3	4.5714	$P<0.052$

Effect of larval density on size, longevity and developmental time

Methods: A correlation was established between pronotal width and dry weight (R^2=0.875 for females and 0.93 for males). Therefore, we used pronotal measurements as an indication of beetle size. We infested leaves with whiteflies and released beetles on them for 24 hours. The number of *D. pusillus* eggs was counted and they were allowed to hatch and develop to adulthood. The adults were collected and kept individually with honey until they died. Thereafter, the width of their pronotum was measured. Density was calculated as the number of adults emerging from the leaf/the number of beetle eggs found. A total of 86 males and 83 females were measured and compared. Comparisons included: pronotal size, longevity and developmental time (T-test). Thereafter, correlation tests were run separately for males and females between density and size, longevity, and developmental time.

Results: Females are significantly bigger than males ($P<0.005$) but longevity and development time did not differ between the sexes. The correlation tests were all insignificant, but there was a tendency at high density to be smaller, develop faster and die younger.

Relationships of longevity and adult size

Since the results of the previous experiment indicated a possible relationship between density at which beetle larvae developed and size, we ran a correlation test between pronotal width of a group of adult females and their longevity. The results showed a positive correlation, R^2=0.6, indicating an advantage to being large.

Discussion

We view the significance of the results from two aspects: mass rearing of the beetles, and their utilization for biological control. The relationship between oviposition, arrestment, and prey density - the density of whitefly eggs - is relevant to both aspects. On one leaf of 24cm^2, it seems most advantageous to mass rear the beetles at a density of 100-150 eggs per cm^2/beetle pair, keeping egg production high, and having the beetles stay on the leaves of release for at least 3 days. The benefits of using a higher egg density can only be considered following a comparative study of prey and predator dynamics.

Contrary to mass production, the utilization of beetles against whiteflies in greenhouses has the purpose of eliminating the prey from the plants, and should not allow a buildup of high prey densities. Therefore, attention must be paid to the function of *D. pusillus* under patchy host distribution of the type that whiteflies exhibit under various population densities. This means that we need additional information about prey finding capabilities under a confined, but densely planted greenhouse environment.

We also need to know how the beetles will behave once the prey has been located, in regard to oviposition, to progeny development, and control of the prey. Hoelmer et al. (1992) showed that beetles have to consume at least 150 eggs/day in order to oviposit. In our experiments, oviposition occurred from 50 eggs/cm^2 and up. Since we used 24cm^2 leaves, our results point to a somewhat higher requirement than theirs. However, both works indicated the need for an abundant supply of prey eggs for maximal oviposition. We also showed that beetle larvae may eradicate the prey population upon the leaf, especially when whitefly populations upon the leaf are not very large.

Finally, it was shown that high beetle density may reduce their fitness. Consequently, such conditions should be avoided during mass rearing.

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EXTENDING SEASONAL LIMITS ON BIOLOGICAL CONTROL

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Abstract
The critical daylength inducing reproductive diapause was determined for two populations of *Orius tristicolor* (White) (Heteroptera: Anthocoridae). The population from Agassiz, B.C., Canada, entered diapause at around 15 h, but a population from Davis, CA, USA, diapause was entered at around 12 hours. Practical solutions to the problem of extending seasonal limits on the activity of natural enemies in northern greenhouses are discussed.

Introduction

In the modern greenhouse, photoperiod may be the only major climatic variable that cannot be changed effectively and economically. For certain high value crops, for example chrysanthemum and rose, lights and black-out curtains are used to modify external photoperiods to induce or maintain flower production. In vegetable crops, lights are used to extend daylength during propagation, but are not in general use.

Insects in temperate zones use daylength in various ways to determine season and therefore trigger major physiological changes such as diapause (Saunders, 1974). Consequently, the cue that indicates season may be at variance with the reality of temperature and crop stage. Some of the natural enemies used in greenhouses diapause in response to photoperiod, and may therefore be inactive during parts of the year when the pests they are targeted against are active. Since one of the major purposes of a greenhouse in northern temperate zones is to extend the growing season past climatic limits, means must be found to extend the period of the year during which the natural enemies used in greenhouses are active.

Three mechanisms for extending the seasonal limits of natural enemies have been demonstrated. Gilkeson and Hill (1986a) showed that low intensity lights on a long photoperiod could be used to keep *Aphidoletes aphidimyza* (Rondi) (Diptera: Cecidomyiidae) from diapausing in winter.

Selection for non-diapausing strains of natural enemies has been demonstrated (Gilkeson and Hill 1986b; Morewood and Gilkeson 1991). The predatory mite, *Amblyseius cucumeris* (Oudemans) (Acari: Phytoseiidae) can be prevented from entering reproductive diapause by maintaining a constant temperature above 21°C (Morewood and Gilkeson 1991).

Insects and mites that are widely distributed possess clinal variation with regard to the critical photoperiod inducing diapause (Dansilevskii 1965, Taylor and Spalding 1986; Vaz Nunes et al. 1990). In general, the critical daylength required to induce a diapause response decreases with latitude (see particularly analysis in Taylor and Spalding 1986). This presents a possible, fourth mechanism for extending seasonal limits of natural enemies in northern temperate greenhouses. If a geographical race from a southern temperate or sub-tropical zone is selected, it should have a short critical daylength relative to more northerly populations of the same species.

In this paper we describe the responses to daylength of two different geographic races of the minute pirate bug, *Orius tristicolor* (White) (Heteroptera: Anthocoridae).

Materials and Methods

Populations of *O. tristicolor* from Agassiz, British Columbia, Canada (Latitude 49°N) and Davis, California, U.S.A. (Latitude 38°30'N) were used. Newly emerged adults from colonies of each of the geographic races were separated into male/female pairs, and caged with snap bean (*Phaseolus* *vulgaris* L.) pods and supplied with frozen eggs of *Sitotroga cerealella* (Olivier). After 48 h, pods containing eggs were placed in clear plastic containers (30 by 60 by 10 cm deep) with twospotted spider mite on bean leaves. The containers were covered by tight-fitting lids with large, mesh-covered vent holes. Twospotted spider mites on bean leaves were added to the containers every other day. These containers were held in growth chambers with a Light:Dark (L:D) cycle set at 16:8, 14:10, 13.5:10.5, 13:11, 12.5:11.5, 12:12, 11:13 or 10:14 hours. Light in the chambers was supplied by 8, 15 watt fluorescent tubes. Day temperature was set at 25°C and night temperature at 15°C. When adults emerged, females were paired with males of the same geographic race and daylength treatment in cages. Cages were supplied with a piece of fresh bean pod and frozen *S. cerealella* eggs. Fresh bean pod and eggs were added every other day. Females were removed from cages after seven days, killed in alcohol and dissected to determine the condition of ovaries. Ovaries were inspected and scored as developed (1 or more mature eggs present) or undeveloped (no eggs present).

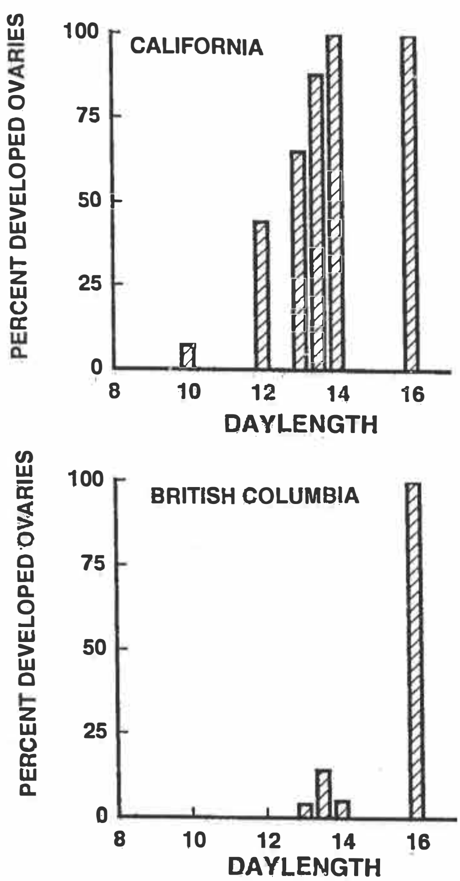

Figure 1. **Percent of ovaries of *Orius tristicolor* (White) females from either California or British Columbia that contained mature eggs when reared from egg to adult at various daylenghts.**

Results and Discussion

Under the test conditions, females from California showed considerable development of ovaries at daylengths above 12 hours, whereas females from British Columbia showed almost no development of ovaries at any daylength other than 16 hours (Fig. 1). The lack of development of ovaries is presumed to be symptomatic of onset of reproductive diapause in this species, as it is in *O. insidiosus* (Kinglsey and Harrington 1982; Ruberson et al. 1991). In these data, the critical daylength for induction of reproductive diapause in minute pirate bugs from California appears to be around 12 hours, and for minute pirate bugs from British Columbia, between 14 and 16 hours.

It is possible that, due to the nature of the experiment, the critical daylength of the minute pirate bugs from California may be over-estimated. In these experiments, adults were returned to the conditions of rearing. Adults experienced not only the daylength noted, but also a Day-Degree accumulation over 7 days that decreased linearly with daylength.

Thus, temperature during the 7 days the adults were held, could have slowed the development of ovaries, producing a similar result to Fig. 1.

The critical daylength appears to be around 15 hours for the population from Agassiz, B.C. This daylength occurs in the first week in August, if one discounts twilight, and in the first week of September is twilight in included. Adult *Orius tristicolor* collected from outdoors around Agassiz, B.C. are reproductive in early August (N=7). Their progeny, found as adults in early September, are in reproductive diapause, as determined by oviposition, and by fat body and ovary examination (N=40).

These results demonstrate that using more southerly geographic races of predators would be a useful approach to the extension of the seasonal limits of natural enemies used for biological control in greenhouses.

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AN ENTOMOPHILIC NEMATODE, *THRIPINEMA NICKLEWOODII* AND AN ENDOPARASITIC WASP, *CERANISUS* SP. PARASITIZING *FRANKLINIELLA OCCIDENTALIS* IN CALIFORNIA.

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Abstract

Biological control of arthropod pests on greenhouse crops continues to be hampered by an inability to successfully control the western flower thrips, *Frankliniella occidentalis* (Pergande). Two new natural enemies have been recently recovered in the state of California and are reported here. An internal entomophilic nematode, *Thripinema nicklewoodii* Siddiqi, has been found parasitizing larval and adult female *F. occidentalis* in several California counties. Additionally, a minute Eulophid wasp, *Ceranisus* sp., recovered from thrips-infested alfalfa and roses, has been found to parasitize larval *F. occidentalis* under laboratory conditions. Although preliminary, these findings document the first known occurrence of a hymenopterous parasitoid successfully attacking and developing on *F. occidentalis*. The potential for utilizing these natural enemies to control *F. occidentalis* is briefly discussed.

Introduction

The western flower thrips, *Frankliniella occidentalis* (Pergande) is currently the most prevalent species of thrips attacking greenhouse floricultural and vegetable crops worldwide (Robb, 1989). Plant damage occurs primarily to developing floral tissue and vegetative growth points resulting in scarred floral parts and malformed foliage and fruit. Feeding injury is often cosmetically undesirable, yet the greatest threat to many crops is the transmission of tomato spotted wilt virus (Allen, 1992). Six thrips species including *F. occidentalis* are presently the only known vectors of this extremely damaging virus (Best, 1968).

Control of *F. occidentalis* is dominated by chemical insecticides (Greene and Parrella, 1992) and is complicated by factors including minute size, short developmental time, high fecundity (Robb, 1989), protected life stages and extreme thigmotactic behavior (Lewis, 1973). Control failures have increased in the last decade (Robb, 1990) with recent documentation of resistance to four major insecticide classes (Immaraju, et al., 1992).

As an alternative to pesticides, biological control of *F. occidentalis* has received increasing attention. Predacious mites and anthocorids have provided adequate control of thrips on greenhouse-grown cucumber and sweet pepper in Canada and Europe (Gilkeson et al., 1990; Lindqvist, 1990; Powell and Lindquist, 1992; Ramakers, 1990; Steiner & Tellier, 1990), while performance in floricultural crops has been largely unsatisfactory (Hessein & Parrella, 1990; Smitley, 1992). Efforts to find other more effective biological control agents such as hymenopterous parasites (Loomans and Van Lenteren, 1990) are ongoing.

As part of a project directed towards developing an IPM program for *F. occidentalis*, regular thrips collections were made from alfalfa and roses in several areas of California for a one year time period (October 1991 - October 1992). In the course of identifying specimens, an entomophilic nematode, *Thripinema nicklewoodii* Siddiqi, was found inhabiting the abdomens of female *F. occidentalis* from several collection sites. Additionally, a hymenopterous parasitoid tentatively identified as *Ceranisus* sp. (M. Schauff, USDA) was found in association with high densities of *F. occidentalis* in field-grown alfalfa and garden roses. When confined in small cages with larval *F. occidentalis*, *Ceranisus* sp. parasitized and completed its development on this host. Here we briefly review the literature regarding these two natural enemies and report our observations to date. While both are new records for the state of California, *Ceranisus* sp. is the first known hymenopterous parasitoid attacking and successfully developing on *F. occidentalis*.

Nematode

Previous records. Parasitic nematodes of thrips were first reported from Europe when Uzel (1895) observed an unnamed specimen within the body cavity of *Thrips physopus* L. In that instance and in several reports that have followed, ovarial tissue of the parasitized thrips was often damaged (Reddy et. al., 1982) and greatly reduced in size (Wilson and Cooley, 1972). This suggested a suppression of oogenesis and concurrent reduction in overall host fecundity.

The first North American record of the entomogenous nematode *Howardula aptini* (Sharga, 1932) (now *Thripinema nicklewoodii* Siddiqi) was reported by Nickle and Wood (1964) when it was observed parasitizing two species of thrips, *Frankliniella vaccinii* Morgan and *Taeniothrips vaccinophilus*, both economic pests of lowbush blueberry in New Brunswick, Canada. Documentation of the nematode parasitizing a new host, *F. occidentalis,* was made by Wilson and Cooley (1972) in El Paso, Texas, representing the first record of *T. nicklewoodii* in the continental United States. A decade later in India, Reddy et al. (1982) reported the same nematode parasitizing a new host, *Megaluriothrips* sp., a pest of several leguminous crops.

We routinely made collections of thrips in several areas of California and a portion of each sample was slide mounted to verify identification. Based on samples from several counties, we report *F. occidentalis* being parasitized by *T. nicklewoodii* in the state of California. In instances where the nematode was found, adult female parasitism ranged from 19 to 33 per cent.

Biology. While penetration of the infective stage nematode into the thrips' body cavity has not been observed, free-living fertilized *T. nicklewoodii* are believed to enter larval thrips by boring through the host cuticle using a slightly protruded stylet. Once within the thrips hemoecel, the female nematode swells to a sac-like organism in which her reproductive system becomes the only visible structure. Copious amounts of nematode eggs (up to 215 as observed by Lysaught) are released into the host hemoecel and upon hatching into vermiform larvae, begin feeding on the fluid contents of the thrips' abdominal cavity. When mature, both male and female nematodes burrow into the lumen of the host gut and pass out of the anus as free-living forms.

Site of transmission. The site of transmission, whether within the soil or in the plant canopy, is still speculative. In the case of *Frankliniella vaccinii* Morgan and *Taeniothrips vaccinophilus* which both produce leaf galls on lowbush blueberries, Nickle and Wood (1964) proposed that both nematode fertilization and penetration into the thrips were likely to occur within the confines of the gall since prevailing high humidity in the gall microhabitat would aid nematode movement. Although *F. occidentalis* does not produce galls, it does feed in tightly confined habitats such as within flowers and foliage terminals where humidity is similarly high. Since mature nematodes exit the thrips anus via frass, these free-living forms probably accumulate in and around foraging sites where thrips defecation activity is high, presumably attaching themselves to and penetrating unsuspecting immatures within the area.

Second instar thrips containing the nematode have been recovered from plants. Since these larvae do not come in contact with the soil until the end of the second instar, transmission is most likely to have taken place on the plant as opposed to the soil.

Recently, nematode-infested *F. occidentalis* adults were confined on a leaf in a modified Munger cell (Munger, 1942; Morse et al., 1986). Within 24 hours, highly active free-living nematodes were found moving about in freshly deposited defecation droplets adhering to the plexiglas walls of the cage. Longevity of these free-living nematodes has not been determined.

Impact on thrips. Lysaught (1937) proposed that parasitized thrips probably do not produce eggs due to a significant reduction in ovarial tissue caused by large numbers of egg, larval and adult stage nematodes inhabiting the abdomen of infected individuals. Our observations confer with this: of the 67 parasitized adult female thrips recovered (N = 227), we observed only one of these individuals containing a matured egg while eggs were present in over 98% of nonparasitized thrips.

Parasitoid

Previous records are scarce. Thirty-two species of hymenoptera (superfamily Chalcidoidea) are known as being parasites of thrips (for a review see Loomans and Van Lenteren, 1990). To date, only one wasp species has been cited as potentially being parasitic on *F. occidentalis*. The citation came from a study of *F. occidentalis* as an economic pest of seed alfalfa in Canada (Seamans 1923) indicating that *Thripoctenus americensis* Gir (now *Ceranisus americensis*), "has been found in association with the thrips in alfalfa (and) might be parasitic" (p. 104). This observation, however, was not substantiated by observations of actual parasitization and development of the wasp within *F. occidentalis*.

Discovery of parasitoid in Davis, California, USA. Sweep-net samples taken from alfalfa fields and collection from garden roses in Davis, California during September 1992 for the purpose of collecting *F. occidentalis* and other arthropods included male and female *Ceranisus* sp. (as per identification by M. Schauff, USDA, Beltsville, Maryland, USA).

To assess the impact of the wasp on western flower thrips, field-collected *Ceranisus* sp. were placed in modified Munger cells (Munger, 1942; Morse et al., 1986) and exposed to first instar *F. occidentalis* larva as per a similar protocol developed by Murai (1990). Shortly after being placed into the arena with 10 hosts, the female wasp caught and subdued the prey by inserting her ovipositor into the lower thorax or abdomen of the host. The wasp then raised its abdomen lifting the impaled host from the substrate. Unable to escape in this position, the host remained for approximately 30 seconds to a minute. If the host was an older first instar or young second instar, it would crawl away as soon as the wasp let it back down onto the substrate.

Host feeding. The younger, smaller first instars were often left paralyzed after being probed by female wasps. In many such cases, the wasp would often turn and feed on the fluids exuding from the site of ovipositor insertion. Host feeding appears to be lethal as thrips that were fed on did not recover.

Development. Host larvae surviving the sting continued to develop and feed normally but became lethargic during the late second instar when abdominal deformities were often observed. Development of these larvae was finally arrested during the pre-pupal stadium when immature parasitoids were visible through the cuticle of the thrips. Within 48 hours, the pupal wasp rises out of the thrips cadaver which is reduced to a dried integument attached both to the leaf surface and to the base of the wasp pupa. The wasp pupa orients itself almost perpendicular to the substrate where it remains till emergence.

Based on preliminary data collected from 76 parasitized *F. occidentalis*, total development time of the wasp from egg to adult is 27.0 ± 1.3 days at a temperature of 25 °C and a light regime of 16L: 8D. Development from egg to pupa was 10.4 ± 1.8 days with the pupal stage lasting 16.2 ± 1.0 days.

Discussion and Conclusion

Although this laboratory study documents parasitization of *F. occidentalis* by *Ceranisus* sp., collections of parasitized larvae from the field are still needed to determine if *F. occidentalis* is in fact a natural host of this parasitoid. Other thrips species collected from alfalfa and roses included *Caliothrips fasciatus* and *Thrips tabaci*, however relative numbers of these species were insignificant when compared to *F. occidentalis*.

Both the nematode and wasp may offer novel approaches to biological control of *F.*

occidentalis. Currently, the effect of these natural enemies on thrips populations remains unclear. Further research addressing the nematode and parasitoid is needed to assess the impact of these natural enemies on populations of *F. occidentalis*.

Acknowledgments

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SUPERVISED CONTROL IN CHRYSANTHEMUMS: ONE YEAR'S EXPERIENCE

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Abstract
At eight commercial chrysanthemum holdings the possibilities for supervised control were assessed. Insect populations were measured by weekly crop sampling and counts on yellow sticky traps. The amount of insecticides used was lower compared with greenhouses where pesticides were applied preventively. Especially in winter and spring the use of insecticides can be reduced. Suggestions for a faster method of assessing insect populations are discussed.

Introduction

In The Netherlands the use of pesticides in floriculture has to be reduced by about 60% in the year 2000 (LNV, 1990). Therefore, a project of supervised control in chrysanthemums was started in 1991 by the Plant Protection Service (PD), the Extention Service (DLV) and the Research Institute for Plant Protection (IPO-DLO). This followed a previous project where supervised control was implemented in one commercial greenhouse (Zwinkels, 1992). The aim of the present project is to obtain more experience with and information on the possibilities and limits of supervised control in several commercial chrysanthemum greenhouses in different parts of The Netherlands.

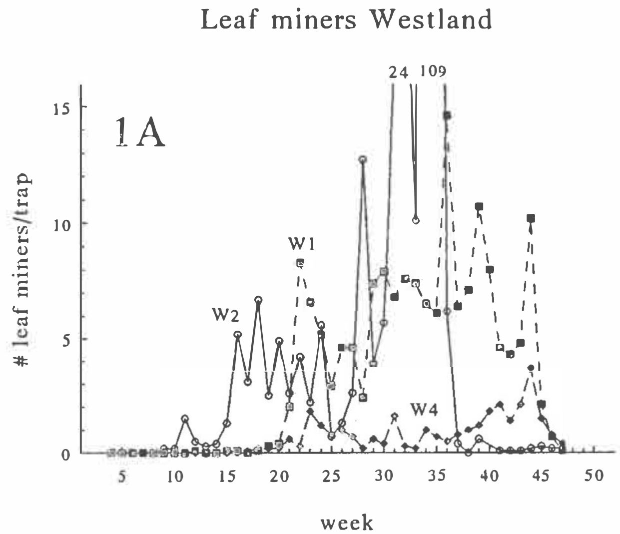
Methods

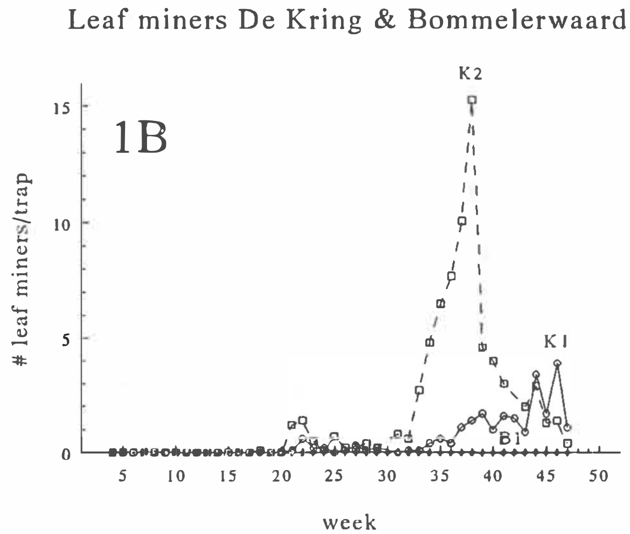
Five growers in Westland (W1-W5), 2 in De Kring (K1, K2) and 1 in Bommelerwaard (B1) joined the project. Westland has the highest density of greenhousew with vegetables and flowers, which may result in a heavier infestation of the crop by several pests than elsewhere. De Kring and especially Bommelerwaard are supposed to be areas with less heavy infestation pressure. The size of the greenhouses ranged from 0.9-2.4 ha.

Weekly monitoring started in Januari or February 1992, and was performed by the grower or his employee, and the Plant Protection Service. In one instance the grower hired a scout. Assessment of infestation of leafminers (*Liriomyza*), thrips (*Frankliniella*), aphids (e.g., *Myzus persicae* and *Aphis gossypii*) and whiteflies (*Trialeurodes*) was monitored using 19-36 yellow sticky traps (Horiver, 10x20 cm) per greenhouse, resulting in 1 trap/265-475m2, or 1 trap/750 - 1160m2 in the two greenhouses larger than 2 ha. Normally, every planting had at least one trap. Further, crop infestation for the forementioned species, spider mites and caterpillars (especially *Spodoptera*) was assessed by incidence counts on 5-7 fixed sampling sites per planting (36-64 plants/site) located on two paths, where infestation was also monitored by just walking through. These data were used, amongst others, to decide about the application of pesticides (see below), though formal action thresholds are not available yet. In monthly meetings, growers, extention workers and scientists discussed the results of the different greenhouses.

Results and discusssion

The monitoring with yellow sticky traps showed that the level of infestation differed between greenhouses and areas (Table 1). Especially in the more isolated greenhouse (B1) fewer insects were found, except for thrips. In Westland the infestation of leafminers started between mid February and the end of April, while in De Kring the first leafminers were found between the





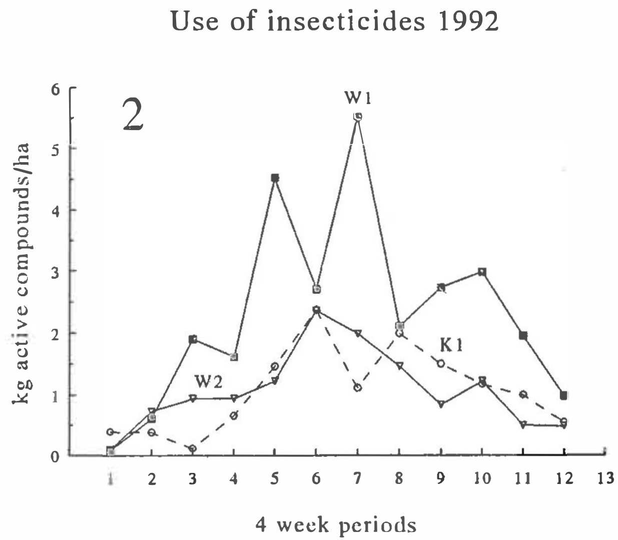


Figure 1. A: mean number of leaf miners counted in 1992 on yellow sticky traps at greenhouses in Westland (W1,2, 4) and B: De Kring (K1,2) and Bommelerwaard (B1).

Figure 2. The use of insecticides measured over 4 week periods in kg active compounds/ha in two greenhouses with a high and low input in Westland (W1,5) and one in De Kring (K1).

Table 1. Mean number (m) and weekly mean maximum (max) of insects counted on yellow sticky traps in 1992 (week 3-7 to 47) at greenhouses in Westland (W), De kring (K) and Bommelerwaard (B). 1st-w=the week of first appearence of leaf miners.

greenhouse		W1	W2	W3	W4	W5	K1	K2	B1
leafminers	1st-w	12	7	12	17	17	20	17	36
	m	3.7	7.0	2.0	0.7	1.3	0.5	1.7	0.0
	max	14.6	108.8	14.2	3.7	4.8	3.9	15.3	0.0
aphids	m	4.6	2.2	3.4	2.5	6.8	0.9	1.0	0.0
	max	36.7	12.2	30.7	12.4	49.4	5.2	11.8	0.1
thrips	m	13.1	6.4	11.7	1.8	5.0	2.8	3.7	6.5
	max	47.0	52.7	47.6	6.5	29.3	15.0	9.5	28.5
whiteflies	m	13.4	5.1	10.4	3.6	9.9	14.3	11.5	0.4
	max	75.1	53.3	110.4	19.6	41.9	50.9	106.1	3.2

end of April and mid May; in Bommelerwaard leafminers did not appear until September(Figure 1, Table 1). By careful monitoring with traps and in the crop the amount of insecticides used to control leafminers can be reduced considerably. Because of the growers' fear of mines in the crop, leafminer control takes place from the first observation until no leafminers are found in the greenhouse anymore.

The peaks of aphids measured on the traps in three greenhouses (W1, W3, K2), which are ca. 5, 20 and 24 km from each other, coincided, and the numbers observed inside one greenhouse (W5) reflected those counted outside very well. This indicates that during the summer the fluctuation in numbers is predominantly determined by migrational patterns of aphids outside the greenhouse, which are mainly aphids not able to live on chrysanthemum (Guldemond, unpubl.). Therefore, in the summer traps are less useful for monitoring aphids in the crop and sampling of the crop is vital (Guldemond, in press). However, aphids found on the traps in the winter, when the vents are usually closed, signals the presence of aphids in the crop. Control of aphids only takes place when one large or several small colonies are found.

The situation with thrips seems to be more complicated than for leafminers and aphids, because some thrips can be tolerated in the crop. The number of thrips on the traps gives an indication of the population, but injury caused in the crop seems to be a more reliable measure for the development of damage thresholds. This is complicated because of differences in resistance of chrysanthemum varieties (Van Dijken & Mollema, 1992; De Jager et al., in press), the influence of season on the sensitivity of the plant for thrips damage and the activity of the thrips, and whether Tomato Spotted Wilt Virus (TSWV) occurs or not.

Whiteflies were sometimes found in big numbers on the traps (Table 1). Only when swarms of flies were observed at specific spots in the crop and honeydew was found on the leaves was control considered necessary. Therefore, the numbers on yellow traps were not considered relevant for descisions about control. Spider mites and beet army worms were only found by crop sampling, and were controlled when present.

The experiences with sampling showed that less emphasis should be placed on the traps and more on crop sampling. The low density of pests and their aggregated distribution (Guldemond, in press) makes the use of fixed sample sites less suitable. Therefore, monitoring is suggested to take place along transects (e.g. along at least two paths per planting and the main path of the greenhouse). Traps are still useful for monitoring the numbers of leafminers and thrips during the entire season, and aphids in the winter season. Monitoring with traps will

Table 2. The use of insecticides and total amount of pesticides in kg active compounds/ha/47 weeks.

greenhouse	W1	W2	W3	W4	W5	K1	K2	B1
insecticides	24.3	27.5	15.9	13.9	12.1	13.0	10.6	31.8
% insecticides	*50*	*44*	*42*	*36*	*56*	*36*	*22*	*51*
total pesticides	48.6	63.0	37.5	38.7	21.6	35.1	49.1	62.9

be more important in winter and spring, because in the summer control levels will be reached more quickly. Also, in summer traps are probably more efficient in catching insects because of their higher mobility. Therefore, fewer traps will be used in the summer (minimal 10/ha or 1 per planting) than in winter (ca. 20-30/ha).

The amount of insecticides used in the participating greenhouses, 10.6-31.8 kg active compounds/ha/47 weeks (Table 2) is lower compared with greenhouses without supervised control, where the lowest and highest 20% were 15.6 and 44.8 kg active compounds/ha/year, respectively (Vernooy, 1992). However, the amount of fungicides used by the participating growers is still high (Table 2). The total amount of insecticides used varied between the greenhouses from the same area and with a similar infestation pressure (Figure 2), which indicates that more reduction is still possible. In De Kring fewer active compounds were applied compared to Westland (Table 2). The greenhouse in Bommelerwaard (B1) was infected with TSWV and spider mites and, therefore, had a higher use of pesticides than expected for an isolated greenhouse.

An optimal method of crop sampling has to be developed to ensure a reliable detection of pests as aphids, whiteflies, spider mites and caterpillars. At the moment, the timing of chemical application in supervised control in chrysanthemums is a rather intuitive one. More precise thresholds would be desirable but constraints are the limited amount of time available for monitoring and the variability between observers in the precision of estimating infestation (Theunissen & Legutowska, 1992). Nevertheless, the project has shown that reduction of the use of insecticides is possible, especially during the winter and spring.

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INTEGRATED PEST AND DISEASE MANAGEMENT IN HUNGARIAN GREENHOUSES

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Abstract
The greenhouse industry in Hungary is described, as well as the occurrence of key pests and the natural enemies which are used in protected crops. An important Hungarian development has been the testing and practical development of microbial control of soil-borne pathogens. Two antagonists, *Trichoderma* spp. and *Streptomyces griseoviridis* are now available as standard biopreparations. One, *Streptomyces*, is registered for use on ornamentals in Hungary.

Greenhouse industry and arthropod pests

The area of protected crops in Hungary is about 5300 ha. Most of it is under plastic (table 1), the area under glass being only about 250 ha. Vegetable crops growing makes up 80% (table 2), mostly on private farms. The main crops are capsicum, tomato and cucumber. On relatively small areas, ornamentals, principaly cut flowers, are produced: carnation, gerbera, rose and chrysanthemum. The three most important, commonly occurring pests are *Trialeurodes vaporariorum, Tetranychus urticae* and aphids (*Aphis gossypii*, *Myzus persicae*, *A. nasturtii*). Biological control is applied against whitefly and spider mite (table 3). *Polyphagotarsonemus latus*, *Liriomyza trifolii* and *Aculops lycopersici* caused considerable economic damage during the eighties. However, in the last few years these pests have not been observed in any crops. Two new glasshouse pests have been described from ornamentals during the last two years in Hungary: *Frankliniella occidentalis* and *Bemisia tabaci*. Their accidental appearance in vegetable crops could lead to direct economic loss, besides endangering biological control systems.

Frankliniella occidentalis was first found in 1989 on various cut flowers all over Hungary. The following year, it caused very serious damage to several ornamental growers. Both chemical and biological control of this pest are rather difficult. Biological trials with *Amblyseius* spp. have failed.

Bemisia tabaci was first found in Hungary as a new pest in 1990, on poinsettias. It was mainly observed on ornamentals but sometimes on tomato and capsicum crops. In summer 1990, it was also found in the field on aubergine. This pest can be controlled by the parasite *Encarsia formosa*, but higher numbers and more frequent regular introductions of *E. formosa* are needed than for control of *T. vaporariorum*. As an additional treatment, buprofezine sprays can be used. This compound is not harmful to *E. formosa* and *P persimilis* and can be applied in IPM.

Biological control research in the near future

The development of IPM in protected crops has to keep in focus the biological control of aphids, *F. occidentalis* and *B. tabaci*. There is some experience against aphids with the parasite *Aphidius matricariae* and the predator *Aphidoletes aphidimyza*. For their application in practice, economical mass rearing has to be developed. Research on entomopathogens (*Verticillium* spp., *Entomophthora* spp.) is needed to determine the possibility of their use.

For biological control of *F. occidentalis*, a programme has been initiated to search for new natural enemies (parasites and predators). For *B. tabaci*, research is planned to study entopathogens (*Aschersonia* spp.. *Verticillium* spp.) and predatory bugs, which could probably be complementary to the parasite *E. formosa*.

Table 1. Area of protected crops in Hungary (in hectares).

Glass			250
Plastic			5050
	- walk-in	4250	
	- low	800	
	- heasted	1600	
	- unheated	3450	
Total			**5300**

Table 2. Potected crops in Hungary (in hectares).

Crop		
Vegetables		
- capsicum	1900	
- tomato	1700	
- cucumber	450	
- others	1050	
Subtotal		5100
Ornamentals		
-cut flowers	160	
-others	40	
Subtotal		200
Total		**5300**

Table 3. Biological control used on protected crops in Hungary in 1990.

Crop	Area (ha) with *Encarsia formosa*	*Phytoseiolus persimilis*
Tomato	22.3	-
Capsicum	1.9	1.5
Cucumber	5.8	1.1
Others	0.3	0.1

Microbial control of soil-borne pathogens in Hungary

Biological control of soil-borne pathogens has been the aim of the Biological Control Laboratory in Hódmezövásárhely since 1982. In Hungarian greenhouses (this means areas both under glass and plastic foil cover), the growing medium is still the natural soil or mixtures based on soil. This is the reason why soil-borne pathogens, such as species of *Fusarium*, *Sclerotinia, Phytium, Botrytis* and *Alternaria,* cause increasing problems, especially at sites where there has been intensive continuous cropping for many years. Soil steaming is very expensive, while methyl bromide and other soil disinfectants are harmful for the environment and especially for the soil microflora.

All this favours the introduction of biological control against soil-borne plant diseases. After laboratory tests, experiments have been carried out over a 9-year period, with good results, on several *Trichoderma* species and strains in relation to practically all glasshouse crops (capsicum, lettuce, tomato, ornamentals, etc.) and in some field crops also. Since 1986 experiments have been done with Finnish-originated strains of *Streptomyces griseoviridis,* then with the preparation Mycostop which was developed from this actinomycete. These were carried out on ornamentals, on vegetables and on some cereals. The preparation was especially effective against *Fusarium* spp. but also against other pathogens.

***Trichoderma* spp.**

The first antagonists tested were various natural isolates of the fungal genus *Trichoderma.* Soils were screened for new, effective isolates of various *Trichoderma* spp., which were bioassayed and screened in the laboratory against isolates of pathogens. Small-scale *in vivo* and large-scale field trials were carried out, with checking of the effects on the soil microflora. Mass-production techniques were developed to produce a biopreparation, and appropriate application techniques were worked out. This work has now been in progress for 9 years, partly in successful cooperation with the Plant Protection Institute of the Hungarian Academy of Sciences. There now exists a Hungarian standard *Trichoderma* biopreparation. Its official registration is likely to be costly, so the possibility fot its commercial application depends on the financial situation of the companies interested in it.

During the experiments, it became clear that *Trichoderma* spp. are effective hyperparasites of plant pathogens. They produce fungistatic of fungicidal types of antibiotics, and are able to lyse the cell walls of pathogens found in an effective of dormant state in the soil. They are also able quickly to occupy the life space and utilize the nutrients in the soil. Experiments carried out in Hungary show that the antagonistic properties do not belong to whole species but to specific strains within specific populations.

Application of the *Trichoderma* biopreparation can be by soil treatment, seed treatment, spraying and in some cases tree wound treatment. The range of soil-borne pathogens which can be controlled by the *Trichoderma* biopreparation is wide: *Sclerotinia, Botrytis, Rhizoctonia, Phytium, Alternaria, Fusarium,* etc. The glasshouse crops which can be protected from the above-mentioned pathogens, according to our experiments, are mainly lettuce, capsicum, tomato and melon, but successful trials were performed in some other crops too. In the majority of cases there was a substantial yield increase, as a secondary but important effect.

Besides the extensive experiments with *Trichoderma* spp., our Laboratory has worked on several strains of other antagonists - fungi like *Gliocladium* and *Ampelomyces* spp. and also bacteria like *Pseudomonas fluorescens* and *Bacillus subtilis.* With these antagonists, only *in vitro* screenings have been performed, the possibilities for field trials being limited by cost.

Streptomyces griseviridis

The situation is different in the case of another antagonist, *Streptomyces griseviridis*, of which strains were obtained from Helsinki Univertity (Finland) in 1985. Early results showed that the incidence of soil-borne plant diseases was low in peat where this actinomycete is present. Several actinomycete strains were isolated from this "suppressive"peat, identified by ATCC, and tested *in vitro* in small-scale trials. Some of these strains were also screened in Hungary and found effective against the majority of important soil-borne fungi. Exchanges with the Finnish colleagues led to involvement in a Finnish project for developing a biopreparation from the best strain of *S. griseoviridis*. This is now called Mycostop.

In Hungary experiments have been carried out with this preparation since 1986 in carnation, gebera, wheat, melon, capsicum, cucumber, etc. From many years of trials here, we mention just some examples. The preparation provided good results against fusarium wilt of carnation which is rather difficult to control with traditional fungicides. Already in 1986/1987, when the fermented standard preparation was not yet available, the provisional laboratory preparation gave better results than the chemical control, though the effect of a single treatment did not last longer than 8 months. The same good results were later obtained with the commercial Mycostop preparation. More than one treatment is required; the best is to repeat the soil drenching every month if temperature is high and fusarium infection is heavy. In capsicum, the biopreparation gave good results against damping-off disease of seedlings. After replanting, it successfully protected capsicum plants against soil-borne diseases, except for primary infection by *Sclerotinia* spp., which comes from sclerotia. Mycostop does not have sclerotium-killing activity, but the product can protect plants against secondary *Sclerotina* infection. In trials with melon, very good results were obtained against fusarium seedling blight and wilt, as also in cucumber (Lahdenperä *et al.*, 1990).

The mode of action of *S. griseoviridis* is mainly based on an antibiotic effect. The microbe begins to grow in moist soil, thrives in the rhizosphere of the host plant and colonizes the rhizosphere in advance of the pathogen. It secretes antibiotic substances which inhibit the growth of fungal pathogens but does not kill them totally. This antagonist microbe acts also by lysis of the pathogen: complete or partial destruction of the cells by enzymes. It also competes with pathogens for living space and nutrients. We have studied how the biopreparation affects the soil microflora. During experiments with Mycostop, soil samples were always taken for microbiological analysis and as a result it was established that, in spite of the good plant protection effect, there is no significant change in the soil microflora in plots with Mycostop treatments. The soil, as a living buffer, accepts the natural microbe. In the case of pesticide treatments, the soil microflora is often much changed, which is not advantageous for the environment. In Hungary, the Mycostop biopreparation is registered on ornamentals.

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BEHAVIORAL RESPONSE OF *BEMISIA TABACI* (GENN.) TO OLFACTORY CUES EMITTED BY POINSETTIA

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Abstract
Sweetpotato whitefly, *Bemisia tabaci,* reared from four different poinsettia cultivars (Brilliant Diamond, Celebrate 2, Lilo, and Red Sails) were observed in a four-arm olfactometer to determine their response to olfactory cues emitted by the same four poinsettia cultivars. While female whiteflies reared from each poinsettia cultivar exhibited a preference for one cultivar over the remaining three, in no case did they prefer the same cultivar from which they were reared. Furthermore, olfactory preference for each of the four cultivars was dependent upon the cultivar from which the females were reared. This observed host-plant dependent olfactory preference may explain the observation made by many growers that poinsettia cultivar preferences are not consistent within or between greenhouses, and these preferences cannot be predicted by poinsettia foliage or bract color.

Introduction
Bemisia tabaci is the most damaging insect attacking poinsettias in California (U.S.A.) greenhouses. To manage the problems caused by this insect, all forms of biological, cultural, physical and chemical control are currently being explored at university, extension, and grower levels. Although management of this pest is the ultimate goal for all levels of research, development of new management techniques or improvement of present control methods for whiteflies require a thorough understanding of the interactions between the insect and its host plant. It is hopeful that an understanding of these interactions will lead to the development and utilization of poinsettia cultivars in such a way that damage from whitefly attack is reduced.

Two factors, color and odor, have frequently been shown to influence insect movement patterns. Adult sweetpotato whiteflies are reported to be most strongly attracted to the yellow range of the color spectrum, and somewhat attracted to the shorter blue/UV wavelengths (Mound, 1962; 1973; Berlinger 1980, 1986). Because many California (U.S.A.) poinsettia growers report no relationship between where they find whitefly outbreaks and bract or foliage color of the infested plants, we have studied the influence of poinsettia plant odors on whitefly preference for different poinsettia cultivars. Although Mound (1962) found no response to host plant odors in *B. tabaci*, these studies were conducted before the detection of the now ever-present new strain/species of *B. tabaci* (Perring et al. 1993). Because other biological characteristics differ between the old 'A strain' and new 'B strain' of *B. tabaci* (Perring et al., 1991), the 'B strain' may use previously undescribed methods of host plant selection.

Materials and Methods
Bemisia tabaci responses to odors emitted from four different poinsettia cultivars (Annette Hegg Brilliant Diamond, Celebrate 2, Lilo, and Red Sails) were studied using an olfactometer fashioned after the machine described by Vet (1983). The four different poinsettia cultivars used in this study were from completely different parental lines and therefore not closely related (Ms. Jan Hall, Ecke Poinsettia, Encinitas, Calif., U.S.A., personal communication). The olfactometer contained four holding chambers into which a single leaf from one of the four cultivars was placed. Clean air was passed through each of the four holding chambers, thereby picking-up the odors emitted by the poinsettia leaves, and into a central observation arena containing an individual female whitefly.

Preference was determined by the relative amount of time a whitefly spent in each of the four odor fields within the central observation arena within a total observation time of 10 minutes. The position of the leaf-holding chambers relative to the observation arena was randomized and the entire system was cleaned with ethanol after each observation. Because *B. tabaci* attack a broad range of host plants, and because poinsettia ranges tend to contain several poinsettia cultivars, whiteflies reared on each of the four different cultivars for at least one generation were tested to see if the host plant from which they were reared influenced their olfactory response. Thirty females reared from each of the four cultivars were individually studied in the olfactometer. Data were analyzed using a replicated goodness-of-fit test (Sokal & Rohlf, 1981).

Results

Bemisia tabaci responses to odors emitted from the four poinsettia cultivars are shown in Figure 1. Responses to olfactory cues were dependent upon the host plant from which the whiteflies were reared. Furthermore, for all four host plants, females did not exhibit an olfactory preference for the host plant from which they were reared. Females reared from the cv. 'Brilliant Diamond' tended to spend more time in the odor plume emitted from 'Celebrate 2',

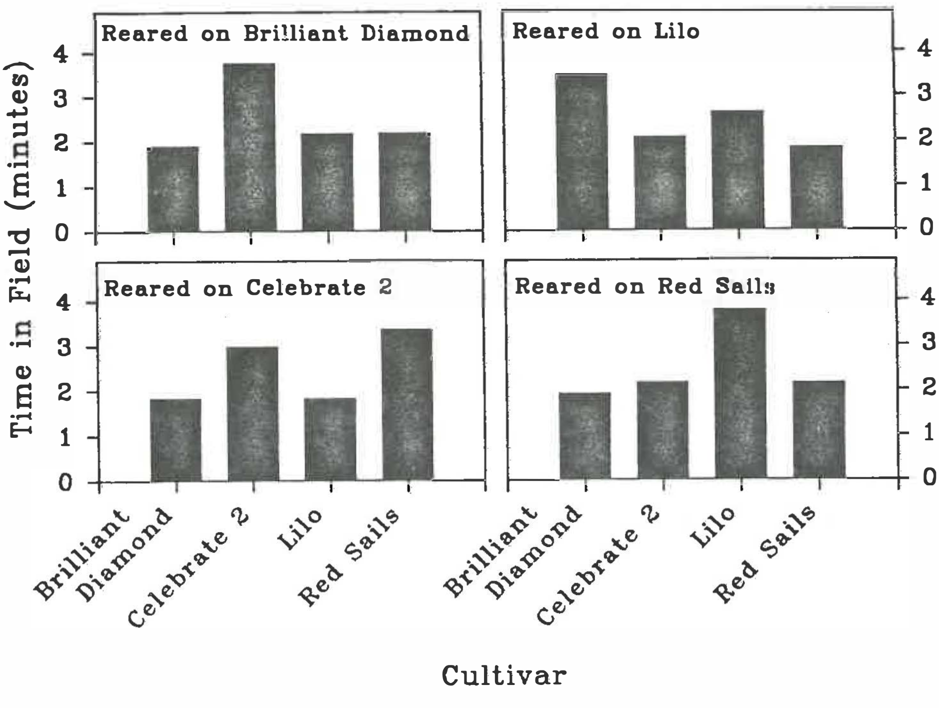

Figure 1: *Bemisia tabaci* responses to olfactory cues emitted by poinsettia cultivars. Responses were measured as the amount of time individual whiteflies spent in a cultivar odor plume within the observation area of a four-arm olfactometer.

and less time in the odor plumes emitted from the three other cultivars ($G = 512.59$, $df = 90$, $p < 0.001$). Likewise, females reared from the cv. 'Lilo' spent the most time in the odor plume emitted from 'Brilliant Diamond' ($G = 311.05$, $df = 90$, $p < 0.001$); females reared from the cv. 'Celebrate 2' spent the most time in the odor plume emitted from the cv. 'Red Sails' ($G = 330.51$, $df = 90$, $p < 0.001$); and females reared from the cv. 'Red Sails' spent the most time in the odor plume emitted from the cv. 'Lilo' ($G = 421.50$, $df = 30$, $p < 0.001$).

Discussion

One focus of this research is to examine how sweetpotato whiteflies perceive different poinsettia cultivars. Elucidation of this phenomena will hopefully facilitate manipulation of the insect's behavior in such a way that will lead to improved methods of control. The results presented here suggest that host plant selection by *B. tabaci* is a rather complex process. While plant-emitted olfactory cues apparently contribute to this selection process, the process is also mediated by developmental history of the insect. Poinsettia propagation and production greenhouses typically contain many different plant cultivars at one time. This variability in host plant material together with cultivar-dependent host-plant preference suggest that it will be extremely difficult to take advantage of differences in host plant preference as part of a *B. tabaci* management program for greenhouse poinsettias.

Further studies are underway to discover the compounds present in poinsettia leaves that elicit the observed behavioral responses in *B. tabaci*, and preliminary data have also been collected on poinsettia cultivar-dependent life history parameters of *B. tabaci*.

Acknowledgments

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VERTICILLIUM LECANII FOR CONTROL OF APHIDS AND THRIPS ON CUCUMBER

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Abstract
Verticillium lecanii has given excellent control of several pest organisms where favourable humidity conditions can be provided. Previous trials indicated that cycling 2 nights elevated humidity with 2 nights of ambient conditions was adequate for reliable pest control. This regime was compared with continuous ambient humidity and with ambient humidity with an oil adjuvant added to the *V. lecanii*. Results confirm an improvement in pest control at elevated humidities, and indicate an improvement with the addition of rape seed oil to the *V. lecanii* over ambient conditions alone.

Introduction
Previous work has shown that the fungal pathogen *Verticillium lecanii* can infect and control aphids (Hall & Burges, 1979), thrips (Helyer & Brobyn, 1988) and whitefly (Hall, 1982). All three pests can cause severe yield losses to many protected crops by leaf damage and distorted fruit. Biological control of the above pests is routinely carried out on several crops. However, on cucumber various problems may arise. The environment of a cucumber crop enables most pests to colonise and breed rapidly often 'out-running' the beneficial organisms introduced for their control. Aphids, particularly *Aphis gossypii*, have developed resistance to the selective pesticide pirimicarb and in some instances also heptenophos (R. Pickford, Humber Growers, UK. pers. comm.). Thrips control with the predatory mite *Amblyseius cucumeris* is successful on sweet pepper but can often fail on cucumber due to poor establishment of the predator. This is possibly because most cucumber varieties in common usage are F1 hybrids and therefore do not produce pollen (pollen being a food source for the mites).

V. lecanii can be used to control these pests but requires high humidity to be fully effective. Excellent control has been achieved on chrysanthemum where humidity was raised to 95% + on specific nights of each week (Helyer et al., 1993). In the chrysanthemum trials, elevated humidities were obtained by fogging water on either 4 consecutive nights each week or cycling 2 nights of fog with 2 nights of ambient conditions. During the above trials no disease symptoms or any physiological disorders were observed on the plants. However, there are still many concerns from growers about deliberately raising humidity to favour one disease (insect pathogen) over another (plant pathogen).

Work by Abraham et al. (1991) indicates that ambient relative humidity is of no consequence in relation to infection (of grasshoppers and locusts) when spores are applied in oils. A commercially available and approved oil adjuvant was therefore included in these trials to evaluate its additive effect to *V. lecanii*. The current work has evaluated the systems on a summer crop of cucumber.

Methods
Three glasshouse compartments were planted with rock-wool grown cucumber cv. Corona and grown as near to commercial conditions as possible. The variety Corona is powdery mildew susceptible and was sprayed with triforine (Saprol 190 g/l; Promark) when necessary. Thrips (*Frankliniella occidentalis*) and spider mites (*Tetranychus urticae*) were introduced and allowed to establish before any treatments were made. Due to problems in mass production, aphids (*Aphis gossypii* and *Myzus persicae*) were introduced 3 weeks after the other pests. Cocoons of the spider

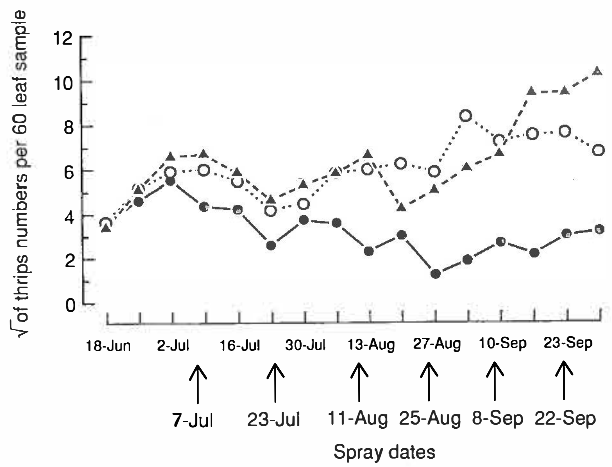

Fig. 1. **Population of thrips treated with *Verticillium lecanii* at ambient humidity (▲), raised humidity (○) and *V. lecanii* plus Codacide oil (●).**

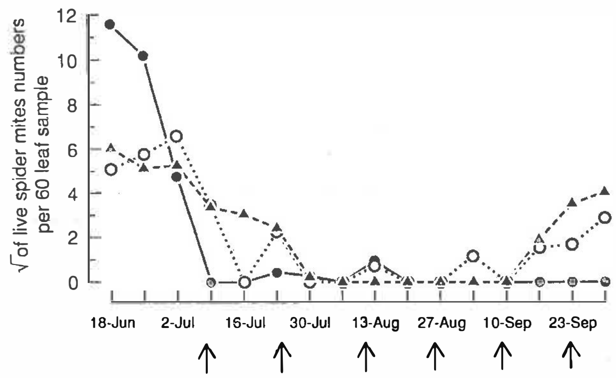

Fig. 2. **Population of spider mites treated with *Verticillium lecanii* at ambient humidity (▲), raised humidity (○) and *V. lecanii* plus Codacide oil (●).**

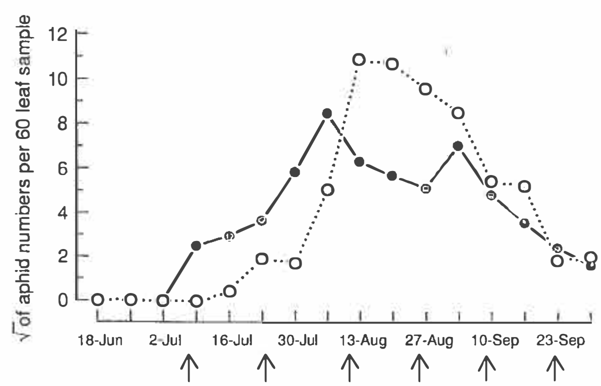

Fig. 3. **Population of healthy (●) and infected (○) aphids treated with *Verticillium lecanii* at elevated humidity.**

mite predatory midge *Therodiplosis persicae* were also introduced to each chamber to determine its potential for establishment on cucumber and integration with *V. lecanii.*

In one compartment Codacide oil (spray adjuvant - Microcide Ltd.) was added to the pathogen spray at a rate of 50 ml oil per litre of water. Codacide is a blend of 95% rape seed oil plus 5% non-ionic emulsifier used to improve the adhesion and spread of a pesticide on a target by a factor of 8-16 times over that of water alone (Chadd, 1986). The oil adjuvant is non irritant and non phytotoxic to most plants tested.

Pathogen sprays were prepared some 3-4 hours before application to enable the dry spores to absorb moisture and so begin the germination process. A 2 litre flask was half filled with water and the dry spores added to make a concentrate which was later added to the spray tank. Where Codacide was used, a paste of water plus *V. lecanii* was first prepared, this was then mixed with the oil before standing for 3-4 h and finally being added to the spray tank. All compartments were HV sprayed fortnightly with *V. lecanii* at a rate of 1 g Vertalec + 1 g Mycotal (both products from Koppert, Holland) per litre and approximately 3,000 litres of water/ha.

The glasshouse compartments were set up as follows:

1 Ambient humidity.
2 Humidity raised by high pressure water fog on a cycling 2 nights of high humidity (10 h/night) and 2 nights of ambient, all other times were at ambient humidity.
3 Ambient humidity - Codacide oil added to *V. lecanii.*

Pest populations were assessed by leaf counts *in situ* from 1 leaf per plant and 10 plants per row using 6 rows per compartment. Humidity and temperature measurements were taken hourly using a Squirrel data logger, the sensors being placed in the centre of the crop within an aspirated screen. Disease incidence was also assessed and corrective measures taken when necessary.

Results and Discussion

Problems with the high pressure fog system caused intermittent running of the machine during the early parts of the trial. These problems were resolved in mid August, after which time the machine operated as planned.

The thrips population built up to between 15 and 25 thrips per leaf at the time of the first spray application on 7 July (Fig. 1). The addition of Codacide oil to *V. lecanii* had the greatest effect in reducing the thrips numbers. This was evident not only in the lower numbers found on the plants but also by the dead insects, particularly adults killed by the oil. In the other compartments very few dead thrips were ever found, and those that were noticed had been killed by *V. lecanii* and nothing else. The elevated humidity treatment showed a slightly lower population of thrips throughout most of the trial. This is possibly due to the intermittent raising of humidity having some effect on the growth of *V. lecanii* but being insufficient for adequate pest control. However, towards the end of the trial a clear effect of raising humidity could be noticed by the declining thrips population in this compartment.

Spider-mites were rapidly controlled where Codacide oil was included (Fig. 2); immediately following the first spray many mites were noticed to have been killed by the oil rather than *V. lecanii. T. persicae* were introduced in each house and established well, often building up to 5-10 larvae/cocoons per leaf. It is thought they may have been responsible for the majority of spider-mite control achieved in the compartments where no Codacide was applied. In the Codacide oil plus *V. lecanii* treated compartment no midges and very few spider mites were found after the first spray application.

Aphis gossypii out-competed *Myzus persicae* to the extent that very few *M. persicae* were found after mid July. Infected aphids were recorded from all treatments indicating activity by *V.*

lecanii (Fig. 4). In compartment 2 the aphid population declined rapidly after the fogging unit was operated correctly (mid August). However, little difference in initial numbers of healthy and infected aphids was noticeable between compartments 1 and 2, therefore only compartment 2 is presented in Fig. 3. The Codacide oil did not appear to have such a strong effect on aphids as on the other pests, although aphid numbers were kept low for about 4 weeks longer where the oil was applied. During September, populations of *Aphidius* sp. and *Aphidoletes aphidimyza* built up in each compartment. Both natural enemies entered the trial spontaneously and along with *V. lecanii* virtually eliminated the *A. gossypii* in all areas. *A. aphidimyza* larvae were killed after each application of Codacide oil but *Aphidius* sp. survived well, possibly being protected within the aphid bodies. It was also observed that aphid parasite 'mummies' and adults could integrate with *V. lecanii* without being infected.

Cucumber powdery mildew (*Sphaerotheca fuliginea*) required spraying once in all compartments before any *V. lecanii* applications were made and once again in compartments 1 and 2 during the trial. It appeared that the oil and *V. lecanii* mixture had a suppressing effect on the mildew. Spencer and Ebben (1981) indicated the possibility of biological control of cucumber powdery mildew by *V. lecanii*. Conidia, suspended in a solution containing 2% glycerol and 1% gelatin to reduce dehydration, gave a marked reduction in disease incidence when compared to untreated plants.

Conclusions

The addition of Codacide oil to *V. lecanii* does not appear to be detrimental to the fungus and may enhance its activity. The oil it self may also have insecticidal properties (suggested by the dead thrips found immediately after each application i.e. quicker than *V. lecanii* could have killed them) which need to be further investigated.

Acknowledgements

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VARIATION IN HOST USE IN *ENCARSIA FORMOSA*

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Abstract
Bemisia tabaci has recently become a serious pest problem in glasshouse crops in western Europe. Unlike the situation with *Trialeurodes vaporariorum*, biological control of *B. tabaci* with the wasp *Encarsia formosa* is not easy. Although in many respects *B. tabaci* appears to be a poorer host than *T. vaporariorum*, we are investigating the hypothesis that there may be variation in *E. formosa* such that the performance of this wasp on *B. tabaci* could be improved given different rearing strategies. Preliminary data suggest that wasps reared on *B. tabaci* more readily accept this host than do wasps reared on *T. vaporariorum*. Thus the host on which *E. formosa* is reared affects its subsequent host selection behavior either due to a genetic response to selection or as a result of environmental conditioning. Experiments aimed at investigating the effects of selection and conditioning on wasp performance are discussed.

Introduction
The control of the greenhouse whitefly, *Trialeurodes vaporariorum*, (Homoptera: Aleyrodidae) in glasshouse vegetable crops with the parasitoid *Encarsia formosa* (Hymenoptera: Aphelinidae) has been an outstanding success (Hussey and Scopes, 1985; van Lenteren and Woets, 1988). The existence of biological control in these crops may now be threatened, however, by the introduction of a new pest, the sweetpotato whitefly, *Bemisia tabaci*. *B. tabaci* was accidentally imported to western Europe from the United States in 1987, and during the growing season of 1992 was considered a serious problem in numerous Dutch greenhouses (W. Ravensberg and J. van Schelt, pers. comm.).

Attempts to control *B. tabaci* with *E. formosa* in vegetable glasshouse crops have achieved mixed results. Tests on poinsettia have been disappointing as well (Parrella, 1990). The data suggest that *B. tabaci* is generally not as good of a host for *E. formosa* as is *T. vaporariorum*. The number of eggs laid, the survival of immatures, and the overall quality of emergent adults is lower (Bosclair, 1990). Although the host used for rearing is not always reported, it appears that all of the research and commercial biological control with *E. formosa* have used populations reared on *T. vaporariorum*. It is now clear that herbivorous insects have tremendous potential to adapt to different hosts plants (reviewed in Gould, 1983; Via, 1990). For example, Gould (1979) was able to select for improved performance in a population of spider mites on a previously resistant cucumber cultivar in 8-16 generations. Much less information is available, however, regarding the adaptation of parasitoids to different hosts.

Thus we are interested in the hypothesis that the parasitic wasp, *E. formosa*, is variable in its use of two different species of host, *B. tabaci* and *T. vaporariorum*, and that the host upon which this parasitoid is reared affects its performance on that and the alternate host. If such variation occurs, and if that variation is heritable, the possibility exists to improve the performance of these wasps on *B. tabaci*. As a very initial test of this hypothesis we have reared wasps for several generations on these two hosts and have then tested the two wasp populations on either host, to determine the effect of rearing history on their host acceptance behavior. In this experiment, differences could either be due to an environmental response (conditioning) or to a genetic response to selection imposed by different hosts.

Materials and Methods
Two wasp populations, one reared on *B. tabaci* and the other on T. *vaporariorum*, were tested. The wasps reared on *B. tabaci* (hereafter referred to as Bt *Encarsia*) were collected in September, 1992, from three greenhouses in the Netherlands that had high infestations of *B. tabaci* during the 1992 growing season. Prior to the experiments these wasps were kept in laboratory culture on *B. tabaci* for 3 generations. The greenhouses from which these wasps were collected had all periodically released *E. formosa* from a commercial insectary, with *T. vaporariorum* as the host, throughout the 1992 season. Thus this wasp population has been reared on *B. tabaci* for a minimum of 3

generations and a maximum of a growing season, or at most 10 generations. The previous host was *T. vaporariorum*.

The second population of *E. formosa* was reared continuously on *T. vaporariorum* (hereafter referred to as Tv *Encarsia*). These wasps were from the same commercial insectary as had originally produced the Bt *Encarsia* population (Koppert Biological Systems, The Netherlands). This population has been reared on *T. vaporariorum* for at least 20 years (Ravensberg, 1992). Thus the two wasp populations being compared are originally from the same population and have been separated for a minimum of three generations and a maximum of approximately ten generations.

The tests were conducted on leaf discs, each infested with either *B. tabaci* or *T. vaporariorum*. Each disc contained a high density of whitefly larvae of varying ages. The whitefly larvae were classified according to size into 4 categories, 1st, 2nd, 3rd-4th instar, and pupae (after Milliron, 1940; Laska et al, 1980; Vet, et al, 1980). Leaf discs (3.5 cm in diameter) were placed in small petri dishes with agar. The leaf discs adhered to the agar and remained fresh through the course of the experiment. The whitefly larvae do not appear to suffer any ill effects from being raised on excised leaves, as long as the leaf stays fresh the whitefly immatures continue to grow and eclose into adults.

Naive female wasps, approximately one week old, were transferred in gelatin capsules to the leaf discs, and observed for the next thirty minutes. Observations were recorded both with a portable computer programmed as an event recorder (Noldus and Potting, 1990) and by hand with a timer. For each encounter with a host the size/age category of the host was recorded as well as the behavior of the wasp. Various behavioral activities were recorded including oviposition (wasp adopting an oviposition posture on the host and appearing to insert her ovipositor) and drumming (tapping the host with her antennae). The data reported here are the ratio of host acceptances to host rejections. Acceptances were defined as contact that resulted in an apparent oviposition. Rejections are defined as any contact with a host that included drumming of the host but did not result in an oviposition or oviposition posture. Chi square tests were used to compare the ratios of acceptances to rejections of each of two hosts by each of the two wasp populations.

There were four different parasite/host combinations tested in this experiment, Tv *Encarsia* tested on *T. vaporariorum*, Tv *Encarsia* tested on *B. tabaci*, Bt *Encarsia* tested on *T. vaporariorum*, and Bt *Encarsia* tested on *B. tabaci*. Because we are interested in how the host on which a wasp is reared affects its behavior, the two comparisons of interest are between either wasp population tested on each host:

A. Tv *Encarsia* vs. Bt *Encarsia* tested on *B. tabaci*

B. Tv *Encarsia* vs. Bt *Encarsia* tested on *T. vaporariorum*.

Results

A total of 37 wasps were tested, which resulted in 216 encounters that could be used in this analysis. The average number of encounters per individual wasp was 5.9 ± 0.66 ($\bar{x} \pm$ SE; range 0 to 15). Because the data do not appear to be strongly affected by a few wasps with an inordinate number of encounters, all encounters within each of the four treatments (each wasp population tested on each host) were pooled. For each of the two comparisons we are reporting, (Tv *Encarsia* vs. Bt *Encarsia* tested on *B. tabaci* and Tv *Encarsia* vs. Bt *Encarsia* tested on *T. vaporariorum*) there was no significant difference in the number of encounters of each wasp population with each different size/age class of whitefly hosts, thus the data for encounters with all ages of whiteflies were also pooled.

When tested on *B. tabaci*, there is a significant difference in the percentage of host acceptances between *E. formosa* reared on *B. tabaci* (Bt *Encarsia*) and *E. formosa* reared on *T. vaporariorum* (Tv *Encarsia*) (Fig. 1a). Bt *Encarsia* accepted a greater proportion of *B. tabaci* hosts than did Tv *Encarsia*. There is no significant difference between Bt *Encarsia* and Tv *Encarsia* when tested on *T. vaporariorum* however (Fig. 1b). Tv *Encarsia* does not accept *T. vaporariorum* significantly more than does Bt *Encarsia*.

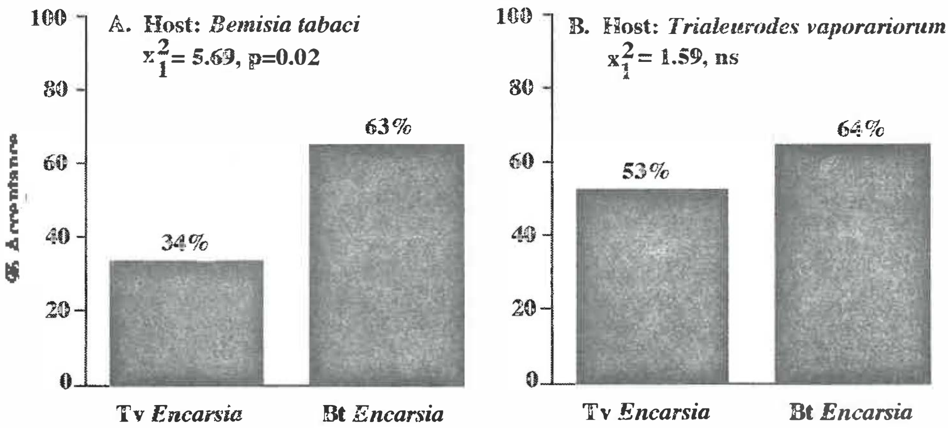

Figure 1. Percent of host acceptance by two different populations of *Encarsia formosa*: wasps reared on *Trialeurodes vaporariorum* (Tv *Encarsia*) and wasps reared on Bemisia tabaci (Bt *Encarsia*). A. Wasps tested on *B. tabaci* . B. Wasps tested on *T. vaporariorum* .

Conclusions

These data suggest that at least for the use of *B. tabaci*, the rearing history of the wasp does have an effect on the wasp's host acceptance. The cause of this difference in behavior could be either environmental or genetic. Wasps may be conditioned to the host on which they were reared, and thus may more readily accept that host for oviposition. This difference in behavior could also be genetic. If there is heritable variation in acceptance behavior, there may have been adaptation to *B. tabaci* within the three to ten generations that this population of wasps was reared on that host. From this experimental design it is impossible to separate environmental from genetic causes of these behavioral differences. Further experiments are planned, however, to investigate this question. A single population of wasps, all from the same host, will be reared for one generation on the two different hosts. Subsequent differences between these two groups of wasps would suggest that environmental conditioning does effect their behavior.

The main focus of our future research will be to more thoroughly investigate the possibility of heritable variation in host use in *E. formosa*. The performance of wasps from populations that have been kept for 40 or more generations on *B. tabaci* will be compared with wasps that have been continuously reared on *T. vaporariorum*. Rearing all wasps the generation immediately prior to the experiment on the same host would reduce the possibility of environmental conditioning as a cause of any differences in parasitoid behavior. Thus this experiment will yield information on whether a response to selection by *B. tabaci* has occurred, and thus whether there is heritable variation in host use in this species of wasp. We will also be selecting for improved performance of *E. formosa* on *B. tabaci*. Starting with a single population of *E. formosa* we will rear separate populations on both hosts. Data from this experiment should yield not only information on whether a response to selection is possible, but also on the rate at which such a response can occur. We will collect data on behavioral parameters, as well as more encompassing measures of overall parasitoid success, such as the number of adult wasps that are produced.

There was no difference in the acceptance behavior of either wasp population on *T. vaporariorum*. Previous to the growing season of 1992 both of the populations were reared on *T. vaporariorum*. A possible explanation for this lack of detectable difference may be that these populations have been selected for many years for the use of *T. vaporariorum*. Thus it may be that rearing the Bt *Encarsia* population on *B. tabaci* did not reduce its ability to use *T. vaporariorum* as a host. We cannot assume that any conditioning or adaptation that improves the acceptance of one host (*B. tabaci*) necessarily decreases acceptance of the other host (*T. vaporariorum*).

The results of these and future studies should contribute to the attempts to use *E. formosa* for the biological control of *B. tabaci*. If the differences in the acceptance of *B. tabaci* seen in this experiment are due to conditioning rather than genetic adaptation, and if further studies reveal no heritable variation in host use in *E. formosa*, the long term rearing of *E. formosa* should not effect its performance on alternate hosts. If these differences do have a heritable basis, however, this would suggest that the mass rearing strategy of *E. formosa* may effect its performance on hosts other than that on which it is traditionally reared, *T. vaporariorum*. If this is indeed the case, it may be possible to improve the performance of this wasp species on *B. tabaci* by using wasp populations reared it on the host on which it is intended to control.

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DEMONSTRATION/INTEGRATED PEST MANAGEMENT PROGRAM FOR POTTED CHRYSANTHEMUMS IN CALIFORNIA

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Abstract
A statewide IPM demonstration project was conducted in potted chrysanthemums utilizing biological control as the primary pest control tactic. Three potted plant growers in three separate growing regions in California participated. Trials consisted of IPM/biological control treatments vs. grower pest control practices. Primary pests encountered were thrips, leafminers, and aphids. Beneficial organisms used for control were: *Diglyphus begini* or *D. isaea* (leafminers), *Amblyseius cucumeris* (thrips) and *Chrysoperla rufilabris* (aphids); pesticides were used as a last resort. Preliminary results indicate that the biological control treatments had greater insect damage than the grower treatments but a high quality crop was still produced. Chrysanthemums grown under the IPM/biological control treatment vs. the grower treatment did not differ in terms of their salability. We are encouraged by these findings and are planning to continue the project this coming year. It is hoped that our results will stimulate growers of ornamental plants to utilize biological control as part of their pest management strategies.

Introduction
The development of integrated pest management (IPM) systems for ornamental crops which rely heavily on biological control is more a dream in the mind of researchers than a reality practiced by growers. The reasons for this have been outlined in the past (Parrella and Jones, 1987; van Lenteren and Woets, 1988; among others); the major hurdle to overcome or satisfy is the preconceived idea of a zero tolerance for pests and their damage on any floriculture commodity.

Where a zero tolerance is mandated by quarantine (for example, importing chrysanthemums into Great Britain from the Netherlands), the possibilities of achieving this using IPM with a firm reliance on biological control may not be realistic. However, there is evidence that the zero tolerance mentality inherent in many quarantine regulations is beginning to diminish (Anonymous, 1992). In addition, where floricultural commodities are destined for consumption within the producing country (for example, most production in the United States), the idea that some pests and their damage can be tolerated is gradually gathering more acceptance by ornamental growers.

For many growers the heavy use of and ultimate reliance on traditional pesticides to satisfy the zero tolerance mandate is becoming increasingly unpopular for several reasons. These include: cost, concerns for the environment and worker safety, development of insecticide resistance which is related to cost and to a reduction in pesticide performance, loss of older pesticides and few new registrations, concerns over residues on plants and loss of markets, and increasing anxiety over liability. These elements when combined with the fact that new pesticide registrations (for example, the insect growth regulators [IGRs] among others) are potentially compatible with natural enemies and growers are beginning to realize the advantages of marketing under an IPM/biological control framework have opened the door for alternative pest management strategies in floriculture crops.

For these reasons and others, many growers are interested in using IPM/biological control for pest control in their production. However, for many floriculture crops guidelines to follow are either not available or are simply a compilation of subjective information passed along by growers and practitioners through trial and error. Some of this information is valid and when followed can lead to successful pest management. However, given the diversity of crops grown, the multitude of pests, the differences in greenhouse structures and locations, etc., generic guidelines developed through trial and error methods will likely end in failure in many situations. The lack of more well-defined and well-documented efforts at implementing IPM/biological control in floriculture greenhouses is a major impediment to wide-scale adoption by the industry.

Of the top three floriculture crops produced (roses, carnations, and chrysanthemums) more information is available on IPM/biological control for chrysanthemums than for any other. The various tenets of a full IPM/biological control program have been published (Parrella and Jones, 1987). Since this publication we have made the picture more complete with continuing IPM related research on the following pests of chrysanthemums: the aphid complex (Bethke and Parrella, 1989; Vehrs et al., 1992), the western flower thrips (Hessein and Parrella, 1990; Robb, 1989) the beet armyworm (Yoshida and Parrella, 1991; 92), and the leafminer (Heinz and Parrella, 1989; Heinz and Parrella 1990a, 1990b; Parrella et al., 1992). In addition, we have considerably advanced our ability to monitor many of these pests in the greenhouse (Parrella et al., 1989; Heinz et al., 1992). Research conducted on biological control in chrysanthemums elsewhere in the world (Wardlow, 1985; Chambers, 1990) also has applicability in California.

Here we report initial efforts to implement an IPM/biological control program on potted chrysanthemums in California during the summer/fall of 1992.

Description of test sites

Three locations in California were chosen to demonstrate the program: San Diego, Santa Barbara, and Salinas (Table 1). Some of the diversity of potted chrysanthemum production was represented in this trial: each location represented a unique production situation in the state with different types of greenhouse structures, surrounding crops/areas, and production areas within the greenhouse. In addition, although the pest complex attacking chrysanthemums is similar throughout the state (Table 2), there are major differences in the severity of species in each location. By applying the program in all three operations, we hoped to be able to demonstrate the ability of the program to function effectively under the array of contingencies likely to be encountered in California and elsewhere in the United States.

Table 1. Sites utilized for trials

Site	Crops Grown[a]	Number of Pots[b]	Surrounding Vegetation	Dates of Trial
Salinas	MU,PO,AF,GE,CA,HY,CY	BC 5220 pots GC 5405 pots	vegetable production	6/18/92-9/2/92
Santa Barbara	MU,PO	BC 2780 pots[c] GC 503 pots	citrus, avocados cut flowers	8/31/92-11/17/92
San Diego	MU,PO,EX,CF	BC 3100 pots GC 9500 pots	residential landscaping	9/22/92-12/3/92

[a]MU=chrysanthemums, PO=poinsettias, AF=African violets, GE=gerberas, CA=carnations, HY=hydrangeas, CY=cyclamen, EX=exacum, CF=cut flowers, [b]BC=biological control area, GC=grower control area, [c]504 pots on one BC treatment bench, 2276 pots on five buffer benches

Table 2. Major chrysanthemum pests

Common Name	Species Name	Plant Part Attacked
Leafminer	*Liriomyza trifolii*	Leaves
Green Peach Aphid	*Myzus persicae*	Leaves, central growth point, buds, flowers
Melon Aphid	*Aphis gossypii*	As above
Western Flower Thrips	*Frankliniella occidentalis*	As above
Beet Armyworm	*Spodoptera exigua*	Leaves, buds, flowers
Lygus Bugs	*Lygus* spp.	Central growth points, buds
Twospotted Spider Mites	*Tetranychus urticae*	Leaves, flowers

Materials and methods

At each site a section of one weekly planting was under our supervision utilizing biological control agents as the primary pest control tactic; pest management for the remainder of the crop was determined by the grower and was based on chemical pest control. The biological control area was separated from the grower control area by gutter to floor polyethylene sheeting in the Salinas and San Diego trials. At the Santa Barbara location the biological control and grower control areas were grown on separate benches in the same greenhouse. These benches were separated from each other by buffer benches which were under a biological control treatment which reduced the risk of contaminating the biological control bench with pesticide sprays.

An evaluation of potential pest problems was conducted prior to the start of all trials. This consisted of a visual inspection of the growing site, an interview with the grower involved and monitoring of the production areas with yellow and blue sticky traps. At the Santa Barbara and San Diego trials 12 percent and 1 percent of the cuttings were inspected, respectively, prior to their placement in rooting areas. Pests detected at this stage were controlled with pesticides, usually insecticidal soap or abamectin (Table 3). It was determined that the most likely pests encountered would be leafminers, thrips and aphids at all three sites.

Three beneficial organisms were selected as biological control agents, *Diglyphus isaea* (Walker) or *D. begini* (Ashmead) for leafminer control, *Chrysoperla rufilabris* (Burmeister) for aphid control and *Amblyseius cucumeris* (Oud) for thrips control. These organisms were chosen because of their commercial availability (Hunter, 1992) and their reported efficacy in controlling target pests (Gilkeson, 1992).

For the first trial (Salinas) releases were made on an "as needed" basis. It soon became apparent that this approach was inadequate and regular releases of beneficial organisms were pre-scheduled for the subsequent Santa Barbara and San Diego trials. Releases of 25-50 adults and immatures *A. cucumeris* and 25-50 eggs and 1st instars *C. rufilabis* per pot were made weekly on cultivars susceptible to aphids or thrips and once every 2 weeks on less susceptible cultivars. Cultivar sensitivity was determined by grower experience, information from the cutting producer and experience gained from the first trial. These organisms were mixed together in bran or vermiculite and sprinkled on each pot. An estimate of the number of *Diglyphus* needed for weekly release was determined by using a predictive model (Parrella et al., 1992): this was approximately 2,000 per week.

Table 3. Natural enemy/pesticide schedule in chrysanthemum IPM/biological control demonstration areas vs. normal grower areas[a].

San Diego (SD)		Santa Barbara (SB)		Salinas (S)	
IPM/BC[b]	Grower[b]	IPM/BC[b]	Grower[b]	IPM/BC[b]	Grower[b]
9/22-abamectin		10/7-abamectin (1/2 rate)	9/26-abamectin	7/21-CR, DB	7/20-abamectin/ chlorpyrifos
10/12-DI, CR, AC	10/31-Bt, chlorpyrifus	10/9-CR, DI, AC	9/29-diazinon	7/24-CR, AC, DB	7/26-naled
10/19-DI, CR, AC	11/6-dienchlor/ fluvalinate	10/16-CR, DI, AC	10/3-abamectin	7/28-DB, AC	8/19-insecticidal soap
10/26-DI, CR, AC	11/12-methomyl	10/23-CR, DI, AC	10/10-diazinon	7/29-abamectin/ insecticidal soap	8/23-diazinon/ insecticidal soap
10/31-*Bacillus thuringiensis* (Bt)	11/21-methomyl	10/30-CR, DI, AC	10/14-oxamyl	8/6-abamectin/ insecticidal soap	
11/2-DI, CR, AC	11/28-chlorpyrifos	11/6-CR, DI, AC	10/17-endosulfan	8/8-DB, AC, CR	
11/9-DI	12/1-kinoprene/ chlorpyrifos	11/10-abamectin (1/2 rate)	10/24-diazinon	8/11-DB, AC	
11/16-DI, CR, AC	12/5-Bt, chlorpyrifos/ dienchlor	11/13-CR, DI, AC	10/31-abamectin	8/14-DB	
11/23-DI			11/14-diazinon/ insecticidal soap	8/15-CR, AC	
11/28-chlorpyrifos				8/18-CR	
12/1-kinoprene/ chlorpyrifos				8/19-insecticidal soap	
12/5-Bt, chlorpyrifos, pentac				8/21-DB	
				8/23-diazinon/ insecticidal soap	

[a]Planting dates 9/22/92(SD); 8/31/92(SB); 6/18/92(S).

[b]Date followed by action taken: CR=*Chrysoperla rufilabrus*, AC=*Amblyseius cucumeris*; DI=*Diglyphus isaea*; DB=*Diglyphus begini*.

Because we were dealing with a crop that would be marketed at the conclusion of the trial, we deferred to the grower to make the ultimate decisions. For example, if the grower felt uneasy about pest population levels after the release of beneficials and wanted to make a pesticide application, we did not interfere. We selected pesticides which would have the least impact on the biological control agents, primarily abamectin for leafminer control and insecticidal soap for aphid and thrips control.Each trial was monitored twice a week. Yellow sticky cards (10.1x15 cm, Seabright Enterprises, Ltd., Emeryville, California) and blue sticky cards (7.5x12.5 cm, Olson Products, Inc., Medina, Ohio) were placed immediately above the crop. The placement and spacing of cards was one of each color every 46 m^2 and the blue and yellow cards were staggered in the greenhouse. A vertical strip equivalent to 20 percent of the surface area of the card was counted at each monitoring date (Heinz et al., 1992). The crop was also visually monitored at this time with particular attention to those cultivars which had been designated as sensitive. Additionally, in the San Diego and Santa Barbara trials one percent of all the plants in the trial was randomly selected for close inspection once each week. Plants discovered with pests or pest damage were tagged and additional beneficials were released on these plants. If pest populations were not dramatically reduced by the next sample date then they were spot treated with a pesticide.

Records were kept of pesticides used and beneficial organisms released (Table 3) as well as sticky card and plant monitoring data. At the end of each trial plants were evaluated for the presence of insect damage and plant salability. Six plants were randomly chosen from each of the cultivars common to each location. The six plants were judged as a group and groups were ranked using a one to five scale for salability as follows: 5 - all plants salable, 4 - one to two plants unsalable, 3 - three plants unsalable, 2 - four to five plants unsalable, 1 - no plants salable. For insect damage the rankings were assigned as follows: 5 - no plants showing damage or live insects, 4 - one to two plants showing damage or live insects, 3 - three plants showing damage or live insects, 2 - four to five plants showing damage or live insects; 1 - all plants showing damage or live insects. Subsamples were chosen from each group and measurements of the mean height, wet and dry weights and the stage of maturity (AFMC maturity scale) of each selected plant were recorded.

Discussion

The data from these trials comparing the grower's crop to the IPM/biological control crop is currently being analyzed and, although preliminary, there does not appear to be any significant differences in plant quality. However, in the Sunnyside trial there was a considerable amount of culled plants from the IPM/biological control treatments due to aphid infestations. Thrips damage was also evident on many IPM/biological control plants in this trial. As was previously stated, no pest control was initiated at this trial until pests were detected which presented two problems: 1) pest populations were at an elevated level by the time they were observed and 2) this was exacerbated by the fact that there was a considerable time lag between pest detection and receipt of the beneficial organisms. When beneficial organisms were released they proved to be too little too late to control pest populations.

The problems associated with the Salinas trial caused us to use excessive numbers of beneficial organisms in the following trials (SD and SB). The expense associated with utilizing biological control in this way is probably not cost effective. Future demonstrations will focus on reducing the number of organisms released without sacrificing pest control or the production of a high quality crop. Because of the small plot size relative to the production areas in each greenhouse, migration of pests into the IPM/biological control areas was a constant problem. This may have been reduced if the IPM/biological control treatments had been applied on a larger area. Potted chrysanthemums are difficult plants to work with for IPM/biological control because they are attacked by many pests and all leaves on the plant are important to the overall aesthetic value of the finished product. Experience gained from this crop can be applied to others where limitations are not as serious (for example, cut flowers where all leaves on the plant are not sold or other potted plants, such as poinsettia, where fewer pest problems occur). We plan to continure to work with potted chrysanthemums, but other crops will also be targets of IPM/biological control demonstrations in the future.

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Biological control of Western Flower Thrips in greenhouse sweet peppers using non-diapausing predatory mites

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Summary
The Naaldwijk strain of the predatory mite, *Amblyseius cucumeris* (Oudemans), is successfully used for biological control of thrips in greenhouses, but it appears not very effective in greenhouse crops during winter. This is probably because the females of the predator species respond to short-day photoperiods by entering diapause. Another cause may be low humidity which negatively affects hatching success of predator eggs. A search for predators that do not enter diapause and/or that are less sensitive to low humidities, resulted in two phytoseiid species as candidates for use in biological control of thrips in greenhouses: (1) a strain of *A. cucumeris* with a low incidence of diapause, and (2) a drought-resistant non-diapausing strain of *Amblyseius degenerans* Berlese.
In the present study these two strains and the Naaldwijk strain of *A. cucumeris* are compared with respect to their performance as biological control agent of western flower thrips in a sweet pepper crop during winter. The results of greenhouse experiments in the period of January to September showed that the establishment early in the season (January, February, March) was greatly improved when using the two non-diapausing strains. The impact on thrips populations during the growing season was greater for *A. degenerans* than for the strains of *A. cucumeris*.

Introduction
Western Flower Thrips, *Frankliniella occidentalis* (Pergande), is an important pest of greenhouse-grown sweet pepper. In Dutch greenhouses this thrips pest is biologically controlled by the predatory mite, *Amblyseius cucumeris* (Oudemans). Starting from March the predator is released successfully as its population persists in the crop, making reintroductions superfluous. This persistence may be attributed to the availability of pollen as an alternative food source (Van Rijn & Sabelis, 1992). Consequently, the predators may even be introduced before thrips infestation. During winter, however, introductions of *A. cucumeris* are not successful, which may be caused by the occurrence of diapause (Morewood & Gilkeson, 1990; Van Houten, 1991) and the insufficient resistance of the predator's eggs to low air humidity, commonly occurring during frost periods. Thus, a non-diapausing thrips predator that is tolerant to low humidities could be a better control agent.
In search of such a control agent, Van Houten et al. (1992) compared 6 species of phytoseiid predators of thrips with respect to a number of relevant characteristics, viz. (1) predation and oviposition rate on a diet of thrips larvae, (2) diapause incidence under short-day conditions, (3) egg hatching success at low humidities and (4) rate of oviposition on sweet pepper pollen. The results of this study showed that a Mediterranean strain of *Amblyseius degenerans* Berlese may be a good candidate. This predator does not enter diapause and is more tolerant to drought than *A. cucumeris*. In another study, Van Houten et al. (in prep) collected a strain of *A. cucumeris* in New Zealand. They selected a line from this strain that showed a diapause response of 5% under short-day conditions.
The present study was undertaken to evaluate the performance of a non-diapause and/or drought-resistant predator as biocontrol agent of thrips. Therefore, *A. degenerans* and two strains of *A. cucumeris* (New Zealand and Naaldwijk) were compared with respect to (1) their establishment early in the growing season (January, February, March) and (2) their establishment and efficacy in controlling Western Flower Thrips during the growing season.

Materials and methods
Amblyseius degenerans originated from an insectary culture of the University of California, Riverside, U.S.A. The Naaldwijk strain of *A. cucumeris* was obtained from the Glasshouse Crops Research Station in Naaldwijk, The Netherlands. The other strain of *A. cucumeris*, with a low incidence of diapause, was collected near Auckland, New Zealand. All species were mass-reared on

plastic rearing units ('arenas') as described by Overmeer et al. (1982). Pollen of the broad bean, *Vicia faba* L., was used as a food source.
The experiment was carried out in a small greenhouse with 12 rows of 15 sweet pepper plants, at the Glasshouse Crops Research Station in Naaldwijk. Each strain was released in 4 different rows of plants. In the second week of January, 1992, when the plants had started to flower, 25 female predators were introduced per plant. At the same time a few thousand adult thrips were released to obtain a thrips infestation.
To monitor thrips and predator populations, samples of in total 15 flowers and 30 leaves from the upper part of 30 plants per treatment were taken every 2 weeks. Because there were only few flowers in January and February, flower samples were taken starting from week 8.

Results and discussion

Establishment of the thrips predators

The New Zealand strain of *A. cucumeris* was more successful in establishment during the winter period than the Naaldwijk strain of *A. cucumeris* (Figure 1). In the first 4 weeks, the plants flowered poorly, so there was hardly any food available for the predators. Consequently the establishment of both *A. cucumeris* strains was not very successful in this period. Starting from week 5, the population of the New Zealand strain increased slowly whereas the population of the Naaldwijk strain remained at a very low level. This is an indication that application of a non-diapause strain of *A. cucumeris* may improve the establishment of *A. cucumeris* during winter in the presence of food.
The establishment of the different strains of predators during the growing season is presented in Figure 2. *Amblyseius degenerans* performed best; the predator population increased very rapidly to high densities. Until week 13 the species was only found on the release plants but from week 13 onwards *A. degenerans* was also present in the other rows where the *A. cucumeris* strains had been released. From this moment *A. degenerans* started to displace *A. cucumeris* from the crop; *A. cucumeris* populations decreased slowly and vanished completely after week 23. Starting from week 23, *Orius* spp. were noticed in the greenhouse and during the rest of the experiment *A. degenerans* and *Orius* spp. were simultaneously present in the crop.
The success of *A. degenerans* may partly be explained by the distribution of the predators on the plant. Although *A. cucumeris* and *A. degenerans* can both feed and reproduce on pollen (Van Houten et al., 1992), there appears to be a difference in the rate at which they visit flowers (Van Houten, unpublished results). During the experiment the thrips density in flowers was considerably higher than the thrips density on leaves. By visiting flowers more frequently, *A. degenerans* may take better advantage of the pollen and/or thrips larvae as a food source than *A. cucumeris*. This in turn could

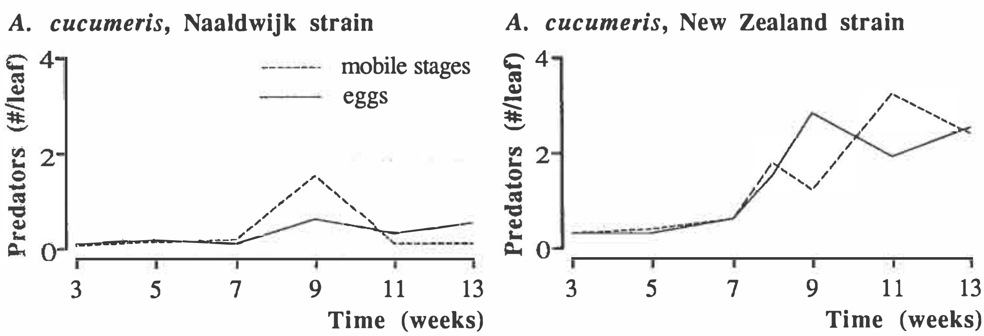

Figure 1. Population fluctuations of the Naaldwijk and the New Zealand strain of the phytoseiid mite, *Amblyseius cucumeris*, on leaves of a greenhouse sweet pepper crop. In the second week of January, 25 predatory females were introduced per plant. Each strain was released in 4 different rows of plants.

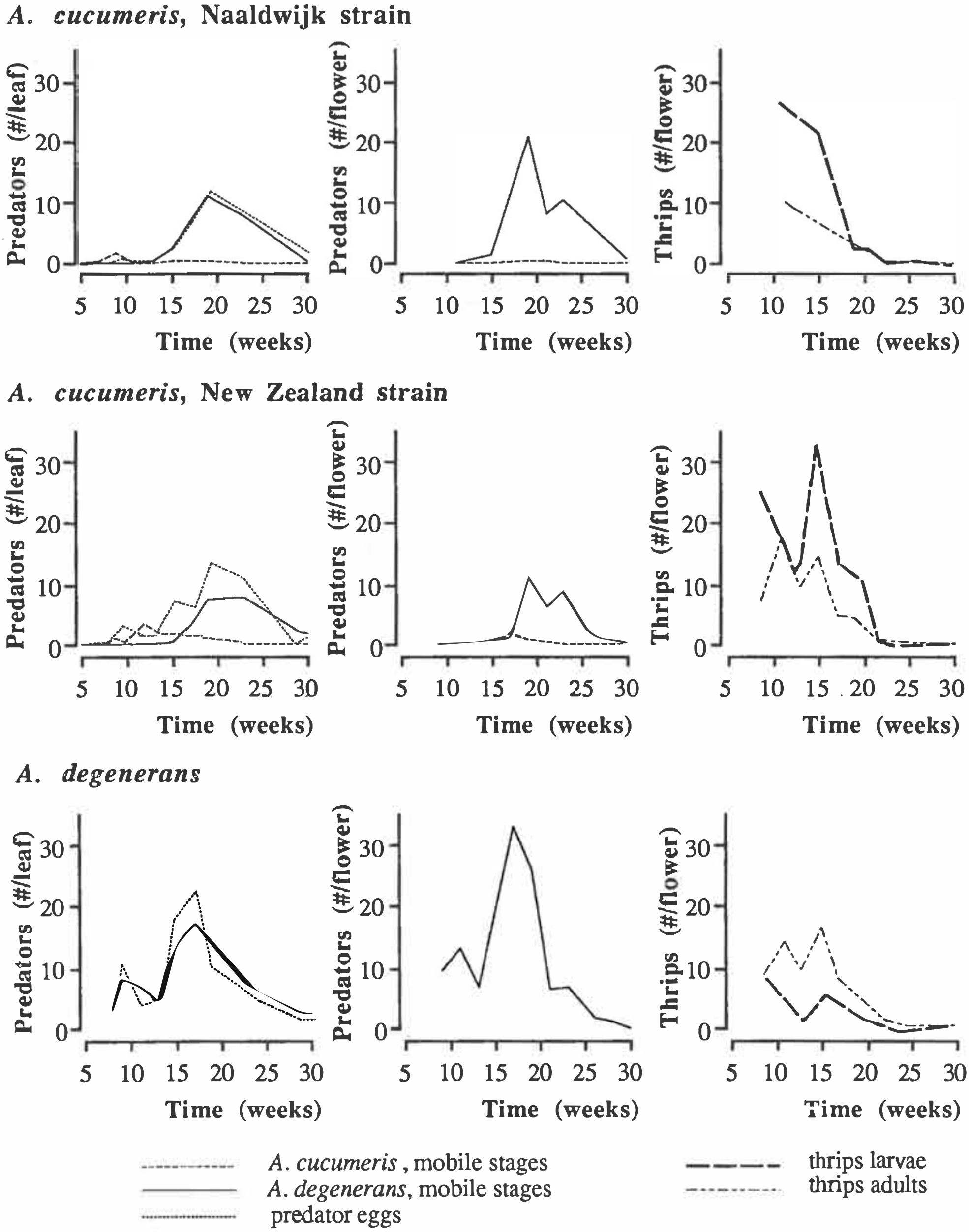

Figure 2. Population fluctuations of western flower thrips, *Frankliniella occidentalis*, the phytoseiid mite, *Amblyseius degenerans*, and two strains of the phytoseiid mite, *A. cucumeris*, on leaves and in flowers of a greenhouse sweet pepper crop. In the second week of January, 25 predatory females were introduced per plant. Each strain or species was released in 4 different rows of plants.

lead to increasing establishment, survival, rate of development and rate of oviposition of *A. degenerans*. Which stimulus causes *A. degenerans* to visit flowers and why *A. cucumeris* hardly visits flowers needs to be investigated.
Another characteristic of *A. degenerans* is that eggs of this predator are more resistant to drought than the eggs of *A. cucumeris*. The winter of 1992, however, was very mild and therefore it was assumed that the humidity levels in the greenhouse have not been below the critical level for the eggs of *A. cucumeris*.

Impact of the predators on thrips populations
Unfortunately, our results do not allow to conclude whether the New Zealand strain of *A. cucumeris* is better able to control thrips than the Naaldwijk strain. This is because only three flower samples had been taken before *A. degenerans* invaded the plant rows with *A. cucumeris* (Figure 2). The results do show that *A. degenerans* decimates thrips populations. *Amblyseius degenerans* wipes out the thrips not only in plant rows where it originally was released, but eventually in all other plant rows in the greenhouse.
It remains to be shown which characteristics enable *A. degenerans* to control thrips. Laboratory experiments revealed that the rate of predation and oviposition on a diet of thrips larvae is somewhat lower for *A. degenerans* than for *A. cucumeris* (Van Houten et al., 1992). Therefore, successful thrips control by *A. degenerans* has to be explained by other factors. One of these may be searching efficiency of the predator. We observed that *A. degenerans* shows higher locomotory activity on the leaves than *A. cucumeris*. Moreover, unlike *A. cucumeris*, which is predominantly found on leaves, *A. degenerans* is also found in substantial numbers in flowers, where there is a higher thrips density (see Figure 2). Laboratory experiments have shown that both predators feed on thrips larvae when pollen and thrips are offered (Van Houten, unpublished results). Both higher locomotory activity and the frequent presence in flowers could lead to a higher number of encounters with thrips larvae, and hence to higher thrips mortality. Experiments at the individual level are needed to elucidate the underlying mechanism.
Future research will show whether or not *A. degenerans* is a good candidate for thrips control in other greenhouse crops as well. A good mass-rearing technique for *A. degenerans* has still to be developed.

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CONTROL OF *FRANKLINIELLA OCCIDENTALIS* WITH *ORIUS MAJUSCULUS*: EXPERIENCES DURING THE FIRST FULL SEASON OF COMMERCIAL USE IN THE U.K.

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Abstract
Orius majusculus were released to control *Frankliniella occidentalis* in 9 pepper, 2 aubergine and over 40 cucumber crops in the N.E. of England during 1992. The establishment and performance of the predators were monitored and the strategies found to be successful in all the pepper crops, one aubergine crop and 6 cucumber crops. Failures were attributed to delayed introductions, release of too few predators, or the use of harmful pesticides. *O. majusculus* established breeding populations under supplementary lighting in localised areas of crop from early March, this being 6 to 7 weeks before the estimated natural threshold for photoperiodic induced reproductive diapause. Improved strategies, including rates of release, are discussed.

Introduction

Frankliniella occidentalis (Pergande) is still the most serious pest of protected pepper, aubergine and cucumber crops in the UK but if prompt action is taken it can be controlled. It has now been demonstrated both in trials (Bennison and Jacobson, 1991) and commercial treatments that *Amblyseius cucumeris* (Oudemans) introduced into crops by the controlled release system (CRS) can suppress development of the pest. Control has even been achieved where action was delayed until after the pest had become well established (Bennison, pers comm) but the number of CRS sachets used was not economically viable. There are however certain situations in which additional action is required.

It has been shown that *Anthocoris nemorum* (Linnaeus) (Jacobson, 1991; Wardlow, pers comm) and various Orius species (Gilkeson et al, 1990; Van den Meiracker and Ramakers, 1991) are voracious predators of thrips and should complement the activities of *A. cucumeris* at times of high invasion pressure. Commercial efforts for 1992 were concentrated on one of the most promising indigenous *Orius* species, *Orius majusculus* (Reuter), because *A. nemorum* had proved difficult to rear economically. However, even this species has certain characteristics which could possibly limit its value in UK salad crops:

i) A form of reproductive diapause is induced at day lengths less than about 16 hours. Such conditions would be experienced in the North East of England until late April.
ii) It does not seem to form breeding colonies at low prey density.
iii) If released in very bright conditions the adults fly up and often straight out of ventilators.
iv) The interaction with its prey is poorly understood. Although it had been demonstrated that 0.5. *Orius insidiosus* (Say) per m^2 (Van den Meiracker and Ramakers, 1991) could be effective against *F. occidentalis* in peppers, similar numbers of *O. majusculus* and *Orius laevigatus* (Feiber) in cucumbers had been disappointing.

Despite these know limitations many UK growers requested supplies of *O. majusculus* during the 1992 season. It was released in 9 pepper, 2 aubergine and over 40 cucumber crops. Its establishment was carefully monitored in all the peppers and aubergines and in 12 of the cucumber crops. The results are summarised below. More detailed case histories are available but are beyond the scope of this paper.

Observations in Pepper Crops

O. majusculus established rapidly and controlled *F. occidentalis* in all 9 pepper crops.
The earliest introduction was under localised supplementary lighting in early March. Rates of use varied from 0.3/m^2 in a short season summer crop, to 4/m^2 in a long season crop which already had a serious thrips problem.

The predators established more readily in peppers than other crops, no doubt due to the suitability of the pollen as a supplementary food source (Van Rijn and Sabelis, 1992).

Observations in Aubergine Crops

In one crop, *O. majusculus* were applied at 5 per m^2 in a 100 m^2 area of *F. occidentalis* infestation. The predators reproduced locally under supplementary lights from late March and controlled the established population of *F. occidentalis* in that area. However, it failed to prevent the pest spreading to other parts of the same crop.

In a second crop, the pest built up very rapidly during May but *O. majusculus* introduced at the rate of 1.5/m^2 from late April achieved control within 10 weeks. At the end of this period there were such large numbers of *O. majusculus* present the grower was able to harvest them for use elsewhere.

It is assumed that the predator also used pollen to supplement its diet in aubergines but this is not proven.

Observations in Cucumber Crops

O. majusculus were released in over 40 cucumber crops during the season. Six were considered successful and a further 7 produced 'promising' results. Overall, the results showed that this predator can breed in cucumber crops and can control *F. occidentalis*.

Where *O. majusculus* were released locally before Week 17 under supplementary lighting they bred successfully and in most cases controlled the pest in the original area. Rates of introduction varied from 3 to 9 per m^2 locally (0.1 to 1.5 m^2 overall). In one such situation there was little further problem but in most cases the predator failed to prevent the pest spreading to other areas.

The most encouraging results were achieved where the pest activity was first detected in April and predator introductions began in early May. *F. occidentalis* and *Thrips tabaci* (Lindeman) were completely controlled with rates of 0.9 and 0.7 *O. majusculus* respectively. In several other cases very large populations of *O. majusculus* were generated but the crop was replanted before the pest was controlled.

Most of the failures in the 'first' crops were attributed to delayed introductions or release of too few predators.

Results were generally disappointing in the replanted crops. Thrips were controlled in one greenhouse where 2 *O. majusculus* per m^2 were used in conjunction with *Verticillium lecanii*, but in most cases the predators were killed by nicotine treatments used against *Aphis gossypii* (Glover) soon after their release.

Discussion and Conclusions

Photoperiodic effect on diapause induction.

O. majusculus established breeding populations under supplementary lighting in localised areas from early March, ie 6-7 weeks before the estimated natural threshold for diapause induction. The quality of the lighting varied from 500 watt sodium lamps at 3 m spacing to 60 watt tungsten filament bulbs strung at 2 m intervals. In all cases the "daylength" was extended to over 16 hours. The predators produced offspring at even the lowest light intensity.

At the time of these observations it was thought that adult female *Orius spp.* were affected by short days. However there is now evidence that it is the final nymphal stage which is susceptible (Ruberson et al, 1991; Stinson, pers comm). This discovery complicates the interpretation of these results since both adult females and final nymphs were released.

The need for supplementary lights to prevent diapause before mid April requires further investigation. However, it is possible that if only adults were released the critical time for unaided establishment could be brought forward by 3-4 weeks.

Recent studies have shown that strains of *Orius spp.* collected from the Mediterranean area may be less sensitive to photoperiodic induced reproductive diapause than strains from Northern Europe (Stinson, pers comm).

Rates of Release

Many of the problems associated with use of *O. majusculus* in 1992 could be attributed to delayed introduction or release of too few predators. The following strategies were formulated to supplement the use of *A. cucumeris* CRS in the 1993 season:

Peppers. In the early season release 3-5 *O. majusculus* per m^2 in hot spots of pest activity followed by a general introduction of $1.5/m^2$ between 2 and 4 weeks later. From early May onwards, atthe first sign of *F. occidentalis* release $0.5/m^2$ with two thirds concentrated in areas of pest activity and the remainder distributed evenly.

Cucumbers and Aubergines. In the early season release 5-10 *O. majusculus* per m^2 in specific areas of pest activity followed by a general introduction of $1\text{-}2/m^2$ between 2 and 4 weeks later. During mid season (eg cucumber replants) release $2\text{-}3/m^2$ in 1 or 2 batches (7 day interval) starting as soon as the pest is seen.

Time of Release

Where *O. majusculus* were released in the early morning or late afternoon, the risk of adults flying straight out of the glasshouse was much reduced.

Control of A. gossypii in Cucumber Crops

Where substantial populations of *O. majusculus* had established before immigration of *A. gossypii*, the plants remained free of this pest despite damaging populations developing in adjacent glasshouses. At lower *O. majusculus* population densities the aphids were not kept under control. Control of *A. gossypii* remains a major difficulty in the overall IPM strategy.

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IMPROVING THE RELIABILITY OF BIOLOGICAL CONTROL BY APPLYING QUALITY CONTROL OF NATURAL ENEMIES

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Abstract
Inundative and **seasonal inoculative** biological control are based on regular introductions of natural enemies. Mass-rearing often takes place at small companies with little know-how, which may result in natural enemies of bad quality and failure of a biological programme. The technology to rear natural enemies on "unnatural" hosts and host plants, or on artificial diets, is not far developed yet and seems to be hampered by lack of understanding of e.g. associative learning of host-habitat and host cues. Conflicting requirements for natural enemies in mass-rearing programmes and greenhouse performance form another obstacle. These problems make good quality-control programmes a necessity. In such programmes not only natural-enemy numbers but also natural-enemy quality (performance in the greenhouse) should be determined. Simple, representative and reliable quality control programmes for natural enemies have been designed as a result of good cooperation between mass production companies and researchers in the global IOBC working group "Quality Control of Mass Reared Arthropods".

Introduction

Qualtity control to mass-reared organisms is applied to maintain the quality of the population. The overall quality of an organism is defined as the performance in its intended role after release into the greenhouse. Characteristics to be measured should be limited in number, but directly linked to greenhouse performance will companies producing natural enemies ever be able to apply quality control on a regular basis. This is not an easy affair (Bigler 1989). The aim of releases of mass-produced natural enemies is to control a pest. **The aim of quality control should then be to determine whether a natural enemy is still in a condition to properly control the pest.** Formulated in this way we do not deal with maximal or optimal quality, but with **acceptable quality**. Often discussions focus on keeping the quality of the mass reared population identical to that of the once collected field population. This is not only an illusion, it is an unnecessary and expensive goal to pursue.

Different quality criteria for different types of biological control

In classical or *inoculative* biological control, where natural enemies are often released a few generations after having been field collected, quality control can be limited. Quality control is essential in *inundative* biological control, where mass reared and periodically released in large numbers to obtain an immediate control effect, and in *seasonal inoculative* biological control, where natural enemies are mass reared and periodically released in relatively small numbers for control of multivoltine pests in crops grown during 6-12 months (van Lenteren & Woets 1988).

Obstacles in mass production

Artificial selection forces in mass rearing may lead to problems if rearing conditions differ largely from the situation in which natural enemies are to be released. If climate conditions in the mass rearing differ considerably from the greenhouse situation, problems with e.g. diapause, symchronization and performance at certain temperatures can be expected. Rearing on different hosts or host plants can create problems with natural enemy quality and the reaction of natural enemies to semiochemicals, etc. Another important obstacle is the production of good quality natural enemies at economical costs. For a comprehensive discussion of obstacles in mass production see Singh & Moore 1985 and van Lenteren 1986a, more specifically for the greenhouse situation see van Lenteren 1986b. Serious consideration of these obstacles leads to the conclusion it is best to rear the natural enemies under as natural a situation as possible.

Conflicting requirements concerning performance of natural enemies in a mass rearing and under greenhouse conditions

Anyone starting a mass rearing does not only have to overcome the above mentioned obstacles but should also realize the conflicting requirements for natural enemies in a mass production programme and for greenhouse performance (table 1). Both, to discover whether one of the obstacles mentioned above plays a role and to be able to trace if important aspects of greenhouse performance listed in table 1 do not get lost in a mass rearing, stress the need for good quality control methods.

Development of quality control

The problem of quality control in mass-rearing programmes of entomophagous insects can be approached from two sides: (a) measure how well the insect functions in its intended role, if it does not function well enough, trace the cause and improve the rearing method, or (b) list what changes can be expected when a mass rearing is started, measure these and if the changes are undesired, improve the rearing method. Many follow the second approach, but causes for deterioration are not so easily identified, demand detailed genetic studies and it is difficult to define and measure detrimental genetic traits. Bartlett (1984) wrote:" I believe an unappreciated element of this problem is that the genetic changes taking place when an insect colony is started are natural ones that occur whenever any biological organism goes from one environment to another."

The size of the founder population will directly affect how much variation will be taken from the native gene pool. Although there is no agreement on the size of founder populations for starting a mass production, a minimum number of thousand individuals is mentioned in the literature (Bartlett 1985). Founder populations for a number of natural enemies were much smaller (van Lenteren and Woets 1988). Fitness characteristics for the greenhouse will be different than those for the laboratory (e.g. difference in importance of ability to diapause, or the ability to locate mates (role of pheromones)), so laboratory selection forces may produce different, unsuitable genotypes for the greenhouse.

Table 1: Conflicting requirements concerning performance of natural enemies in a mass rearing and under greenhouse conditions

Appreciated in mass rearing	Important for greenhouse performance
1. polyphagy, makes rearing on unnatural host easier	mono-, oligophagy, more specific, greater pest reduction capacity
2. good parasitism at high host densities	good parasitism at low host densities
3. no strong migration as a result of direct or indirect interference	strong migration as a result of direct or indirect interference
4. migration behaviour unneccessary and unwanted, abilityto disperse minimal	migration behaviour essential
5. associative learning not appreciated	associative learning appreciated

One of the cures often suggested to overcome or correct for genetic revolutions is the regular introduction of wild individuals from the field. But if the rearing conditions remain the same in the laboratory, the introduced wild individuals will be subjected to the same selection process. If one wants to introduce wild genes it should be done regularly and from the start of a laboratory rearing onwards. It should not be delayed until problems occur. The risk of introducing native insects are concurrent introduction of parasites, predators or pathogens.

Another effect of laboratory colonization can be inbreeding. The rate of inbreeding is directly related to the size of the founder population (Bartlett 1985). Inbreeding can be prevented by (Joslyn 1984): (a) selection and pooling of founder insects from throughout the range of the species to provide a wide representation of the gene pool, (b) providing a variable laboratory environment (climate variation over time and sufficient space), and (c) the regular rejuvenation of the gene pool with wild insects.

What is the effective population size to keep genetic variation sufficiently large? Joslyn (1984) says that to maintain sufficient heterogeneity, a colony should not decline below the number of founder insects. The larger the colony the better. Joslyn mentions a minimum number of 500 individuals as effective population size.

Quality control in a wider perspective

Even if natural enemies leave the production unit in an excellent condition it does not mean that they are still in good when they are released in the greenhouse. Storage, shipment, developmental stage of natural enemy during shipment and release, method and moment of introduction of natural enemies can all cause a decrease of quality (examples in van Lenteren 1986a).

Erratic performance of natural enemies may occur if one does not know the causes of such behaviour. Our research group has, in cooperation with Lewisses group in the USA, developed a conceptual framework for thinking about the variability in responses of foraging natural enemies (Lewis et al. 1990, Vet & Dicke 1992). Response patterns of natural enemies to plant, prey or host cues can be influenced by the insect's (1) genetic composition, (2) phenotypic plasticity and (3) physiological condition. At the natural enemy selection phase one should screen for the diversity of genetic traits and ensure that traits of the population are correctly attuned to the situation in which they will be released. Further, during mass rearing, experience in either pre-adult or adult stages can strongly modify adult behaviour. Variability in foraging behaviour ultimately results in variability in the effectiveness of natural enemies in controlling pests. Understanding the nature of behavioural variablility may mean being able to manipulate it to our benefit.

Production companies are usually very hesitant to discuss their methodology or standards. When we distinguish product control (rejects faulty products), process control (tells how the manufacturing processes are performing) and production control (maintains consistency of production output), this problem may ~~be easier~~ to handle (Leppla and Fisher 1989). Elements as production and process control are seldomly used in small mass-rearing programmes, which form 95% of the total number of producers. If success is to be obtained, quality control of the end product is essential, but producers are generally more than happy if they can meet demands. Here the aspect of product control is the issue. Setting minimum standards and simple methods to control standards is of mutual benefit to producers and researchers. It is of great importance that producers of natural enemies will be considered reliable partners in crop protection. This means that their products should have a certain basic quality. Minimal performance standards and the methods to determine these should therefore be developed and agreed upon.

Conclusions

Elements of quality control programmes should be designed to obtain acceptable quality, not per sé the best quality. The number of tests will be smallest if the natural enemies are reared under conditions at which they also have to function in the greenhouse: same climate, same host and host plant. The more artificial rearing becomes, the more tests will have to be performed and pre-release training may be necessary. Small companies starting with production of natural enemies are often rather ignorant about the obstacles and complications related to mass rearing. They are even more ignorant about the development and application of quality control. A special point of concern is the lack of knowledge about the sources of variability of natural enemy behaviour and methods to prevent genetic deterioration of natural enemies.

Cooperation within the field of quality control between state funded research and commercial producers has been a frustrating affair to date. If production and process control are left to the companies, mutually beneficial work should be possible in the area of product control. Will the biological control industry survive and florish, the production of reliable natural enemies meeting a certain quality standard is elementary. Organizations like IOBC could play a very positive role by developing training courses in this area to meet the rapidly increasing demand for consistent biological control. In good cooperation we will be able to provide such natural enemies and, in this way, we help solving an important environmental problem.

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QUALITY CONTROL FOR NATURAL ENEMIES USED IN GREENHOUSES

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Introduction

The guidelines listed herein were developed during two workshops of the IOBC global working group "Quality control of mass reared arthropods" (Wageningen, The Netherlands, March 1991, Hørsholm, Denmark, November 1992) and they refer to **product control** procedures, not to production or process control. They were designed to be as uniform as possible so they can be used in a standardized manner by producers. They should preferably be carried out by the producer **after all handling procedures, and just before shipment**. The grower can apply (aspects of) the same quality test, like percent emergence or number of live adults.

Some tests are to be carried out frequently by the producer, i.e. on a batch-wise basis. Others will be done less frequently, i.e. on an annual or seasonal basis, or when the rearing procedures will be changed. This is specified in the tests.

For each test two coordinators are appointed to follow up the application of quality control tests by the producers and, upon their feedback, to reassess the technical and economic feasibility of those tests. If necessary, coordinators will contact relevant scientists or producers in order to design and carry out further studies which are essential for the completion of the quality control guidelines.

Most of the tests were drafted at the Wageningen 1991 meeting. All participants of that meeting and mass production companies were asked to comment on these drafts. During the Hørsholm meeting the comments were discussed and tests were adapted after evaluation of last years test results. Several new guidelines were drafted that will be tested during the coming year. Further, appointments have been made about additional tests and experiments for improving guidelines. During the next full meeting of the IOBC global working group on "Quality Control of Mass Reared Arthropods" in Rimini, Italy (13-17 September 1993) it is expected that most of the tests will be officially accepted and function as standard guidelines. This remarkable success is the effect of very positive cooperation between commercial producers and scientists active in the field of biological control of pests. Information about this IOBC working group can be obtained from its chairman, Dr. F. Bigler, Swiss Federal Research Station for Agronomy, CH-8046 Zurich - Reckenholz, Switzerland.

For all natural enemies:

1. When rearing procedures are changed all elements of a set of guidelines should be carefully tested for untreated (directly from the mass rearing) and treated (processed and ready for shipment) natural enemies.
2. The expiry date - the date after which the natural enemies should no longer be sold/used - should be added on containers or packaging material.
3. Details for some of the tests described below will be given in the proceedings of the Hørsholm and/or Rimini meeting

***Encarsia formosa* Gahan (Hymenoptera: Aphelinidae)**

Test conditions:	Temperature: 22°C; RH: 60-90%; Light regime: 16L:8D.
Quantity and: rate of emergence	Number of adults specified on the label which will emerge during 2 weeks; a weekly or batch-wise test
Sex-ratio:	>= 98% females; n=500; a weekly or batch-wise test
Adult size:	Head width >= 0.28 mm; n=20 females; an annual test
Fecundity:	>= 7 eggs/female/day for days 2,3 and 4 after emergence of the adult; n=15; an annual test. Procedure is described by Ravensberg in Wageningen proceedings 1991 (p. 80-89).
Flight activity:	Short range test ready, needs to be tested. Long-range test to be developed; an annual test
Comments:	Short-range flight test based on Enkegaard's design will be tested by several producers; Dept. Entomology Wageningen will develop a longer-range emergence test. Annual tests to be performed in August/September/October when the population is at its lowest number
Coordinators:	*J.C. van Lenteren & W. Ravensberg*

***Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseidae)**

Test conditions:	Temperature: 22 (20-25)°C; RH: 70+/-%; Light regime: 16L:8D.
Quantity:	Number of live predators as specified on the container; a weekly or batch-wise test.
Sex-ratio:	>= 45% females; a weekly test; n=500
Longevity:	Minimum 5 days, reached by at least 80% of the females in the sample; n=20; a seasonal test.
Fecundity:	>=2 eggs/female/day for 5 days after egglaying starts; n=20; a seasonal test.
Coordinators:	*S. Steinberg, J. Dale*

***Diglyphus isaea* (Walker) (Hymenoptera: Eulophidae)**

Test conditions:	Temperature: 22°C; RH: 60+/-5%; Light regime: 16L:8D.
Quantity:	Number of live adults specified at the label; a weekly or batch-wise test
Adult mortality:	<= 5%, based on 3 containers sampled and n= 500 or more; a weekly or batch-wise test
Sex-ratio:	>= 45% females; n=500; conducted once every 4 weeks
Fecundity:	>= 50 eggs/female from 3rd to 7th day after emergence; n=30; an annual test; pre-oviposition period of *Diglyphus* is 2 days; procedure: daily oviposition of a single pair of wasps on brown beans (*Phaseolus vulgaris*) infested with sufficient (minimum 30 L2 & L3 larvae) *Liriomyza trifolii*, if insufficient hosts are offered many might be killed by host feeding. Other host species can be used but should then be specified.
Coordinators:	*C. Fleurynck & G. Nicoli*

***Dacnusa sibirica* Telenga (Hymenoptera: Braconidae)**

Test conditions:	Temperature: 22°C; RH: 60+/-5%; Light regime: 16L:8D.
Quantity:	Number of live adults specified at the label; a weekly or batch-wise test
Adult mortality:	<= 5%, based on 3 containers sampled and n= 500 or more; a weekly or batch-wise test
Sex-ratio:	>= 45% females; n=500; conducted once every 4 weeks
Fecundity:	>= 50 eggs/female within 5 days; n=10; an annual test; procedure: daily oviposition of a single pair of wasps on brown beans (*Phaseolus vulgaris*) infested with sufficient *Liriomyza trifolii* and a source of carbohydrate.
Coordinators:	*R. Greatrex, J. Dale*

Aphidius[1] spp. (Hymenoptera: Braconidae)

Test conditions: Temperature: 22°C; RH: 60+/-5%; Light regime: 16L:8D.

Quantity: When shipped as adults: number of live adults as specified on the package; Shipped as mummies: number of live adults that have to emerge from the package. Minimum of 3 containers counted. A weekly or batch-wise test.

Adult mortality: < = 5 %, based on 3 containers sampled and n= 500 or more; a weekly or batch-wise test

Emergence rate: 70%; 50% emergence within 5 days; n=500; conducted once every 4 weeks

Sex-ratio: > = 45% females; a weekly test; n=500

Fecundity: > = 65% parasitism; n=25; to be conducted 4 times per year. Procedure for *Aphidius matricariae* targeted at *Myzus persicae*: each female wasp is offered 20 *M. persicae* aphids on sweet pepper leaves in a petridish. Procedure for *Aphidius colemani* (or *A. matricariae*) targeted at *Aphis gossypii*: each female wasp is offered 20 *A. gossypii* on cucumber leaves in a petridish. To be tested 4 times per year.

Flight activity: As mummies can easily be damaged during the harvesting process, a flight test will have to be developed by Steinberg.

Comments: [1] The target pest - the aphid species name - for which this parasite should be used needs to be mentioned on the container, as well as the *Aphidius* species name.

Coordinators: *J. van Schelt & S. Steinberg*

***Aphidoletes aphidimyza* (Diptera: Cecidomyiidae)**

Test conditions: Temperature: 22°C; RH: 80%; Light regime: 16L:8D. Weekly emergence test at 25°C.

Quantity: Number of adult insects as specified on the label; a weekly test

Emergence rate: 70% emergence within 7 days; a weekly test; n=500

Sex-ratio: > = 45% females; a weekly test; n=500

Fecundity: >= 40 eggs/female within 4 days; n=25; to be conducted monthly; Procedure: allow females to oviposit individually on *M. persicae* on sweetpepper leaves (for details see Van Schelt, Wageningen Proceedings 1991: 90-95).

Flight activity: Short distance test as for *E. formosa* to be conducted 4 times a year. A longer-distance flight test will have to be developed

Coordinators: *A.T. Gillespie & J. Douma*

***Chrysoperla carnea* Steph. (Neuroptera: Chrysopidae)**

Test conditions: Temperature: 25°C; RH: 70-90%; Light regime: 16L:8D.

When shipped as eggs

Quantity: Number of eggs as specified on the package; a weekly test.

Longevity: Minimum 5 days reached by at least 80% of the females in the sample; n=20; a seasonal test.

Hatching rate: >= 65% within 5 days; n=200; eggs must be isolated to prevent cannibalism after emergence; a weekly test.

Predator quality: > = 65% of newly hatched larvae has to develop to 2nd instar larvae within 4 days; to be conducted once a year or when the rearing system is changed. Procedure: offer individual, freshly emerged larvae at least 50 prey items on a leaf on agar in a petridish (30 cm diameter); n=30; three species of aphids can be used as prey items: *A. gossypii* on cucumber, *Macrosiphum euphorbiae* on strawberry or potato, or *M. persicae* on sweet pepper.

When shipped in 2nd larval stage

Quantity: Number of live predators as specified on the package: a weekly test.

Composition: > = 65% of 2nd instar larvae has to develop to 3*rd* instar larvae within 5

	days; to be conducted once a year or when the rearing system is changed. Procedure: offer individual, freshly emerged 2*nd* instar larvae at least 100 prey items on a leaf on agar in a petridish (30 cm diameter); n=30; three species of aphids can be used as prey items: *A. gossypii* on cucumber, *Macrosiphum euphorbiae* on strawberry or potato, or *M. persicae* on sweet pepper.
Comments:	Test to evaluate the searching capacity of 1st and 2nd instar larvae of *Chrysopa* should be developed.
Coordinators:	*M. Benuzzi & Californian producer*

***Orius* spp. (Hemiptera: Anthocoridae)**

Test conditions:	Temperature: 22°C; RH: 70+/-5%; Light regime: 16L:8D.
Quantity:	Number of live adults as specified on the container. Counting method: 3 samples from each of 3 containers, assessed by weight, sample size 30 insects per container. A weekly or batch-wise test. Adult/nymph ratio:to be specified by the producer on the label; a weekly or batch-wise test done similarly with athe quantity test; n=300
Sex-ratio:	>= 45% females; a weekly or batch-wise test
Fecundity:	>= 20 eggs/female during a 10 day oviposition period; start after pre-oviposition period of 5 days; n=30 pairs individually kept as described in annex 2. A monthly test.
Comments:	- new test, will be adopted next year - the species (composition) must be mentioned on the container
Coordinators:	*W.J. Dale & G. Manzaroli*

***Amblyseius cucumeris* (Oudemans) (Acarina: Phytoseiidae)**

Test conditions:	Temperature: 22°C; RH: 70+/-5%; Light regime: 16L:8D.
Quantity[1]:	When delivered in container: number of live predators as specified on the container, excluding eggs. When delivered as slow release system: the number of live predators as specified on the label, excluding eggs when sold, and the number of predators released per week during a specified number of weeks. Three samples from different packages should be tested per batch. A weekly or batch-wise test.
Fecundity:	According to earlier published methods.
Comments:	[1] two types of counting methods will be compared: a dry and a wet method - new test, will be adopted next year - no test for other *Amblyseius* spp. were developed as they are applied on a very limited area.
Coordinators:	*J. Douma*

***Aphelinus abdominalis* (Hymenoptera: Aphelinidae)**

Test conditions:	Temperature: 22°C; RH: 60-80%; Light regime: 16L:8D.
Quantity:	Number of live adults and/or mummies as specified on the label; a weekly or batch-wise test.
Adult mortality:	<= 10% per package; n=250, based on sample from 3 containers; a weekly or batch-wise test.
Emergence rate:	80% within 2 weeks, n=200, weekly or batch-wise test
Sex-ratio:	>= 45% female, n= 250, batch-wise or weekly
Fecundity:	>= 60 eggs/female during 8 days; n=10. Female fed with honey. Indirect measure on whole plant by counting mummies. Plants infested with *Macrosiphum euphorbiae* (ample amount) on tomato. Annual test
Coordinators:	*C. Fleurynck & H. Haardt*

DEVELOPMENT OF AN IPM PROGRAM IN LEAFY AND TUBEROUS CROPS WITH LIRIOMYZA HUIDOBRENSIS AS A KEY PEST

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Abstract
An IPM program is being developed for leafy and tuberous crops, such as lettuce and radish. It is necessary to find natural enemies or selective chemical agents to replace the broad spectrum chemicals currently used. So far, the leafminer *Liriomyza huidobrensis* can be controlled by the parasitoid *Dacnusa sibirica*. Most problems are caused by *Frankliniella occidentalis* and Lepidoptera.

Introduction

In The Netherlands, the New World leafminer species *Liriomyza huidobrensis* (Blanchard) (Diptera: Agromyzidae) appeared harmful in many crops in glasshouses as well as outside (De Goffau, 1991). Occasionally, lettuce crops and *Gypsophila* were completely destroyed on large areas. Chemical control was obviously not effective with the usual agents (Macdonald, 1991, Van der Staay, 1992) and legislation of new chemicals seemed unlikely. Besides biological control of *L. huidobrensis* in tomato (Van der Linden, 1991), development of biological control in leafy vegetables was proposed (Van der Linden, 1990). Lettuce and radish, a tuberous crop, are important vegetable crops, following tomato, sweet pepper and cucumber. Lettuce is grown on a glasshouse area of 250 to 300 ha producing 995 ha on a yearly basis (1992). Most growers have two or three plantings per year, a minority has six plantings per year. Radish is grown on a glasshouse area of 150 to 200 ha. Most growers have six crops per year producing 1035 ha on a yearly basis (1992).

Open rearing system

Observation of leafminers in lettuce pointed out that high densities are controlled by *Dacnusa sibirica* eventually. To prevent high leafminer densities an open rearing system of the parasitoids was very helpful. The open rearing system consisted of an alternative host plant, *Ranunculus asiaticus* (peony type), an alternative host the leafminer *Phytomyza caulinaris* and either *Dacnusa sibirica* or *Diglyphus isaea* (Van der Linden, 1992). Both parasitoids performed well in an open rearing system when the ranunculi were planted in glasshouses with lettuce. When the lettuce was infected intentionally with *Liriomyza huidobrensis*, *Dacnusa sibirica* moved into the lettuce and controlled the pest, while *Diglyphus isaea* did not. *Diglyphus isaea* occurred only in mature heads of lettuce with higher leafminer density. In general, *Dacnusa sibirica* was by far the most dominant species in lettuce. Part of the success of *D. sibirica* may be explained by the fact that in earlier observations this parasitoid seemed to prefer the lower part of a tomato crop, and it was able to detect and parasitize spot infestations, in contrast with *D. isaea* (Van der Linden, 1988). The necessary size of an open rearing system in relation to the area of the crop has to be established yet. The system may be useful in other vegetable or ornamental crops as well, such as radish and chrysanthemum. In lettuce it was not necessary to maintain the open rearing system during summer. When the crop was infested with *Liriomyza huidobrensis* the rate of parasitism was usually 100% or nearly so. Apparently the emerging *D. sibirica* in the glasshouse were perfectly able to destroy the immigrated leafminers from outdoors throughout the season. There were always crops of different ages in the glasshouse. When a crop was harvested the parasitoids were able to move to a younger crop.

Appendix 1.

Table 1. Review of diseases and pests in glasshouse lettuce with the chemical agents which are used at present, the alternatives for an IPM program and possible future solutions.

Disease/pest	Chemical control	IPM	Future solutions
Bremia lactuca	(resistant varieties) propamocarb fosethyl-aluminium	(resistant varietie) propamocarb fosethyl-aluminium	(resistant varieties)
Botrytis *Pythium* *Rhizoctonia* *Sclerotinia*	iprodion * vinchlozolin * * or mixed with thiram or tolclofos-methyl or tolylfluanide	iprodione * vinchlozorin * * or mixed with thiram	tolclofos-methyl tolylfluanide
Agromyzidae (leafminers)	oxamyl granules dichlorvos deltamethrin propoxur	*Dacnusa sibirica* *Coenosia* spp.	
Aphididae (aphids)	pirimicarb heptenofos mevinfos propoxur	pirimicarb	resistant varieties vegetable substances insect pathogens parasitoids
Lepidoptera (moths)	deltamethrin	*Bacillus thuringiensis*	pheromone traps viruses vegetable substances
Thysanoptera (thrips)	dichlorvos	*Orius* spp.	vegetable substances insect pathogens predatory mites
Aleyrodidae (white flies)	mevinfos dichlorvos deltamethrin permethrin cypermethrin	*Coenosia* spp. *Encarsia formosa* (ranunculi banker plants)	insect pathogens vegetable substances parasitoids
Sciaridae (sciarid flies)		*Coenosia* spp. insect pathogenes	predatory mites nematodes
Agrotis spp. *Tipula* spp.	granular bait: parathion (ethyl) temefos chlorpyrifos	granular bait: parathion (ethyl) temefos chlorpyrifos	insect pathogens nematodes predatory flies beetles
Gastropoda (slugs)	methiocarb granules metaldehyde granules	metaldehyde granules	beetles predatory flies

In lettuce a low level of infestation by *L. huidobrensis* is acceptable because the mines occur on the oldest leaves, which are trimmed off when the lettuce is harvested. The same might hold good for chrysanthemum and few mines on radish may be sorted out at harvest, when the radish will be marketed with foliage and without foliage its even easier.

IPM in lettuce and radish

Biological control of leafminers in lettuce is possible, but the use of natural enemies or selective chemicals against other pests and diseases is strictly necessary. Predatory flies, *Coenosia spp.* (Diptera: Anthomyiidae) occur spontaneously in glasshouses. These flies are general predators preying upon shore flies (*Scatella* sp.), *Bradysia* sp. (Sciaridae), leafminers and white flies. So far, in lettuce, the most problematic pests next to *L. huidobrensis* were *Frankliniella occidentalis* and Lepidoptera. *F. occidentalis* was neither controlled by *Orius* spp. nor by repeated applications of *Verticillium lecanii*. Caterpillars (mainly *Chrysodeixis chalcites* and *Autographa gamma*) were not controlled by repeated applications of *Bacillus thuringiensis*. A survey of diseases and pests in lettuce is given in Table 1, with the broad spectrum chemicals currently used, the selective alternatives or natural enemies and possible future solutions. For radish the list of pests in Table 1 must be completed with *Delia brassicae* (Hofm.) and *Tyrophagus similis* Volgin. Possibilities for IPM will be studied further.

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EVALUATION OF ENTOMOPATHOGENIC NEMATODES FOR CONTROL OF FUNGUS GNAT LARVAE

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Abstract:
Laboratory and greenhouse evaluations were conducted using single and multiple applications of *Steinernema feltiae* - Otio and No. 27 isolates and *Steinernema carpocapsae* -All and Umeå isolates for control of fungus gnat larvae (*Bradysia coprophila*; Diptera: Sciaridae) in a soil-free potting mix. A laboratory experiment used 6 cm diam plastic petri dishes, and growth room or greenhouse experiments used 10 cm diam plastic pots. Host plants were corn and chrysanthemum. In greenhouse and growth room experiments, individual pots were covered to confine emerging fungus gnat adults or groups of pots were confined within cheesecloth-covered cages. Adults were trapped on 5cm square yellow sticky traps.

Although fungus gnat emergence, as measured by adult emergence was variable within replications of the individual treatments, best overall fungus gnat control was obtained with the *S. feltiae* isolates and the *S. carpocapsae* - Umeå isolate. Similar results were obtained in petri dishes or in experiments whether pots were covered with styrofoam covers or were placed within cages. Horizontal yellow traps were useful for measuring effects of nematodes.

Introduction:
Fungus gnats are among the most controversial of the insects associated with greenhouse crops. They are sometimes considered as simply nuisance pests by research and extension specialists. However, there is no doubt that fungus gnat larvae can stunt and/or kill young seedlings and transplants, if numbers are high enough. They have also been associated with aiding in the spread of some plant pathogens (Stanghellini, 1991). Growers of ornamental plants often think of them as one of their most difficult pests to control, at the very least because of possible consumer resistance to the presence of adults.

Regardless of their actual or imagined economic importance, pesticide applications have traditionally been used to control fungus gnats. However, with losses of registered pesticides, restrictions on exisiting materials, re-entry intervals and the general promotion of integrated crop management procedures, alternative managment methods are being evaluated. Entomopathogenic nematodes are among these alternatives. Much of the following review is from Gaugler and Kaya (1990). Entomopathogenic nematodes have been used experimentally to control insect pests for more than 60 years . Most of the species used are in the families Steinernematidae and Heterorhabditidae, including *Steinernema glaseri, S. carpocapsae, S. feltiae*, and *Heterorhabditis bacteriophaga* (=*H. heliothidis*) These microscopic roundworms carry bacteria in the genus *Xenorhabdus*, which multiply in insect haemolymph.

The infective juvenile stages of the nematodes generally enter the insects' body cavity through natural openings, although some species are able to directly penetrate the body wall. The bacteria are released by the nematodes, multiply in the haemolymph and kill the host insect, generally within 48 hrs. The nematodes multiply within the insect, feeding on the bacteria, and either seek out or await other hosts.

In addition to differences among individual nematode species, there are isolates within species that may be more effective against certain insects.Most of the nematodes used against fungus gnats are isolates within *S. feltiae* and /or *H. bacteriophaga* . Several recent studies have documented the efficacy of these nematodes against sciarid fly larvae (e.g. Fransen et al., 1992; Gouge et.al., 1992; Nickle and Cantelo, 1991; Richardson, 1987) . A number of commercial nematode products using isolates of *S. carpocapsae* are also available for fungus gnat larval control (and other pest insects) in the United States. We report here results of experiments to evaluate fungus gnat control by two *S. feltiae* and two*S. carpocapsae* isolates in laboratory and greenhouse experiments.

General Methods:
Nematodes used in experiments reported here were *S. feltiae* (Otio and No. 27 isolates) and *S. carpocapsae* (All and Umeå isolates). All nematodes were obtained from commercial sources and

handled as suggested by each supplier. Application times, rates and intervals varied, depending upon the nematode and experimental design. Nematodes were applied in distilled water to tops of moist growing media in individual pots, or in small petri dishes. Nematodes were examined under a microscope immediately before application to ensure that there was movement. Pots were subsequently irrigated from below. Wax moth larvae (*Galleria mellonella*) were used to periodically (generally weekly) bioassay for nematode activity.

Fungus gnats used in the petri dish experiment were mass-reared in the laboratory on a mixture of agar, ground yeast and ground alfalfa. The growth chamber and greenhouse experiments relied on natural infestations, maintained by continuously adding pots containing fresh potting mix and decaying plant material to the area where fungus gnat activity was desired.

All experiments reported here utilized Pro-Mix^{TM} as the potting medium. Field corn and chrysanthemum ('Nob Hill') were used as host plants.

Description of Individual Experiments:

1. Comparing nematodes in petri dishes: Fungus gnat larvae from a laboratory-reared culture (30 mid-late instar larvae/dish) were transferred to plastic petri dishes (6 cm diam) containing a thin layer of moist Pro-Mix, and the different isolates and species of nematodes applied at ca. 7.4 mld/ha, in 1ml of distilled water. Nematode treatments were *S. carpocapsae*-All, *S. carpocapsae*-Umeå and*S. feltiae*-OtioThere were six replicates of each treatment. Laboratory temperature was quite constant at 25° C. As a check on nematode activity, *Galleria* larvae (3/dish) were placed in each of three petri dishes with each nematode treatment. Efficacy (Figure 1) was assessed by recording the number of adults that emerged.

2. Comparing nematodes and the effect of liquid drench rates on nematode efficacy: Field corn was planted in pots in a plant growth room and allowed to grow to a height of approx. 15 cm. Fungus gnat adults were actively flying inside the growth room. Plants were then clipped and the leaf clippings placed on the potting mix surface. *S. feltiae*-27 and *S. carpocapsae*-All were applied at the same high rate, ca. 45,000/pot (ca. 51 mld/ha) in three different drench volumes/10.5 cm diam pot; 17, 35 and 70 ml of distilled water. There were six single pot replicates of each treatment. Following nematode application, each treated and control pot was covered with a styrofoam cover containing an organdy screen top. A 5 cm x 5cm yellow sticky trap was placed face up on the potting mix surface of each pot. Traps were replaced weekly for 4 weeks. The styrofoam covers were lifted only to change traps. The growth room was set for a 14:10 hr light:dark cycle (fluorescent lights) and a constant temperature of 21°C. Results are presented in Figure 2.

3. Comparing nematodes and single vs. multiple applications: A greenhouse experiment was conducted using *S. carpocapsae*-All and *S. feltiae*-Otio. Corn was planted in each of 180 10.5-cm diam. pots. Pots were arranged on a greenhouse bench and exposed to a natural fungus gnat infestation. As the corn grew, plants were clipped and the leaf clippings were left on the potting mix surface. When fungus gnat larvae were observed feeding on the rotting vegetative matter, pots were randomized and divided into six groups of 30 pots each. Nematodes were then applied, as well as a microencapsulated diazinon treatment (1.9l/100l, 120 mls drench/pot). Each nematode species was applied at ca.7665/10.5 cm pot (7.4 mld/ha) once and ca. 2555/pot (2.5 mld/ha) three times at weekly intervals. Each pot, in a group of 30 pots, was covered by an organdy-screened styrofoam top for 7 days. A 5x5 cm yellow sticky trap was placed face up on the surface of each covered pot. A different group of 30 pots was covered each week for 5 weeks. Greenhouse temperature controls were set at 24°C (day) and 18°C (night). Results are presented in Figure 3.

4. Comparing nematodes in single and multiple applications: A greenhouse experiment designed to compare applications of *S. carpocapsae*--All (one or three applications, each at ca. 2555/pot; 2.5 mld/ha), *S. carpocapsae*-Umeå (one application at ca.4215/pot; 4 mld/ha), and *S. feltiae*-Otio nematodes (one or three applications, each at ca.2555/pot; 2.5 mld/ha) using chrysanthemums ('Nob Hill'), was conducted within specially-constructed cages (70 cm wide, 85 cm long, 70 cm high, covered on all sides with cheesecloth). Plants, in 10.5-cm diam pots, were arranged on a greenhouse bench, and exposed to a natural fungus gnat infestation for one week, then divided into groups of 15 and placed into the cages. The first nematode applications, were made 1 week later in 20 mls distilled water. Two subsequent applications of *S. carpocapsae*--All and *S. feltiae*--Otio were made at weekly intervals. There were three replications of each treatment. Two 5x5 cm yellow sticky traps were placed face up in each cage to record adult fungus gnat activity. Traps were replaced weekly. A single microencapsulated diazinon application (1.9l/100l; 120 ml drench solution/pot)

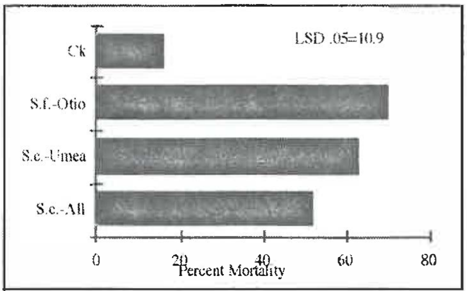

Figure 1. Application of nematodes for fungus gnat larval control in petri dishes. S.f.-Otio=*Steinernema feltiae*-Otio; S.c.-Umeå=*Steinernema carpocapsae*-Umeå; S.c.-All=*Steinernema carpocapsae*-All.

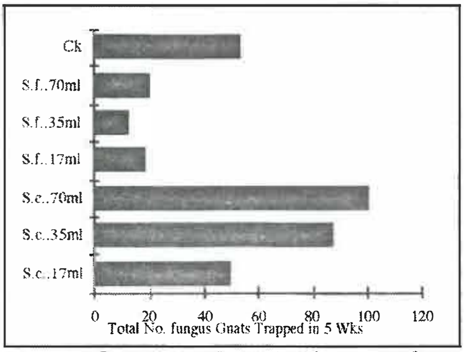

Figure 2. Comparison of drench volumes and fungus gnat control. S.f.=*Steinernema feltiae*-27; S.c.=*Steinernema carpocapsae*-All; ml=drench vol.

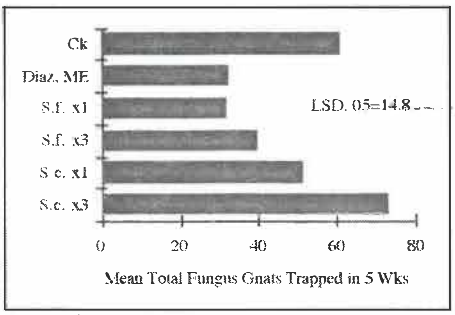

Figure 3. Fungus gnat control with one application at the maximum rate, or three applications at reduced rates; S.f.=*Steinernema feltiae*-Otio; S.c.=*Steinernema carpocapsae*-All.

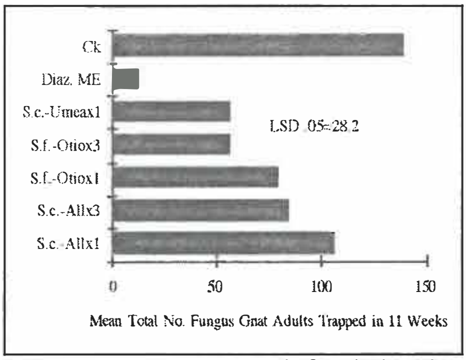

Figure 4. Fungus gnat control after single and multiple applications of nematodes, or microencapsulated diazinon to potting mix containing chrysanthemums;S.f.-Otio=*Steinernema feltiae*-Otio; S.c.-All=*Steinernema carpocapsae*-All;S.c.-Umeå=*Steinernema carpocapsae*-Umeå; x1=1appl.;x3=3appl.

was made at the time of the first nematode applications. Greenhouse temperature controls were set at 24°C (day) and 18°C (night). Results are presented in Figure 4.

Results and Discussion:

In the laboratory petri dish experiment, all nematodes provided 50-70% control, and were significantly better (P=0.05) than untreated controls (Figure 1). *S. feltiae*-Otio and *S. carpocapsae*-Umeå were significantly better than *S. carpocapsae*-All.

Applying the same nematode dosage in different drench volumes affected *S. carpocapsae*-All more than *S. feltiae*-27 (Figure 2). *S. feltiae*-27 also was more effective. The application rates used in this experiment were ca.7 times the maximum rates used in other experiments due to a miscalculation. The results are included here because they provide useful information on how drench voulme in a given potting mix can affect control. Low drench volumes (20 mls) were used in subsequent experiments for all nematodes.

A single application of*S. feltiae*-Otio at 7.4 mld/ha was better than one (7.4 mld/ha) or three applications of*S. carpocapsae*-All, each at at 2.5 mld/ha (Figure 3). Differences between one application of *S. carpocapsae*-All (7.4 mld/ha) and three applications of*S. feltiae*-Otio (2.5 mld/ha) were not significant, nor were differences between one and three applications of*S. feltiae*-Otio. Both *S. feltiae*-Otio treatments were equal to microencapsulated diazinon.Results indicate that properly timed applications of nematodes at higher dosages may be more effective than a series of applications at lower dosages.

In the cage experiment with chrysanthemums (Figure 4) results were similar to those in previous experiments. Mean total numbers of fungus gnat adults trapped in the*S. feltiae*-Otio (one or three applications at 2.5 mld/ha)*S. carpocapsae*--Umeå (one application at 4 mld/ha) treatments were similar, considerably less than the number trapped in the *S. carpocapsae*-All (three applications at 2.5 mld/ha). However, differences among these treatments were not significant (P=0.05). All of these treatments were significantly better than a single application of *S. carpocapsae*-All. The microencapsulated diazinon treatment provided the best control.

To summarize, *S. carpocapsae* - All generally did not provide control equal to that by*S. carpocapsae*--Umeå, or *S. feltiae* - 27 or Otio, using our application procedures. Application drench volume may affect the efficacy some nematodes. In one experiment (Figure 2), a single nematode application at 7.4 mld/ha was more effective than three applications at 2.5 mld/ha. These results are in general agreement with those studies on the efficacy of *S. feltiae* isolates in sciarid larval control.

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INFLUENCE OF SIZE OF *FRANKLINIELLA OCCIDENTALIS* (THYS.: THRIPIDAE) LARVAE ON HOST ACCEPTANCE BY *CERANISUS MENES* (HYM.: EULOPHIDAE)

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Abstract
The influence of larval size of *Frankliniella occidentalis* on host acceptance by two European strains (AB and Cab) of the solitary endoparasitoid *Ceranisus menes* was studied. Detailed analysis of acceptance behaviour showed that with increasing size and strength of the host larvae, significantly less larvae were attacked and parasitized. For both strains, attack time increased with size, and insertion-ratio (completed attacks) decreased. In sizeclasses 0.5 - 0.8 mm, about equal to the size of the parasitoid (0.7 mm), strain AB was more successful than strain Cab. Also encounter, attack and insertion times differed between strains, Cab spending more time on each of these handling components. The influence of specific kinds of escape and defense measures by different sizes of *F. occidentalis* larvae on host acceptance by *C. menes* is discussed.

Introduction
Ceranisus menes (Walker) is a solitary endoparasite of larvae of thrips. Its host range is quite wide: more than twenty species in genera like *Frankliniella, Thrips, Taeniothrips, Megalurothrips*, etc. (Thysanoptera: Thripidae) have been recorded as hosts. Except for North America, its distribution is almost worldwide (Loomans & Van Lenteren 1993). In 1990 *C. menes* was collected from cactus flowers in The Netherlands, roses in France (Loomans 1991), carnation in Spain in 1991 (Riudavets et al. 1993), infested with *F. occidentalis* in glasshouses and in the field respectively.

In evaluating the potential of *C. menes* as a biological control agent of *F. occidentalis*, the efficiency by which the different phases of the host selection process (Vinson 1976) are completed, can be considered as important criteria. Under glasshouse conditions *F. occidentalis* oviposits continuously throughout the year and generations overlap. *C. menes* females, searching for hosts, will thus encounter host larvae of various ages. Differences in acceptance and suitability of these various host ages might have a significant impact on its ability to control *F. occidentalis* infestations. Earlier observations on the parasite-host relationship between *C. menes* and *F. occidentalis* (Loomans et. al. 1992), showed that *C. menes* prefers first and early second stage larvae of *F. occidentalis*. As the size of *F. occidentalis* larvae varies between 0.4 mm just after hatching upto 1.1 mm for fullgrown second stage larvae, and the size of *C. menes* ranges from 0.65 mm till 0.85 mm, host acceptance is expected to be affected by the length and activity of the host. This paper deals in particular with the impact that larval host size might have on acceptance by *C. menes*.

Material and methods
Preparation of hosts and parasitoids
For the method of rearing host larvae and parasitoids (*C. menes*), see Loomans 1991, except that *F. occidentalis* was reared on cucumbers. Larvae were devided into seven size groups, from 0.5 mm to 1.1 mm. Females of strain Cab (brown abdomen, collected in Cabrils (Spain), September 1991) and strain AB (yellow abdomen, collected near Brignoles (France), September 1990), reared in the laboratory on *Frankliniella schultzei* Trybom, were used as test material. Only experienced two day old females were used, i.e. they had at least one oviposition experience 4-8 hrs (Cab) or 20-28 hrs (AB) prior to testing. In every sizeclass five females of each strain, size 0.7 mm, were observed.
Experimental set-up
As an observation unit, a Munger-cell modified after Tashiro (1967), was used. 25-30 host larvae of a one sizeclass were introduced into the cell - 25 mm diameter, 10 mm high -using a sweet pepper leaf as host substrate. One to two hours later, after the larvae had settled, a single female parasitoid was introduced. Immediately after introduction, the wasp's behaviour was observed continuously for the first 10 contacts with a host larva by a stereomicroscope. Parasitized larvae were removed during the experiment. All observations were done in a climate room, 21 °C ± 1 °C.

Behavioural components of C. menes

We recorded numbers and duration of three components as a measure for the acceptance of a thrips larvae as a host: encounter, attack and insertion. They are defined as follows: when a female parasitoid contacts a host with her legs and/or antennae ("encounter") she bends her abdomen towards the larva and extends her ovipositor and overpowers the host larva in a short struggle ("attack"). After inserting the ovipositor and turning 180 °, the parasitoid lifts the larva up in the air (lifting) or remains in a "tail to tail" position (tailing), attempting to oviposit ("insertion"). Host insertion (attack-success)

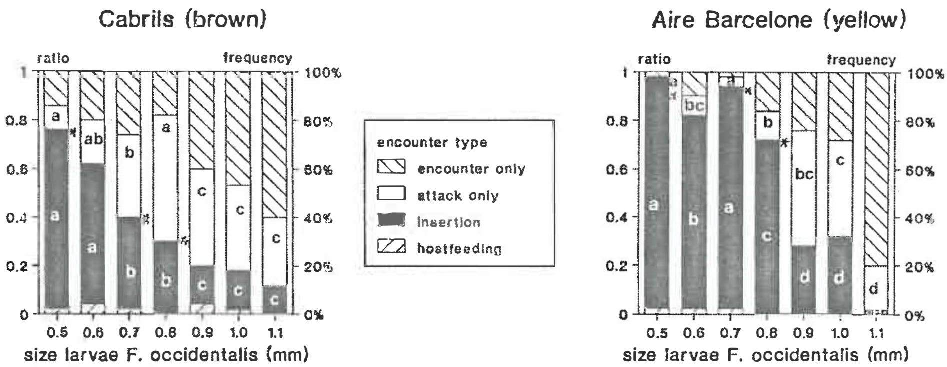

Figure 1. Average frequency of different encounter types occurring between two strains of *C. menes* and various size classes of *F. occidentalis* for the first 10 encounters with a host. Averages indicated by different letters are significantly different between sizeclasses (multiple comparison after Kruskall-Wallis test: $p<0.05$), averages indicated by an * are significantly different between strains (Mann Whitney U-test), $p<0.05$)

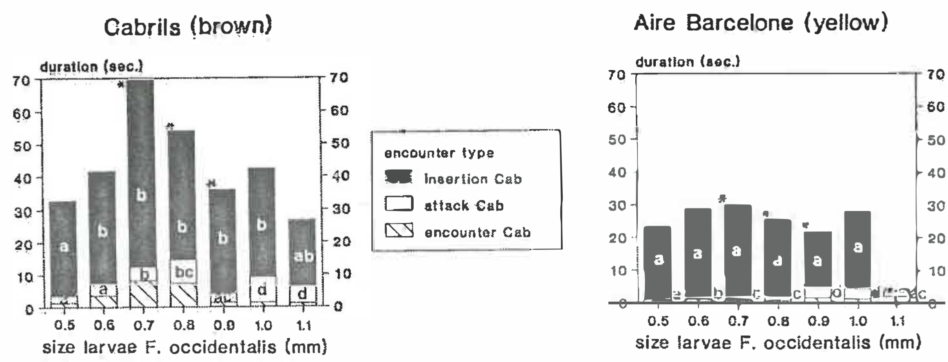

Figure 2. Average duration of different encounter types occurring between two strains of *C. menes* and various size classes of host larvae of *F. occidentalis* for the first 10 encounters. Insertion times preceeding hostfeeding (AB 226.0 ± 38.7 sec (n=3), for Cab 251.7 ± 105.2 sec (n=7) are excluded. Symbols: see figure 1.

ratio is defined as the number of inserted hosts devided by the number of attacked hosts, the acceptance ratio as the number of insertions per encounter. A detailed scheme of the different behavioural components of the search and attack sequence of *C. menes* is described by Loomans et.al. 1992. All behavioural components were recorded, using The Observer 2.0 (Noldus Information Technology, Wageningen), to register and calculate the number, kind, sequence and times of contacts with the hosts. Results were tested statistically between sizeclasses within strains (multiple comparison after Kruskall-Wallis) and within sizeclasses between strains (Mann-Whitney U).

Results and discussion

Acceptance of different sizes of *F. occidentalis* larvae was determined by analysing the numbers (figure 1), times (figure 2) of the three encountertypes and their success ratio's (figure 1, table 1). Small sized larvae - upto 0.8 mm - were rejected after contact to a ratio of 0.15-0.25 by Cab, and 0.02-0.16 by AB (figure 1). The attack-ratio decreased significantly with increasing host size for both the brown and the yellow strain of *C. menes,* till 0.40 and 0.20 respectively. Encounters with the big sized larvae often were interrupted. In small sized larvae, AB was successful in completing an attack in almost all cases, Cab did so in a decreasing ratio (host insertion-ratio, table 1). In big sized larvae this ratio was less than 0.45 for both Cab and AB. Attack and insertion ratio result in an overall acceptance ratio (figure 1, black bars). In AB two distinct groups of sizeclasses can be distinguished: sizes smaller and equal to that of the parasitoid (0.8 mm) and sizes which were bigger. In the first group the larvae were inserted successfully, upto a ratio of 0.98 till 0.72, in the second only upto 0.32-0.02. Another brown strain (Hyères) also showed a decreasing insertion ratio with increasing age correlated to the size of *F. occidentalis* larvae (Loomans et. al. 1992).

This decrease in ratios in the interaction between host and parasitoid can be largely explained by behavioural reactions of the thrips larva once they are touched by a parasitoid (or another larva). Defense reactions have been observed in many other thrips species when disturbed (Lewis 1973), or when attacked by phytoseiid predators (Van der Hoeven & Van Rijn 1990). All sizes of *F. occidentalis* reacted either by abdominal movements as a defense response and emission of anal exudates. In small sized larvae (upto 0.8 mm) the wasp could overcome these defense measures, but in larger sized hosts only in a decreasing number of cases: encounters often were interrupted or larvae escaped by running away. Once being attacked, vigourously moving larvae managed to escape increasingly with size, due to their increase in strenght. Few other studies have mentioned the influence of the size of thrips larvae on acceptance by *C. menes,* and most descriptions are only qualitative. Asian strains of *C. menes* attacked all sizes of larvae of *Frankliniella intonsa* (Sakimura 1937) and *Thrips tabaci* (CAB 1971, Sakimura 1937) indiscriminately, and showed no violent defense measures. Saxena (1971) recorded a preference for second stage larvae of *T. tabaci. C. menes* however failed to complete parasitization in larvae of *Taeniothrips alliorum* and *Haplothrips floricola* (Sakimura 1937) and large sized larvae of *T. tabaci* often escaped parasitization (Saxena 1971, CAB 1971), because of vehement defense.

Of the host handling components only attack times differed between sizeclasses for both strains (figure 2). The time of an encounter did not differ regardless if a larvae was attacked or not. Attack times generally increased with increasing host size: it took the parasitoid two attacks or more in a row to overpower a host. In both strains an unsuccessful attack lasted longer than a successful one in small larvae (0.7mm or less). However, once the host larva was overpowered, insertion times did not differ significantly between sizes for AB, and in Cab only insertion in larvae of 0.5 mm took less time (except for 1.1 mm). There were clear differences however between both strains. Overall host handling times varied from 7.4 - 229.5 seconds for Cab, and from 2.8 - 150.6 seconds for AB, extreme insertion times occurring in sizes upto 0.8 mm. AB-females in general spent less time contacting and attacking a host. In medium sized larvae insertion time was shorter than for Cab-females (figure 2). Larvae of all sizes were lifted by females of both strains (40-70 % of the encounters, 10-30 % size 0.5 mm), but with increasing size larvae had to be lowered more often. When host and parasitoid were in a tailing position larvae tried to escape by crawling away, dragging the wasp behind her. Big sized, physically strong larvae thus managed to reduce insertion time. Differences in hosthandling time of various strains of *C. menes* parasitizing thrips larvae have been found before. Another European strain (Hyères, brown), upto more than 500 seconds parasitizing *F. occidentalis* (Loomans et.al. 1992). Times handling larvae from other hostspecies varied from 17-69 seconds (Hirose 1989) for *Thrips palmi*, 30-60 seconds (CAB 1971) and 60-180 seconds (Sakimura 1937) for *T. tabaci*.

Table 1. **Host insertion-ratio for two strains of *C. menes*, encountering larvae of *F. occidentalis*. Averages followed by different letters are significantly different between classes (multiple comparison test, after K-W, $p<0.05$) or between strains (MW U-test, $p<0.05$), preceded by an *.**

	sizeclass (mm bodylength)						
strain	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm	1.1 mm
AB (yellow)	*1.00[a] 0	0.91[bc] 0.12	*0.96[ab] 0.08	*0.87[c] 0.16	0.37[d] 0.24	0.46[d] 0.28	0.17[c] 0.13
Cabrils (brown)	*0.88[a] 0.08	0.74[a] 0.23	*0.56[b] 0.29	*0.36[cd] 0.15	0.31[c] 0.10	0.43[bd] 0.22	0.39[cd] 0.38

The negative correlation between host size and host acceptance is a first step towards understanding the potential of *C. menes*. Although in our experiments the yellow strain (AB) was more efficient than the brown (Cab) one, other factors which influence successful parasitism in *F. occidentalis* larvae, like oviposition rate and suitability of the host larvae, should be taken into account as well. For a proper evaluation of the prospects of *C. menes* as a biological control agent of *F. occidentalis*, also more information is necessary about its efficiency to find the most suitable host size in a crop situation.

Aknowledgements
We like to thank Hanneke van Heest for rearing thrips and parasitoids, Lia Hemerik for statistical analysis of the results and Tamotsu Murai for discussions on the host-parasite relationship. This research was supported by E.C.-C.A.M.A.R., projectnumber 8001-CT90-0026.

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BIOLOGICAL CONTROL IN PROTECTED CROPS IN FRANCE IN 1992

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Abstract

Launched in France in 1980, biological control in greenhouses covers now an area of 755 ha, and is mainly applied in tomato producing areas. Tomato is the most important greenhouse crop in France (701 ha).

Beneficials used on a large scale are *Encarsia formosa* and *Phytoseiulus persimilis*. Parasitoids and predators of aphids and of leaf-miners are on the increase.

Biocontrol decreased on cucumber, after arrival of a new pest, *Frankliniella occidentalis*. Starting from 1993, biocontrol on cucumber should expend again with the introduction of the minute pirate bug, *Orius* sp.

Introduction

Biological control began to develop in France in 1980 with the use of two beneficials, *Encarsia formosa* and *Phytoseiulus persimilis*. *Phytoseiulus riegeli* was shortly produced in Rennes (France) (Redlich et al 1970). The "Service de la Protection des Végétaux" (Plant Protection Service, Ministry of Agriculture) in Brest has conducted a survey to assess the areas under biological. The data are presented in this report. Earlier surveys of biological control in greenhouses in France have been published by Maisonneuve (1989, 1990). The situation for southern France was recently summarized by Onillon (1990).

Methods

To conduct the survey, a questionnaire was sent to each organization and technician dealing with biological control in greenhouses in France, including firms marketing insects. More than sixty people replied to the survey. The areas given in this survey are the actual areas of the greenhouses, without taking into account the number of crops grown per season. It is common to grow two tomato crops per season. In that case, the area under biological control is only included once in this survey, also when both tomato crops were treated with beneficials.

Results for 1992

Total areas

The area under biological control amounts to about 755 ha. After a fast increase we see a levelling off (Fig. 1), because of:

- a decline of the area with cold plastic tunnels in the south of France
- importation of *Frankliniella occidentalis*, giving problems in cucumber
- importation of *Liriomyza huidobrensis*
- a decrease in tomato area
- increasing problems with *Bemisia tabaci* in the southern France

Presently, growers totally refuse to take the slightest risk and prefer to protect their crop with insecticides. Moreover, in southern France, chemical control is systematically used at the beginning of the season (from October to January), and biological control is only used afterwards.

Beneficials used

Encarsia formosa. This insect was the first natural enemy used in greenhouses together with *P. persimilis*. In 1992, it was used on 750 ha (Fig. 2) on differents crops, mainly tomato.

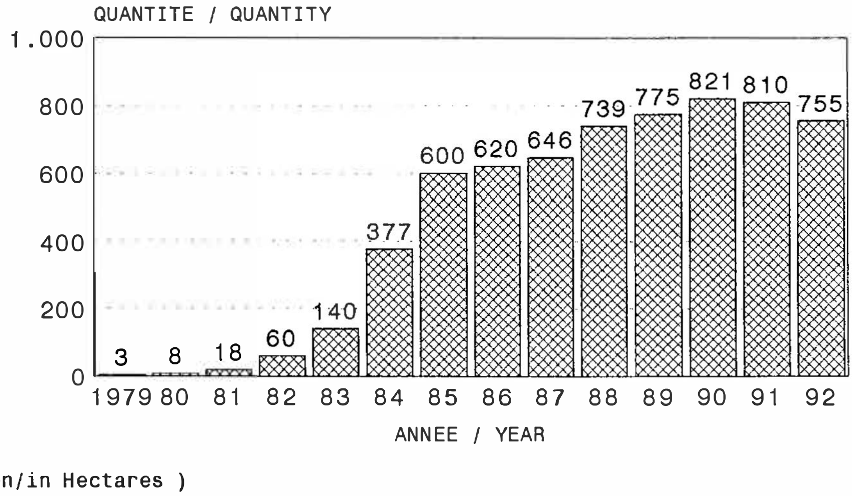

Figure 1. Development of the area under biological control (hectares) in protected crops in France

Phytoseiulus persimilis. The use of this predator (52 ha in 1992) is decreasing because of new pest problems in cucumber. It is increasingly used on strawberries, but not yet on a very large area.
Dacnusa sibirica and *Diglyphus isaea.* These parasitoids are used on 178 ha, mainly in tomato. When introduced early they perform well. As they are shipped as adults - a very delicate stage - sometimes problems with the quality at arrival were observed. This could explain their low effectiveness in a few cases.
Parasites and predators of aphids. Aphid natural enemies were applied 125 ha this year. The increase in use of these beneficials contitutes was the big novelty this year. Used were *Aphelinus abdominalis*, *Praon volucre*, *Aphidius* sp., and *Aphidoletes aphidimyza.*

Control of the aphids proves to be not so easy and difficulties are still met. It is quite likely that, in the case of aphids, we have to use severals parasitoids and predators, as we have already pointed out (Maisonneuve et al 1989).
Various natural enemies. In this category falls *Orius*, which marketing started this year. We must underline the efforts made in 1992 by the firms (KOPPERT, DUCLOS) as well as the efforts of research and implementation services (INRA, CTIFL, APREL, AIREL, SRPV ...) to develop the application of *Orius*. When *Orius* is successful it wil allow the revival of biological control on crops such as cucumber and strawberry. It is important to select the best *Orius* sp.

Additionally, *Macrolophus caliginosus*, which occurs naturally in South-West France, is an efficient predator in cucumber and strawberries.

The crops
The area of crops produced in greenhouses in France is given in figure 3.
Tomato. With 701 ha in 1992 versus 750 ha in 1991, this crop is slightly on the decrease compared to last year. Most of beneficials mentioned before are used on that crop, with the exception of *P. persimilis.* Moreover, the use of *Bombus terrestris* as pollinator makes producers aware of the necessity of biological control.

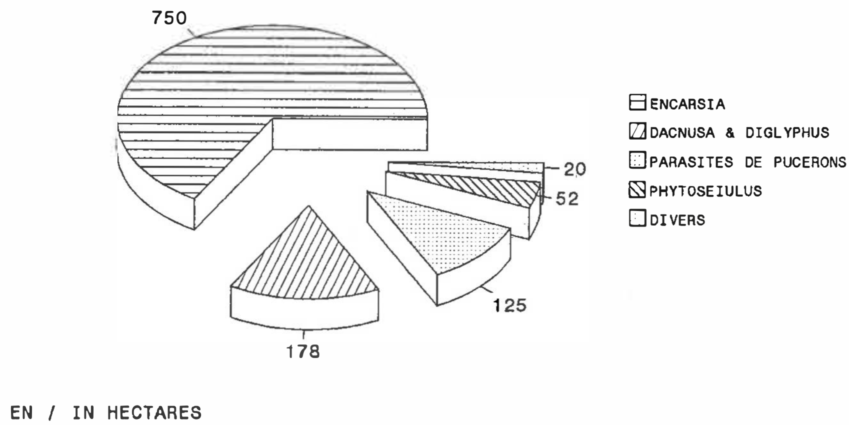

Figure 2. The area under biological control (hectares) by different natural enemies in France in 1992

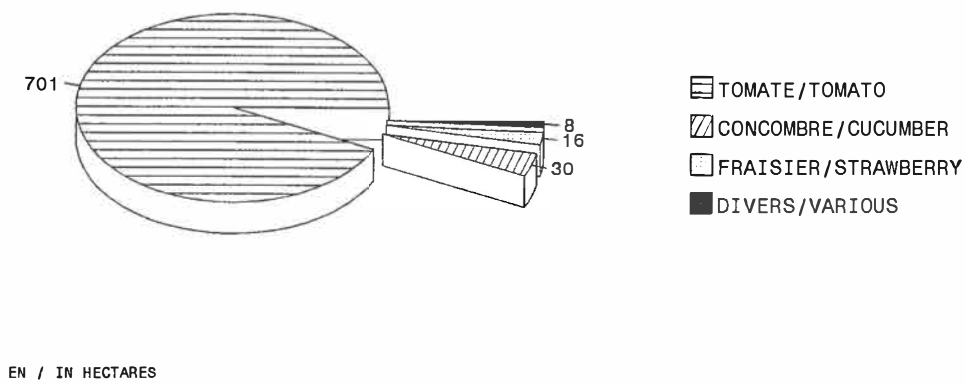

Figure 3. The area of different crops under biological control (hectares) in France in 1992

Cucumber. With hardly 30 ha this year, the use of beneficials for that crop becomes very marginal. As soon as a biocontrol solution will be found for *Aphis gossypii* and *F. occidentalis*, we expect an increase of application.

Strawberry. Here, biocontrol was applied on 8 ha in 1991 and on 15 ha in 1992. The increase is the result of the use of *Orius* against *F. occidentalis*.

Suppliers of beneficial insects

The following companies/suppliers are present in France:

- supplying everywhere in France :
  - French company: DUCLOS AGRO-BIOTECH
  - Foreign companies: KOPPERT (NL)
    BIOBEST (B)
- regional supply: GIE LA CROIX (Bretagne)
- producing for its own members: Coopérative CODEA (06 NICE)
- producing for its own needs: GAEC AUDA (06 CARROS)

Future prospects

The main development will be the selection of an efficient *Orius* sp. for control of thrips. Another bug, *Macrolophus caliginosus*, a predator of whitefly which is naturally present in a lot of greenhouses, could be marketed soon (Malausa 1989; Trottin-Caudal et al 1992).

Conclusions

After a period of rapid increase use, biological control levelled off due to the presence of new pests (*F. occidentalis*, *B. tabaci*) on cucumber and on strawberry. We expect to see an increase in 1993 when new natural enemy production facilities in France will be in function. The best way for development of long-term application of biological control would be to inform consumers about this technique. It is expected that consumers would then be willing to pay more for non-sprayed products (van Lenteren 1990).

Acknowledgements

I express my grateful thanks to the more than sixty persons who provided information about biological control in greenhouses.

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OVIPOSITION SITES OF *ORIUS INSIDIOSUS* IN SWEET PEPPER

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Abstract
Oviposition sites of *Orius insidiosus* (Say) [Heteroptera: Anthocoridae] on caged sweet pepper plants were determined. Almost two thirds of all eggs were recovered in or adjacent to the growing tips. Stem parts and leaf petioles were more often selected as oviposition site than axillary buds and leaf veins. Because only very few eggs were found in flowers and fruits, it is reasonable to conclude that *O. insidiosus* causes hardly any damage to a sweet pepper crop.

Introduction
Western flower thrips, *Frankliniella occidentalis* (Pergande), is a major pest of several greenhouse crops and ornamentals. On sweet pepper effective control of this thrips can be achieved using *Orius insidiosus* as a biological control agent (van den Meiracker and Ramakers, 1991). In the Netherlands, commercial application of this predatory bug started in 1991, mainly on sweet pepper. In 1992 *Orius* was released in 95% of the 845 ha of this crop (J. van Schelt, pers. comm.).

There are good reasons why it is important to study where *Orius* deposits its eggs. First, the eggs are inserted in the plant tissue and may therefore cause some damage to the crop. Clearly, the amount of damage very much depends on the plant parts selected for oviposition. Second, since growers prune apical parts and branches of sweet pepper plants, they may remove predator eggs, and thereby change the predator-prey ratio. In this paper results are presented on oviposition site selection of *O. insidiosus* on sweet pepper plants in cages.

Materials and Methods
Experiments were carried out with laboratory reared *O. insidiosus* originating from Georgia (U.S.A.). They were reared on eggs of *Ephestia kuehniella* Zeller, and bean pods were provided as oviposition sites. For rearing details see van den Meiracker and Ramakers (1991).

Small potted sweet pepper plants (25-35 cm high) with 2-5 opened flowers and several very young fruits were used. In all plants the main stem bifurcated at 17-25 cm. The secondary stems also bifurcated; the next bifurcation usually occurred in the growing tips. Growing tips are defined here as short (< 1 cm) distal parts of the stem with small leaves and floral buds. Some thrips were probably present in the flowers. At the start of the experiment one plant was placed in a perspex cage (40 x 40 x 50 cm), with a 11 cm diam. hole in the top, covered with fine nylon gauze. The cage could be locked at the front by a sliding door with a gauze covered opening (of 30 x 40 cm).

Ten 1 1/2 week-old females were collected from the rearing. Subsequently they were put in a small pot (without lid) and placed against the main stem. After 2 days the predatory bugs were recollected and released in a cage with a fresh sweet pepper plant. After 3 days they were recollected again for a last oviposition period on a fresh plant (2 days). This procedure was carried out twice at 25°C and 16L:8D. The second time the last oviposition period was omitted.

Plants were examined immediately after removal of the predatory bugs. All leaves (with axillary buds), flowers (and floral buds), and fruits were located in relation to the growing tip of

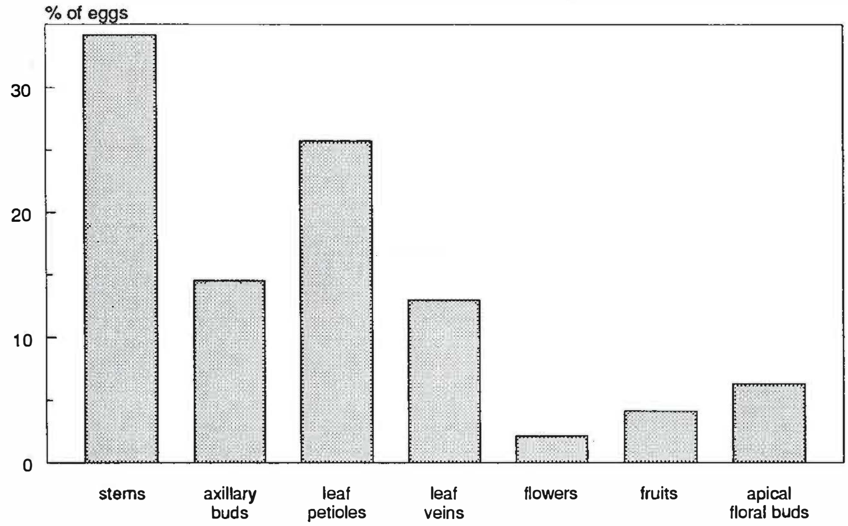

Fig. 1. The proportion of eggs of *Orius insidiosus* laid in the different parts of caged sweet pepper plants.

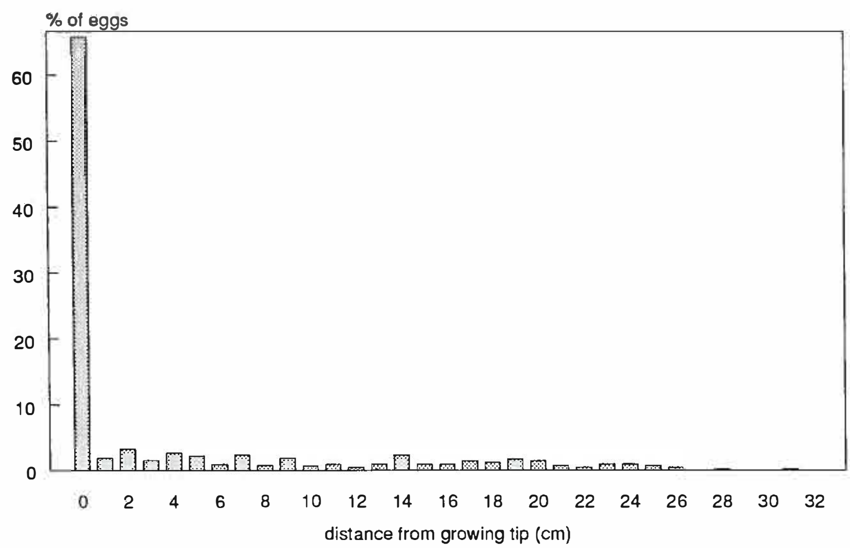

Fig. 2. Stratification of eggs of *Orius insidiosus* in caged sweet pepper plants.

the plants. These parts were cut off and stems were cut at bifurcations. All parts were examined under the microscope. Number and location of eggs were recorded.

Results

In both replicates all 10 females survived the first and the second oviposition period. After the third oviposition period of the first replicate only 9 females were recollected. The total number of eggs found amounted to 653 (5.44 per female per day). The mean number of eggs per female per day was 5.8, 4.9 and 4.2 during the consecutive oviposition periods of the first replicate, and 5.6 and 6.6 during the two oviposition periods of the second replicate.

Most frequently stem parts and leaf petioles were selected as an oviposition site (Fig. 1). Almost two thirds of the eggs were laid in the growing tips or in their immediate vicinity (Fig. 2). Below the growing tips eggs were distributed rather homogeneous.

Most eggs in the stems were laid in the tender, distal parts. Seventy-six percent of the eggs in the stems was present in the growing tips. Below the growing tips eggs in the stems were usually laid adjacent to petioles or at bifurcations. Axillary buds were only present on the main stems. They contained the major part of all eggs laid below the bifurcation of the main stem.

Thirty-nine percent of all eggs was found in the leaves. Half of the eggs in leaves was laid in the growing tips. In the petioles eggs were nearly always laid in the upper side (98%), and usually within 0.5 cm of the stem (85%). For oviposition in the veins the upper side of the main vein was preferred (73%); only 11% was laid in lateral veins (mostly very close to the main vein). No eggs were deposited in the interveinal leaf area.

Very few eggs were laid in flowers. On flowers and fruits the peduncle was preferred for oviposition; nearly always close to either the stem or the calyx. Only 5 eggs were found on the fruits themselves; three of them were empty and not inserted into the tissue. All eggs in the small apical floral buds were laid in the peduncles.

Eggs were most frequently laid singly, but sometimes 2 to 3 eggs were inserted close together. In axillary buds of the main stem and in the growing tips egg density was often high, but eggs were never laid in dense groups of more than 3 eggs.

Discussion

In this study more than 70% of all eggs was laid in (tender) stems, leaf petioles, and main veins. Similar oviposition sites were already recorded for *O. insidiosus* (Iglinsky and Rainwater, 1950; Isenhour and Yeargan, 1982), and other *Orius* species, e.g. *O. tristicolor* (Askari and Stern, 1972; Graham and Jackson, 1981), *O. majusculus* (Sands, 1957), *O. minutus* (Niemczyk, 1978), and *O. albidipennis* (Tawfik and Ata, 1973). Also other oviposition sites occur, e.g. the ovary of flowers in *O. niger* (Sands, 1957), or flower stalks in *O. indicus* (Rajasekhara and Chatterji, 1970) and *O. albidipennis* (Tawfik and Ata, 1973). On corn *O. insidiosus* prefers moist fresh silks (Barber, 1936); Dicke and Jarvis (1962) found that before the silks were exposed eggs were laid in the auricles of corn.

The eggs of *O. insidiosus* were sometimes laid in clusters, but usually they were laid singly. This agrees with the observations of Askari and Stern (1972). *O. tristiocolor* exhibits a similar oviposition behaviour (Barber, 1936). Tawfik and Ata (1973) observed that eggs of *O. albidipennis* were always inserted singly. In contrast, *O. majusculus* and *O. minutus* often lay eggs in small groups of 2 to 4, close to each other (Collyer, 1953; Niemczyk, 1978).

The major part of the eggs of *O. insidiosus* was found in the apical parts of sweet pepper plants. Similar results were observed for *O. insidiosus* on soybean (Isenhour and Yeargan, 1982) and for *O. tristicolor* on alfalfa (Graham and Jackson, 1981). This may reflect the relative softness of these parts, which facilitates oviposition. In addition, these places offer relatively much cover to ovipositing females. Eggs below the growing tips were also laid in relatively sheltered positions: in stems at bifurcations or near petioles, in axillary buds, in petioles near the stem, and in peduncles near the stem or the calyx.

On the sweet pepper plants *Orius* mainly depends on fully opened flowers, to feed on either thrips or pollen. However, flowers were rarely selected for oviposition. Sweet pepper has short-lived flowers. If the petals with the stamen detach before the eggs hatch, nymphs will have to migrate in search of food. In that case the growing tips with floral buds are a better place for oviposition. When, on the other hand, a flower would still provide food after hatching of the eggs, nymphs may be exposed to cannibalism.

Since only 2 eggs were found actually inserted in fruits (at a high *Orius* density), it is not very likely that the oviposition behaviour of *O. insidiosus* will cause crop damage. This is in agreement with the results of van den Meiracker and Ramakers (1991), who found no crop damage of *O. insidiosus* on sweet pepper in field experiments.

In sweet pepper crops apical parts or branches are pruned regularly. Since many eggs are deposited there, care should be taken with the timing of pruning. Since *Orius* predatory bugs are usually released as adults, an oviposition peak will occur shortly after introduction. When pruning is done at that moment many eggs may be lost, and population build-up will be retarded. It is recommended to delay pruning until after hatching of the first-generation-eggs.

Acknowledgements
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DEVELOPMENT AND IMPLEMENTATION OF IPM IN GREENHOUSE FLORICULTURE IN ONTARIO, CANADA

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Abstract

The development of IPM programs in 4 and 9 greenhouses growing cut chrysanthemums and poinsettias respectively, demonstrated mean reductions in pesticide use of 80% of Active Ingredient applied in chrysanthemums and 30% in poinsettias over a 3 year period (1989-91). Concurrently there were substantial improvements in the efficacy of pest control programs. In 1992, a training program was developed for growers who were interested in implementing their own IPM. Preliminary results show a high level of success among the growers involved.

Introduction

The floriculture industry in Ontario was worth nearly $250 million in 1991 (Statistics Canada 1992), the majority of which is concentrated in the southern part of the province in the Niagara Peninsula or in the southwest near Leamington.

In 1987, the Government of Ontario made a commitment to reduce the use of agricultural pesticides by 50% by the year 2002. Among other commodities specifically targeted was greenhouse floriculture with an initial emphasis being place on demonstration trials in 2 of the most important floricultural crops grown in the province, cut chrysanthemums and poinsettias.

When implementation of IPM on a broader scale became the primary emphasis of the program (1991-92), we defined our approach according to the following criteria which were modified from Parrella (1990):

Phase I - which stressed the importance of growers becoming familiar with monitoring as the primary tool of an IPM program (pest identification, record-keeping).

Phase II- which focused on better management of pesticide use (timing and targeting of sprays, early detection of pests, developing "action levels").

Phase III- where biological control is integrated into the IPM program where possible. It should be stressed, however, that crops/pest complexes will vary in their suitability to this approach and we did not insist on the inclusion of biological control.

Development of IPM

In 1989, 4 cut chrysanthemum growers and 9 poinsettia growers in the Niagara region formed the basis of the IPM program which was divided into 2 stages of development:

i) In the first year (1989), the emphasis was placed on establishing a baseline of information against which future years could be compared. Pest complexes and pesticide use patterns were monitored and growers continued to make their own pest management decisions.

ii) In years 2 and 3 (1990 and 1991), the monitoring continued exactly as in 1989, but all growers agreed to follow pest management recommendations made on a weekly basis by the authors.

Pesticide use for all growers was measured in 3 ways: total cost, number of sprays and quantity of Active Ingredient (A.I.) applied.

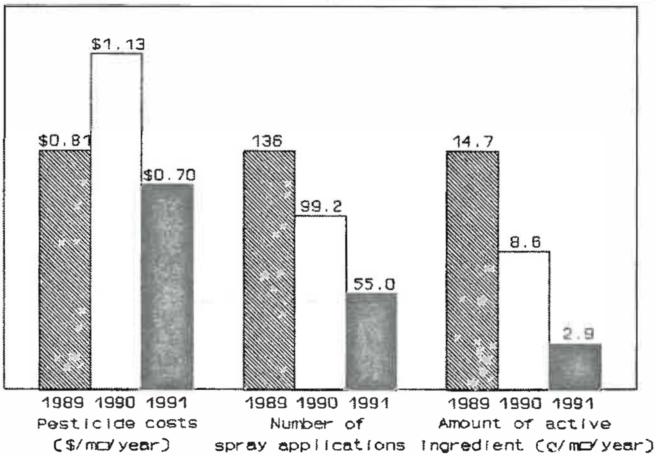

Figure 1. **Mean pesticide costs, number of spray applications and Active Ingredient applied in 4 chrysanthemum greenhouses, 1989-91.**

Results

Cut chrysanthemums Reasons for the large reductions (>80% reduction in A.I. over 3 years) shown in Figure 1 vary from greenhouse to greenhouse, but include: excessively frequent applications of pesticides for some pests which monitoring showed to be unwarranted; preventative applications prior to the program for pests such as aphids or mites regardless of whether or not they were present; naturally occurring seasonal variations in pest populations which had not been previously recognized. From a grower's perspective, the maintenance of acceptable levels of pests (and pest damage) is at least as important as the pesticide usage. For each of the greenhouses, pest populations remained at or below 1989 levels with minimal crop damage.

Poinsettias Pesticide use in poinsettias (Figure 2) declined by 30% of A.I. applied over 3 years. The number of sprays applied in 1991 increased by about 20% over 1990. However, there was likely an overestimation in 1991 resulting from a greater use of spot sprays. The number of sprays refers to "whole spray equivalents", but for some growers (who had recorded their own pesticide use) it was difficult to determine after the fact whether they had applied full or part sprays. The other positive aspect of the poinsettia IPM is the effectiveness of the program when compared to greenhouses which were not using IPM. In November, 1990 and 1991, surveys of poinsettia crops were carried out in southern Ontario to assess the impact of sweet potato whitefly, *Bemisia tabaci*. The survey also allowed the comparison of whitefly populations between IPM greenhouses (9 in 1990, 8 in 1991) and non-IPM greenhouses (32 in 1990, 13 in 1991). We found significant differences in whitefly populations between the two groups of greenhouses in both years. In the non-IPM greenhouses, the percentage of leaves with whitefly was twice that of the IPM greenhouses in 1990 and 1.6 times in 1991. There were also significantly fewer pupae and early instar whitefly found per m^2 in the IPM greenhouses than in the non-IPM greenhouses in both years.

Implementing IPM

If IPM is to be promoted to the industry, it is important that it is first shown in field demonstrations

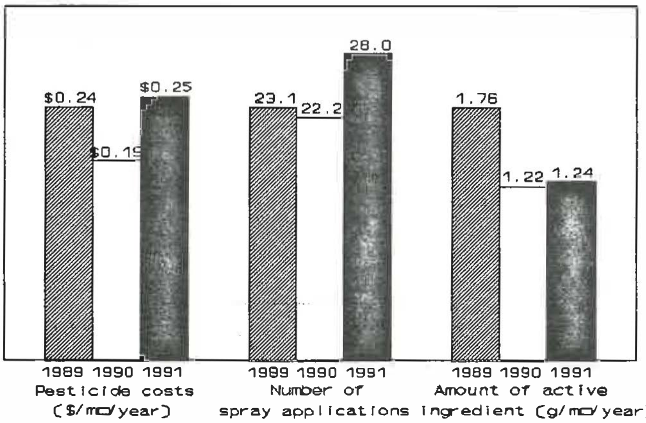

Figure 2. Mean pesticide costs, number of spray applications and Active Ingredient applied in 9 poinsettia greenhouses, 1989-91.

to be effective in achieving its objectives. However, the ultimate aim of the program is to have IPM accepted and used by the wider grower community. Two approaches to this problem have been taken: 1. Grower-operated IPM and 2. Grower-funded IPM scouts.

Grower-operated IPM In January 1992, a workshop was held for growers interested in implementing their own IPM. Attendees were asked to commit themselves to maintain an IPM program in their greenhouses for a full year. Twenty greenhouses (more than 15% of the total greenhouse flower growing area in Ontario) were represented. Regular follow-up visits were made to the greenhouses during 1992.

A questionnaire has been developed to assess growers' attitudes to the program and their future plans for IPM in their greenhouses. At the time of writing, the questionnaire had not been circulated to growers. However, impressions gained from growers during the year and information obtained from most recent visits have been very encouraging. Of the 20 operations involved, 15 have maintained a full IPM program as laid out in the workshop, including regular monitoring and record-keeping. A number of growers have also set up computer databases on which all records are kept and many have established their own action threshold levels for their major pest(s). Of interest, is that of the 5 growers who have not maintained a full IPM program, all are in complete charge of the operation with many competing responsibilities. Where an employee had responsibility for IPM as a part of his/her duties, the whole program has been better maintained.

Expansion of the program will continue with another workshop being scheduled for January 1993 for another group of interested growers.

Grower-funded IPM scouts It is realized that not all growers will be in a position to implement their own IPM (see 4.1). For this reason, it is planned to run an additional program in 1993 whereby a group of growers will pay for a scout to monitor their greenhouses on a weekly basis and provide them with the results. It will then be the responsibility of the grower to contact extension staff if assistance is needed in interpreting results. At this stage, full details of the program have not been finalized.

Where biological control fits in

The initial objective of the implementation program was to have growers understand the benefits and reasons for monitoring, weed control, sanitation and other aspects of IPM, and to reduce pesticide use before attempting to integrate a biological control component into their IPM programs. Some of the growers from the first workshop are interested in taking IPM further than the first two phases outlined in Section 1. It is proposed to form a smaller focus group with these growers to examine the potential of integrating biological control into their IPM programs.

There have also been a number of smaller biological control trials conducted between 1989-92 in various greenhouses where we have been working. Trials against leafminer, western flower thrips, whitefly and aphids have had varying levels of success. To date no greenhouses have maintained long-term biological control, although in poinsettias, *Encarsia* has been used successfully from April-November; and in chrysanthemums, excellent parasitism (>90%) of leafminer by *Diglyphus isaea* was achieved before an increase of a secondary pest, tarnished plant bug (*Lygus* sp.), caused the trial to be terminated. In 1993, demonstration trials of the biological control of fungus gnats by the predatory mite, *Hypoaspis miles*, are planned in 4 or 5 greenhouses.

Conclusions

This work has highlighted two important issues in trying to reduce pesticide use through the introduction of IPM programs in greenhouse floriculture.

i) The potential of the program should be demonstrated to that particular segment of the industry at which it is aimed. Results need to be shown to be relevant to those growers whose behaviour we are trying to change, to demonstrate that IPM will work under conditions specific to them (e.g. climate, production practices, crops, registered pesticides).

ii) Implementation of IPM on a broad scale should become the primary focus, once its potential has been demonstrated. With every greenhouse requiring individual evaluation, it is beyond the resources of government extension services to establish IPM programs for growers on a one-to-one basis. Therefore these resources should be used as cost-effectively as possible. There are a number of alternative approaches for implementing IPM:
   - consultants to become actively involved in maintaining IPM programs for growers.
   - grower co-operatives funding their own scouts.
   - hiring someone specifically to maintain the IPM program in a particular operation.
   - growers to develop the necessary skills to maintain their own IPM programs.

   With each grower having different needs and circumstances there is not one option which will suit all growers. However, the case for IPM has been given considerable support in this study by the reductions in pesticide use and improvements in pest control demonstrated. As biological control is further integrated, the benefits of IPM will become even more apparent.

Acknowledgements

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INTEGRATED CONTROL OF *THRIPS PALMI* KARNY ON EGGPLANTS IN OPEN FIELD WITH *ORIUS SAUTERI* POPPIUS

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Abstract
Integrated pest control of *Thrips palmi* was tested on eggplants in open field, using *Orius sauteri* and some selective insecticides. The results were good and might help to develop future integrated pest control for greenhouses.

Introduction
Thrips palmi Karny is the most serious pest of eggplants in western Japan. Even very low population density of *T. palmi* causes severe economic injuries on fruits of eggplants. It shows high level of resistance to most of the current insecticides. Because of these problems, chemical control of *T. palmi* was very difficult.

In 1984, *Orius sauteri* Poppius was found out on the eggplants in an open field where no insecticides were applied in spite of infestation of *T. palmi*. *O. sauteri* was considered to be an important natural enemy of *T. palmi* and responsible for suppression of the population density of *T. palmi* on eggplants in open field, but additional chemical control is still needed to obtain completely damageless fruits as demanded by the Japanese consumers (Nagai et al., 1988; Nagai, 1990a). Pyriproxyfen (insect growth regulator; registration pending in Japan.) appears to kill *T. palmi* but does not directly cause reduction of the population density of *O. sauteri*. When pyriproxyfen emulsifiable concentrate of 100 ppm was sprayed on eggplants on which *O. sauteri* were present, the population density of *T. palmi* decreased quickly due to the effect of pyriproxyfen and *O. sauteri*, in contrast with situations where *O. sauteri* was absent (Nagai, 1990b).

In Japanease eggplant fields, *Epilachna vigintioctopunctata* (Fabricius), *Polyphagotarsonemus latus* (Banks) and some other pests are necessary to be controled by insecticides. If non-selective insecticides are sprayed for the control of these insect pests, the population density of *O. sauteri* in the field decreases. For the control of these pests, less toxic insecticides against *O. sauteri* were selected from the registered insecticides (Nagai,1990c). Based on these results, an integrated control program of *T. palmi* and other pests on eggplants in open field was tested in 1989.

Integrated control program for *T. palmi* on eggplants
Population trends of *T. palmi*, *T. kanzawai*, *A. gossypii* and their predator, *O. sauteri*, on eggplants in an open field were compared in integrated and chemical control programs. In the integrated control program, two insect growth regulators (pyriproxyfen and buprofezin) which showed no toxicity to *O. sauteri*, were used. Buprofezin wettable powder was sprayed at 250 ppm once on E. *vigintioctopunctata*, and 100 ppm of pyriproxyfen emulsifiable concentrate was sprayed twice on *T. palmi*. In the chemical control program with nine insecticides and one acaricide sprayed fifteen times against *T. palmi* and once each against *A. gossypii*, *T. kanzawai* and *E. vigintioctomaculaty*, the predator population was suppressed.

The population density of *T. palmi* in the integrated control program remained low throughout the eggplant growing period (Fig.1). But it increased greatly from mid August to early September in the chemical control program. Eggplant fruits in the integrated control program sustained less economic damage from *T. palmi* than in the chemical control program where damage was especially serious from late August to early September (Fig.2). In both programs, fruit damage

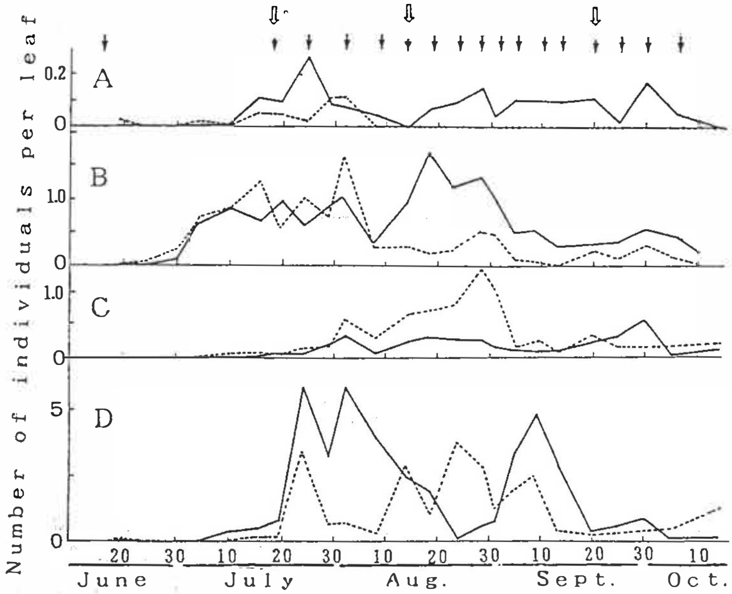

Figure 1. Population trends of nymphs and adults of O.sauteri (A), adults of thrips except T.palmi (B), adults of T.palmi (C), and larvae of thrips including T.palmi (D) on eggplants under integrated control (solid lines) and chemical control (broken lines) programs. Arrows indicate the insecticide and acaricide treatments in integrated control (⇩) and chemical control (↓) programs.

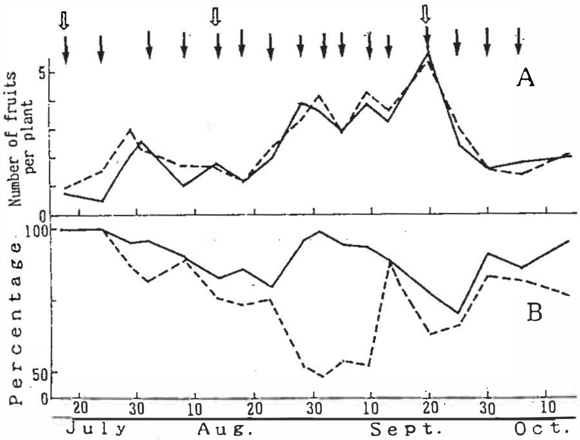

Figure 2. Changes in number of harvested eggplant fruits (A) and percentage of economically-tolerable fruits damaged by T. palmi (B), under integrated control (solid lines) and chemical control (broken lines) programs. The meaning of the symbols are the same as in Fig.1.

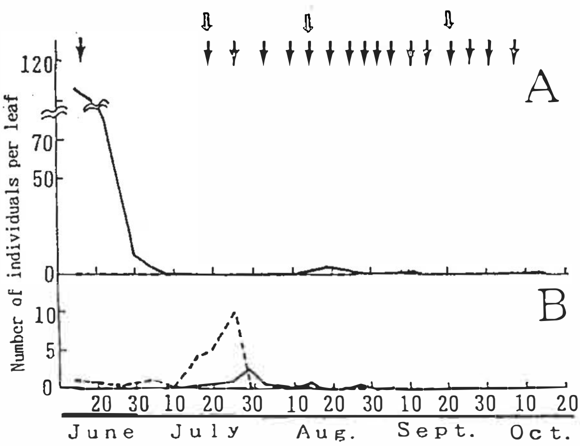

Figure 3. Population trends of adults and nymphs of A.gossypii (A) and adult females of T.kanzawai (B) on eggplants under integrated control (solid lines) and chemical control (broken lines) programs. The meaning of the symbols are the same as in Fig.1.

by other insect pests was slight and no significant difference was found between them.

In the integrated control program, the population density of *A. gossypii* increased in June. The population density of *T. kanzawai* did not increase in the integrated control program but spraying of an acaricide for *T. kanzawai* was necessary in the chemical control program (Fig.3).

From these studies in the open fields, we got two important suggestions for the integrated control of *T. palmi* in the greenhouses. The first one is that *O. sauteri* is a very useful natural enemy of *T. palmi*, and the second is that pyriproxyfen and buprofezin will be applicable in greenhouses with *O. sauteri* to control *T. palmi*. In order to use *O. sauteri* in greenhouses, mass rearing for *O. sauteri* is investigated now.

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POTENTIAL INTERFERENCE AMONG NATURAL ENEMIES OF *BEMISIA TABACI*

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Abstract
Interest in the release of more than one species of natural enemy against *Bemisia tabaci* (Gennadius) has prompted research into the intra- and interspecific interactions of these species. Of particular concern is the potential for mutual interference among them that might affect their efficacy. With this in mind, we examined three natural enemies of *B. tabaci*, two parasitoids (*Encarsia tabacivora* Viggiani, and *E. luteola* Howard) and one predator (*Delphastus pusillus* (LeConte)). The endoparasitoid *E. tabacivora* causes mortality of its host by parasitism and adult host-feeding, overlapping in the size of host used for both behaviors. It responded to increases in host density by increased host-feeding, though the rate of parasitism reached a plateau. *Encarsia tabacivora* is an autoparasitoid, whose male offspring develop as hyperparasitoids on the immature females of conspecifics or congeneric species. In theory, the density-dependent sex ratio shifts may stabilize a parasitoid-host complex; however, there is concern over the preferential destruction of females of another species in multiple species releases. We also examined the compatibility of *E. tabacivora* and the predatory coccinellid *D. pusillus* and determined that while adult beetles fed on whitefly nymphs containing very young parasitoids, they differentially avoided feeding on hosts containing parasitoid pupae which were at least 9 days old.

Introduction
In future IPM programs aimed at controlling the sweetpotato whitefly, *Bemisia tabaci*, it is likely that two or more parasitoids and/or predators may be released in the same program, the idea being that their attributes will contribute to overall control. Numerous studies have indicated that in agricultural systems, as in nature, several natural enemies acting together can achieve a higher level of control of a pest than one alone (Zwolfer 1971, Miller 1980). The major concern regarding multiple releases, however, has been that competition and interference among biological control organisms may reduce their effectiveness against the pest. This is a particularly important consideration where hosts/prey are clumped, providing greater potential for interference or when control of low densities of hosts is required, causing natural enemies to compete for the same hosts. Thus, it is strongly advocated that laboratory studies examining species' behavior and their interactions be carried out before selection of biocontrol agents is made and costly programs initiated (Waage 1990). Furthermore, with knowledge gained about the behavior of natural enemies and their interactions, educated decisions can be made on how best to use these species to maximize their impact on the pest while minimizing any negative interactive effects.

This paper outlines three areas under investigation in which competition or interference by parasitoids and a predator of *B. tabaci* may influence their performance: (1) Competing behaviors by a single endoparasitoid species, and the influence of host availability on these behavioral choices, (2) The potential for interference between two parasitoid species, and (3) Interference between a predator and parasitoid

Host-Feeding and parasitism by *Encarsia tabacivora*
Encarsia tabacivora is an endoparasitoid which causes mortality of the whitefly nymph either by oviposition in it or by adults feeding directly on nymphal tissues. Parasitism and host-feeding are non-concurrent behaviors (*sensu* Jervis and Kidd 1986). An investigation of the size distributions used for each behavior (Fig. 1) indicate that although the smallest hosts are used

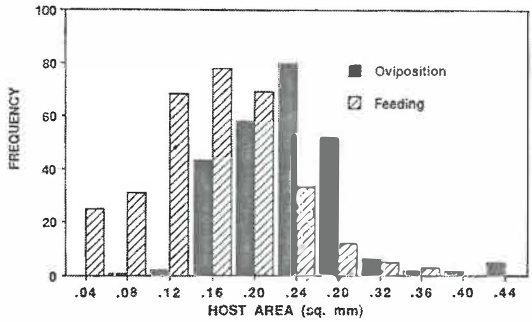

Figure 1. Size distribution of *Bemisia tabaci* nymphs used for oviposition or host feeding by *Encarsia tabacivora*

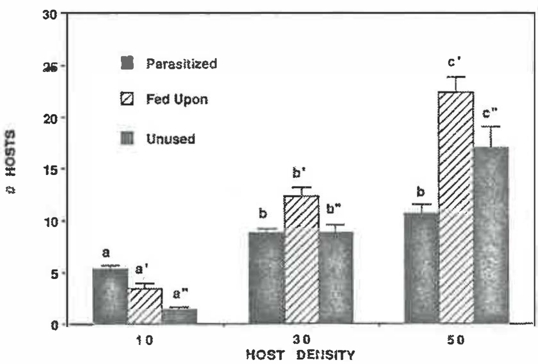

Figure 2. Oviposition and host-feeding as a function of availability of *Bemisia tabaci* 3rd and 4th instar nymphs

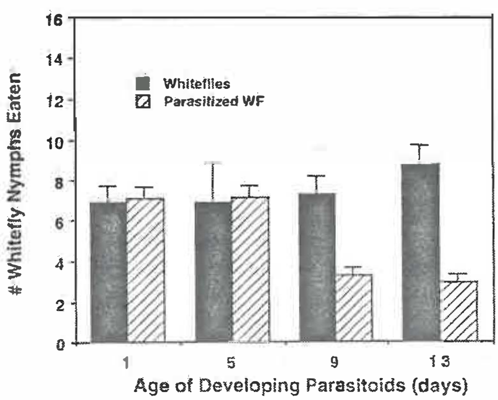

Figure 3. Feeding by *Delphastus pusillus* on unparasitized whitefly nymphs and nymphs containing developing parasitoids

for host feeding and largest for oviposition, there is a extensive area of overlap in the mid-region corresponding to third and early fourth instars. It is in this region that females must make the choice whether to host feed or oviposit.

To examine the influence of the availability of hosts on this choice, one-day-old females were mated and contained in clip cages containing whitefly nymphs of suitable size on poinsettia leaves at densities of 10, 30 and 50 nymphs per 5 sq cm. Ten females were tested at each density; after 48 hours hosts were dissected to verify oviposition or host feeding. An analysis of variance was performed for each behavior across densities. Host feeding increased significantly in response to host density (Fig. 2), while oviposition remained constant over mid and high densities, suggesting egg limitation. Further investigation of reduced parasitism at low densities revealed that host-feeding by young females occurring 24 hours prior to oviposition removed hosts from potential parasitism.

Intra- and interspecific interference between parasitoid species: male production by *E tabacivora*

E. tabacivora is an autoparasitoid whose females develop as primary parasitoids on whitefly hosts and males as hyperparasitoids on immature females of conspecifics or congeneric species. In order to produce a male, a female must locate and lay an egg in a parasitized whitefly containing a 7-9-day-old parasitoid female developing inside. Thus, for every male produced, a developing female parasitoid must be destroyed. If only *E. tabacivora* is present, this hyperparasitism can result in drastic shifts in sex ratio, especially when host densities are low and unparasitized hosts become less available. As unparasitized whitefly hosts become scarce, mated females are forced to lay eggs in already parasitized hosts; the next generation therefore, tends to be male biased, providing fewer females in the next generation to inflict mortality on the whiteflies. One body of theory has suggested that these density-dependent sex ratio shifts may actually make autoparasitoid populations more persistant than primary parasitoid populations (Hassell et al. 1983). When a second *Encarsia* species is added to the program, the potential exists for *E. tabacivora* to use immatures of the other species preferentially over her own or those of conspecifics in producing males. This preference for hyperparasitism of another species has been shown in studies of *E. tricolor* Foerster with *E. formosa* Gahan (Avilla et al. 1991). We are presently investigating the possible preferential use of *E. luteola* by *E. tabacivora* and the influence of host availability on this interference interaction.

Interference between a predator (*D. pusillus*) and a parasitoid (*E. tabacivora*)

Delphastus pusillus is a coccinellid predator whose adults and immatures feed on eggs and all immature stages of the sweetpotato whitefly (Hoelmer 1993, *in press*), providing great opportunity for competition with parasitoids for hosts. However, the greatest concern regarding programs involving these species has been the possible devouring of parasitized hosts by *D. pusillus*.

We therefore conducted four choice experiments in which *D. pusillus* adult beetles were given a choice of 15 unparasitized whiteflies and 15 parasitized whiteflies containing *E. tabacivora* immatures of the same developmental stage. Four ages of developing parasitoids were used: 1 day, 5 days, 9 days and 13 days after oviposition. The beetles were allowed to feed for 24 hours; 24 were tested in each experiment. For each, a Chi-square test was performed using half the total numbers consumed in each replicate as the expected value.

When parasitoids were less than 9 days into development, *D. pusillus* showed no preference for parasitized or unparasitized whiteflies and they were eaten in equal numbers (Fig. 3). However, after 9 days (pupal parasitoid), the beetles differentially avoided feeding on hosts containing parasitoids. The mechanism responsible for this avoidance is being studied. It may be a function of the ongoing sclerotization of the parasitoid pupa; moreover it is likely that as the parasitoid pupa draws away from the whitefly case, the air pocket formed may prevent the beetle's mandibles from piercing the parasitoid.

Discussion

It is clear that studies of the complex behaviors of natural enemies can shed light on the success and failure of IPM programs involving natural enemy introductions and indicate how they might best be used. *Encarsia tabacivora*, though egg limited, displays a high degree of host-feeding. This is an advantage in inundative releases (as in floriculture greenhouses) where the emphasis is on rapid host kill by the introduced enemies, rather than the impact of future generations. Host-feeding behavior and its influences on host-parasitoid dynamics are often overlooked in studies of biocontrol. In the field, hosts killed by adult feeding are probably lumped together with natural mortality, while parasitism is usually the primary criterion used to evaluate control capability. It is clear that this behavior can make an important contribution in any evaluation of a natural enemy's impact and should be considered as a positive characteristic.

Intuitively, species of parasitoids exhibiting autoparasitism might be considered poor candidates as biocontrol agents. However, they have contributed to some of the most stable host-parasitoid interactions in biocontrol (Hassell et al 1983, Huffaker and Messenger 1976). Their density-dependent sex ratio combined with their superior competitive ability allow them to persevere over a range of host densities (Hunter 1991). Yet, in biocontrol programs, their negative interaction with another species through the possible destruction of that species' females is a matter of concern and must be considered, not only as a factor in selecting species for multiple release, but because of incidental introduction or migration of such a species into a greenhouse. *E. tabacivora* is a species endemic to northern and central California; it has been found parasitizing whiteflies in several poinsettia ranges and on cotton in the San Joaquin valley, and may interact with parasitoid species introduced for control. For this reason, and because of its strong searching and host-feeding behaviors, studies into its potential use are continuing.

The compatibility of a predator and parasitoid may depend on how each is used. Since *D. pusillus* avoids feeding on whiteflies in the late stages of parasitism, release of the predator two weeks after the parasitoid, for example, may allow parasitoids to develop to a less vulnerable stage. Moreover, one might take advantage of the predator's preference for high host numbers by releasing *D. pusillus* into "hot spots"of whiteflies as needed while allowing parasitoids to keep *B. tabaci* at low numbers throughout the range.

In conjunction with studies of individual behaviors and the potential interactions they reveal, field experiments are ongoing involving the efficacy of individual species and of combinations of natural enemies against whitefly populations on poinsettia. It is hoped that concurrent laboratory experiments as described can help explain the patterns seen in these trials and make contributions towards defining selection criteria for natural enemies and the manner of their introductions.

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NECESSITY FOR INTEGRATED PEST MANAGEMENT OF MULTIPLE PESTS ON STRAWBERRIES GROWN IN JAPANESE GREENHOUSES

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Abstract
Repeated pest immigration into the greenhouse makes control by their natural enemies impossible. This is the primary difficulty in using biological control. Our preliminary work on pest control methods which are compatible with biological control is reviewed.

Introduction

There are few biological pest control systems used in Japanese greenhouse except *Bacillus thuringiensis*. One of the problems is that repeated entry of a variety of pests into the greenhouse makes biological control difficult. The control of only one pest species is meaningless for protected vegetables that require simultaneous protection from other pests.

Nemoto and Okada (1990) reported the integrated pest control programme of strawberries grown in a greenhouse consisting of microbial control of the common cutworm, *Spodoptera litura* (Fabricius) by the nucleopolyhedrosis virus (*Sl*NPV) and cultural, chemical and physical control of aphids. Control of spider mites, however, remains a problem. These pests were well- controlled with *Phytoseiulus persimilis* (Nemoto, 1992), but the repeated entry of aphids necessitated regular chemical applications which killed the predatory mite.

This paper reports control methods which are compatible with biological control.

Characteristics of Japanese strawberry greenhouses

Most of Japan's strawberries supplied during the cold season (November - April) are grown under protected cultivation with plastic covers. Minimum nighttime temperatures often fall below zero. The days of autumn and spring, however, are warm and to avoid too high a temperature, a greenhouse must be ventilated by opening a skylight and/or side windows. Alomar et al. (1990) pointed that doors and side openings of greenhouses in the Spanish Mediterranean area may not fit tightly, and Japan's vegetable crop greenhouses have a similar drawback.

Pest control methods which are compatible with biological control

Fertilization, crop condition and IPM. The aphid density on strawberry seedlings raised in pots was lower than that raised in nursery beds (Fig 1), and the nitrogen content level of leaves of the seedlings raised in pots was also lower. In nursery garden pots it is easier to control the level of nitrogen content of the seedlings than it is in a nursery bed. When strawberry seedlings were grown in water culture made up of varying concentrations of fertilizer, aphid density was dependent on the concentration. Less fertilizer resulted in lower density of aphids (Fig. 2). This control method is believed harmless to beneficial arthropods.

Herbicidal control of spider mite on weeds around the greenhouse and/or on surrounding crops. The autumn seedlings are infected by the spider mite *Tetranychus* spp. from outside weeds and surrounding crops. The success of integrated pest management (IPM) in winter protected crops is linked with the control exercised in adjacent fields during the autumn. Weeds around the greenhouse treated with the usual herbicides did not prevent the spider mite from emigrating to the vegetables; however, if the herbicide biarahos was used, the mites did not move onto the vegetables (Table 1). In order to reduce carry-over of the pest between outdoor crops and greenhouse crops, the plants were sprayed with biarahos or glufosinate following picking of the crop.

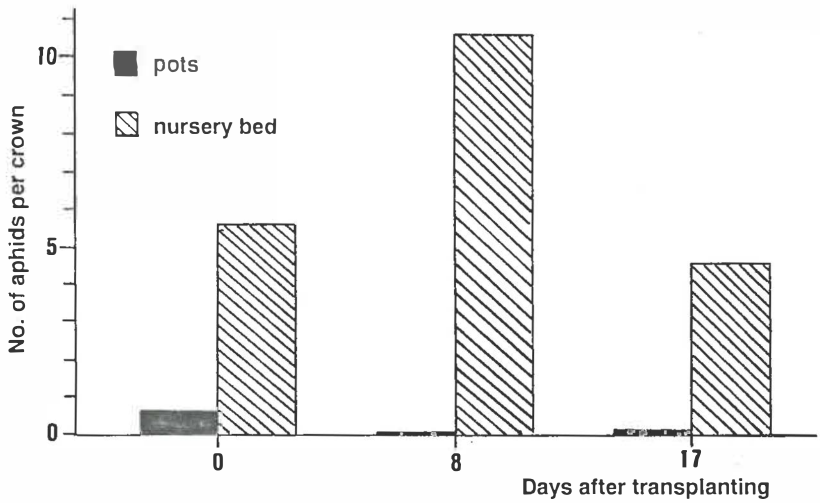

Fig. 1. Population changes of the cotton aphid Aphis gossypii on strawberry seedlings after transplanting.

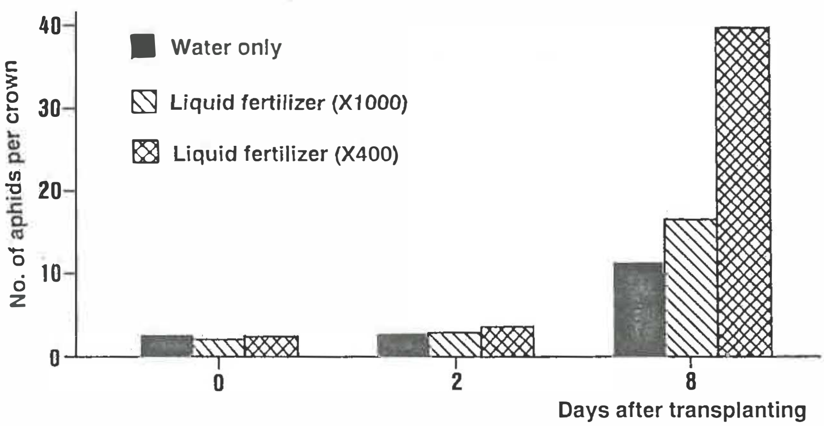

Fig. 2. Population changes of the cotton aphid Aphis gossypii on strawberry seedlings grown water culture.

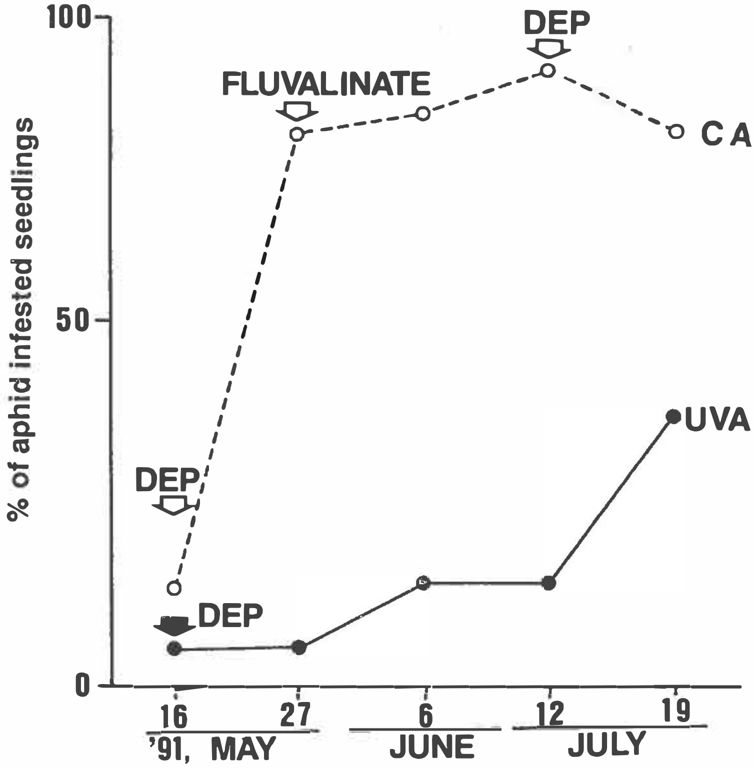

Fig. 3. Changes in percentage of aphid Aphis gossypii infested strawberry seedlings under two kinds of vinyl film. UVA: vinyl film absorbing ultraviolet region spectra (solid line); CA: standard vinyl film (broken line).

Table 1. Effect of herbicide treatment on emigration of *Tetranychus urticae* Koch

Herbicide	Rate (g AI/a)	Density Index of mite on on weed(%)*	No. of mites immigrating onto kidney beans**
diquat + paraquat	7	90.0	14.2
glufosinate	5.6	81.7	5.7
glyphosate	20.5	85.0	27.6
biarahos	6.0	66.7	0.2
reaping with hook		95.0	13.2
Control		86.7	3.5

* Just before treatment; Index=(sum(f)/3N)*100; f:density of mites on weed; f=(0:none; 1:a few; 2:moderate; 3:heavy; N:number of weeds examined).

** 8 days after treatment

Utilization of a vinyl film which absorbs the ultraviolet region of spectra (UVA). Efficacy of UVA on prevention of invasion of the aphid *Aphis gossypii* Glover into the greenhouse was evaluated. Immigration was less into a greenhouse covered with UVA than into one covered with standard vinyl film. The percentage of aphid infested strawberry seedlings in a UVA-covered greenhouse was also less than one covered with standard vinyl film (Fig. 3).

Discussion

Japanese greenhouses are not well isolated from the outside, are usually small (ca. 3-4 a) and surrounded by weeds or open fields. Thus, vegetables grown in the greenhouse in autumn are infected early by pests from outside. Repeated pest immigration into the greenhouse makes their control by natural enemies very difficult. This is the primary problem in using biological control. Integration of biological, chemical and other controls must be used for control of the multiple invading pests. Control methods presented in this paper are compatible with biological control.

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BIOLOGICAL CONTROL IN THE INTEGRATED PEST MANAGEMENT PROGRAM AT THE LAND, EPCOT CENTER

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Abstract
Biological control is being used extensively in the integrated pest management (IPM) program in The Land at EPCOT Center. The leafminer *Liriomyza sativae* is controlled by the parasitoid *Opius dissitus*, the broad mite (*Polyphagotarsonemus latus*) by the predator *Neoseiulus barkeri*, and the sweet potato whitefly (*Bemisia tabaci*) by the lacewing *Chrysoperla rufilabris*. Cultural and mechanical controls also play key roles in this IPM program.

Introduction
"The Land" represents agriculture in EPCOT Center at the Walt Disney World Vacation Resort in central Florida. More than 35 crops are grown in greenhouses visited by up to 2000 guests hourly via the 14-minute "Listen to the Land" boat ride. The Land is a communications, research, and food production facility. Objectives of The Land show include increasing public awareness of the major world crops, providing exposure to potentially important crops, and familiarization with concepts, technologies, and tools for agriculture in the future. A recurring theme in The Land is that crop production methods must be developed which minimize adverse effects on the environment. Guests see several aspects of an integrated pest management (IPM) program which emphasizes use of biological control. Biological control receives a tremendous amount of exposure at The Land. The millions of guests who visit annually represent a major audience and include many international visitors, scientific groups and government officials. Media coverage is extensive, including hundreds of radio and television events annually, as well as coverage in printed media.

Cultural and mechanical controls
The use of resistant cultivars simplifies the pest complex making it easier to implement an IPM program which utilizes biological controls. For example, powdery mildew resistance in cucurbits eliminates the need for routine fungicide applications, some of which are harmful to beneficial insects present in the crop canopy. Also, screening (20 mesh) of incoming air has virtually eliminated lepidopterous pests that had previously been a considerable problem. Removal of the oldest leaves of cucumber reducing populations of *Bemisia tabaci* Gennadius and *Aphis gossypii* Glover. *Erwinia carotovora* subsp. *carotovora* (Jones) Bergey et al., a bacterial stem-rotting pathogen that requires free leaf moisture and a wound to infect plants, has been a serious problem, especially in summer months. It is controlled by growing the most resistant cultivars, avoiding unnecessary wounds to the plants, and pruning in the afternoon when leaf moisture has dried.

Monitoring
Locating insect infestations when their populations are small increases the likelihood of success with biological control. In cases where the pest population does not grow extremely fast, an inoculative release of the biological control agent may be all that is required for control. If no biological control is available for a pest, spot treatment of localized infestations with insecticides may preserve other biological control agents present in the same crop.

Biological control of Leafminers

The foremost problem in the early 1980's was damage to a wide variety of host plants caused by *Liriomyza sativae* Blanchard. *Opius dissitus* Muesebeck was first collected here in 1983 inflicting considerable moratality to *L. sativae* populations in greenhouse tomatoes (*Lycopersicon esculentum* L.) (Petitt, 1984). Because of this initial success and a very limited number of options available for controlling *L. sativae* on greenhouse food crops, a program was initiated to rear and release *O. dissitus* into the greenhouses. Research has concentrated on development of an effective rearing program for *O. dissitus* by studying its biology, as well as the biology of its leafminer host.

O. dissitus is a braconid parasitoid about 1.5 mm in length that lays its eggs in first, second, or third instar leafminer larvae. Parasitized leafminer larvae continue to feed and develop, and emerge from the leaf at the same time as unparasitized larvae. The parasitoid consumes the leafminer within the puparium and emerges about 13 d after oviposition at 25°C (16.5 d for *L. sativae*).

The rearing program for *O. dissitus* at The Land has been studied in detail. *O. dissitus* has been reared using *L. sativae* on bush lima bean (*Phaseolus lunatus* L. 'Henderson') primary leaves. Caged populations of *L. sativae* are provided lima beans on which they lay eggs for one day. To obtain predictable oviposition rates, these cages must be kept at constant temperatures. The number of ovipositing flies is determined by the capacity of the cage and the leaf area provided is adjusted daily so that preselected larval densities result. Leafminer eggs and larvae develop in plants held in greenhouse cages. The incubation time required in the greenhouse before exposure to parasitoids is determined by a phenology model (Petitt et al., 1991). Studies have shown that when *O. dissitus* is provided second or third instars in which to oviposit more offspring are produced (Petitt & Wietlisbach, 1992a).

Studies of intraspecific competition among leafminer larvae in lima bean have shown percentage survival to be $>= 90\%$ at densities of < 1.0 larva/cm^2, but with further increases in density percentage survival and pupal weight decreased linearly (Petitt & Wietlisbach, 1992b). Parasitoid size was correlated with host pupal weight ($r^2=0.75$), but laboratory studies have shown parasitoid longevity and lifetime fecundity to be inversely related to host weight (Petitt & Wietlisbach, 1992b).

Data collected to date indicates that additional males above a 1:1 parental sex ratio does not improve offspring sex ratio. Lower host:parasitoid ratios result in a higher percentage of female offspring (typically about 60% females at H:P ratios of 10-15). Plants containing parasitized larvae are placed over large funnels and larvae are collected as they drop from the leaves. Differences in the timing of adult eclosion of flies and wasps are used to separate them before release in the greenhouses or field.

The *L. sativae* biological control program using *O. dissitus* has been succesfull in many crops at such as eggplant (*Solanum melongena* L.), tomato, beans, cucumber (*Cucumis sativus* L.), and other cucurbits. Leafminer densities are so low that damage is insignificant. Rapid increases in the *L. sativae* population after treatments with non-selective insecticides have provided some evidence that the parasitoid is responsible for suppression of *L. sativae.* Currently work is underway in screen cages in the greenhouse to determine required release rates.

Releases of *O. dissitus* are now also being made in exterior bedding plants. *L. trifolii* (Burgess) has been the predominant leafminer collected from bedding plants, such as marigolds (*Tagetes sp.*). A recent laboratory study here (unpub.) has shown that *O. dissitus* parasitizes *L. trifolii* as well as *L. sativae*, whereas the European species *O. pallipes* Wesmael did not successfully parasitize *L. trifolii* (Parrella & Kiel, 1984). *L. trifolii* damage has been noticeably reduced following release of *O. dissitus* in bedding plants.

Biological control of Broad Mites

The broad mite, *Polyphagotarsonemus latus* (Banks), has caused considerable damage primarily to solanaceous crops grown in The Land, including pepper (*Capsicum annum* L.), eggplant, tomato and a few herbs. Damage has been most severe on pepper where infestations cause extensive leaf distortion and death of the terminal growth. Gerson (1992) reviewed the biology and control of the broad mite. During the spring and summer of 1990 and 1991 the predator mite *Neoseiulus* (=*Amblyseius*) *barkeri* (Hughes) was released and provided very effective control. In 1992 it was determined that releases of 10 to 30 *N. barkeri* per plant per week were adequate. Voucher specimens from greenhouse studies have not yet been confirmed, but laboratory studies conducted in 1992 show that *N. barkeri* (vouchers confirmed) can consume up to 15 adult female *P. latus* per day (unpub.).

During the fall of each year *N. barkeri* apparently entered a reproductive diapause resulting in control failure. Sulfur applications which replaced the use of the predator during late fall, winter and early spring were effective. The reproductive diapause was possibly caused by low night temperatures where the predators were reared (Morewood & Gilkeson, 1991). In the insectary temperatures is increased during fall and winter 1992 and insectary-reared *N. barkeri* will be compared with *N. barkeri* being reared at The Land.

Biological and selective chemical control of Spider Mites

Despite being present on other crops in the same greenhouse, twospotted spider mites, *Tetranychus urticae* Koch, rarely occur on and have never increased to damaging levels on the powdery mildew resistant cucumber cultivar 'Vetomil'. After purposeful introduction of *T. urticae* onto this cultivar, however, caged populations survived and reproduced. *T. urticae* has never been observed infesting any tomato cultivar grown at The Land. Tomato cultivars that have been grown here routinely include the following: 'Carnival', 'N65', 'Sweet 100', and 'Sweet Million'. On pepper (*Capsicum annum* L.), *T. urticae* has increased to damaging levels sporadically. At present, lacewing releases targeted for green peach aphids reduce the populations or additional lacewings are released in "hot spots". Twospotted spider mites occurring occasionally on other crops used for food are treated with insecticidal soap and non-food crops may also be treated with abamectin.

Biological, mechanical and selective chemical control of Homopterous pests

Greenhouse whitefly (*Trialeurodes vaporariorum* Westwood) has been exclusively replaced by sweet potato whitefly (*Bemisia tabaci* Gennadius) since its initial collection here in 1988. We are currently making weekly releases of *Chrysoperla rufilabris* Burmeister for biological control of *Bemisia* on cucumber and during the first one-half of eggplant and tomato crops. The *Chrysoperla* released for whitefly control also have reduced populations of *Aphis gossypii* on cucumber and *Myzus persicae* Sulzer on eggplant and tomato.

Limiting whitefly movement within a greenhouse containing multiple crops has been the key to our ability to manage *Bemisia*. Whitefly biological control cannot be accomplished if large numbers of whiteflies fly into a new crop from older plantings. To reduce whitefly movement between crops, plastic barriers are erected around the mature crops being disturbed or removed and are coated with vegetable oil. Whiteflies are trapped on the barrier when they fly from disturbed crops. Hot spots of whiteflies are also removed by vacuuming seedlings. If whitefly populations require insecticidal treatment in cucumber or eggplant, a high volume spray of piperonyl-butoxide-synergized pyrethrins (Pyrenone Crop Spary[R], Fairfield American Corp.) is applied. In older tomato crops, insecticidal soap is applied as warranted.

Thrips

The western flower thrips, *Frankliniella occidentalis* (Pergande) has not caused much damage during the past two years. *Neoseiulus* (=*Amblyseius*) *barkeri* that is being released for control of broad mites may also be reducing thrips populations (Bonde, 1989). *Thrips palmi* Karny has not yet been collected here.

Root Knot Nematodes

Meloidogyne incognita (Kofoid & White) Chitwood), is an obligate endoparasite of thousands of different plant species, including many of those grown in sand culture at The Land. Steam pasteurization of the sand has been the traditional method for the suppression of nematode populations at The Land, but steam treatments have never been completely successful and often damage electrical and plumbing systems. *Pasteuria penetrans* (Thorne) Sayre & Starr, an obligate procaryotic hyperparasite of various *Meloidogyne* spp., has been utilized effectively to control root knot nematodes (Oostendorp et al., 1991). An infected female of *M. incognita* does not complete its life cycle, and egg production is halted. Mature endospores are released into the soil from the dead nematodes upon the natural microbial degradation of plant roots. *P. penetrans* has not been grown successfully on artificial media. Research at The Land has begun to enhance the production of *P. penetrans*, identify the best methods and rates of application for greenhouse crops, and test the compatibility of the biocontrol agent with other horticultural activities in the greenhouse displays. The research is being conducted in cooperation with scientists from the University of Florida.

Acknowledgments

Development and operation of the IPM program at The Land would not be possible without the considerable efforts of plant pathologists Bill Hammer, Bret Norman and Andrew Schuerger and the entomologists Marian Coffey, Richard Etzel, Yuqing Fan, and David Wietlisbach.

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COEXISTENCE OF TWO THRIPS PREDATORS,THE ANTHOCORID *Orius insidiosus* AND THE PHYTOSEIID *Amblyseius cucumeris* ON SWEET PEPPER.

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Summary
On glasshouse grown sweet peppers populations of the thrips predators *Orius insidiosus* and *Amblyseius cucumeris* were found to coexist from March till October. Monitoring did not indicate that the population development of *O. insidiosus* was affected by the presence of the other predator. In the absence of the anthocorid, both the thrips and the phytoseiid reached very high densities temporarily, with nearly 10 predatory mites per leaf compared to 1.5 in the plot with anthocorids. The conclusion is being proposed that *Orius* influenced the abundance of *Amblyseius* more via prey competition than by direct predation.

1. Introduction

For control of thrips both *Amblyseius cucumeris* (Oudemans) [Acari: Phytoseiidae] and recently *Orius insidiosus* (Say) [Hemiptera: Anthocoridae] are commercially available. They are competing predators of small arthropods including each other, and are both able to feed on pollen. After the successful introduction of *O. insidiosus* in sweet pepper growing (van den Meiracker & Ramakers, 1991) the question arose whether the anthocorid should be released in addition to or instead of the phytoseiids already in use.

Sufficient control cannot be achieved easily with *Amblyseius* alone (Hansen, 1988; Ramakers et al., 1989; Bennison et al.,1990), particularly since Western Flower Thrips, *Frankliniella occidentalis* (Pergande) [Thysanoptera: Thripidae] became a main pest. Combinations of two phytoseiid spp. have been tried before, resulting in elimination of one species (Ramakers, 1988; van Houten, 1993). The present paper describes the dynamics of anthocorid and phytoseiid populations both separately and together developing on sweet pepper crops with WFT as a host.

2. Material and Methods

Three identical glasshouses of 76 m² were planted with 179 sweet pepper plants each. The houses were designed to be insect proof except for thrips.

The young plants were contaminated with thrips while still together in a propagation house, after which they were distributed over the three experimental glasshouses in the second week of January 1991. Two glasshouses were used to observe the predators developing separately; the house with only *Amblyseius* will be indicated as "Plot A" and the house with only *Orius* as "Plot O". In the third glasshouse both predators were introduced to demonstrate the possibility of coexistence ("Plot A+O"). Since the much smaller *Amblyseius* was considered the 'underdog', the sequence of entering the houses was always Plot A → Plot A+O → Plot O.

Laboratory reared *O. insidiosus* were introduced on January 22 by releasing 250 young adults from a single point in each house. The next generation (observed February 26) appeared to continue reproduction, so no further introductions were considered.

A. cucumeris was introduced by hanging open rearing units of 4 gram ("Amblypack CRS", Bunting & Sons) in the plants. Initially the bags contain over 100 predators each, but they have the potential to produce several thousands afterwards (Ramakers & van den Meiracker, 1992). On February 4 a bag was attached to every 15th plant. The introduction was followed by a period of cold weather with high pipe temperatures, after which the bran was found desiccated. In the beginning of March a second introduction was thought to be necessary. Because of the meanwhile advanced thrips population the predator dose was increased to one bag on every second plant.

Spider mites were controlled with *Phytoseiulus persimilis* ("Spidex", Koppert B.V.) and aphids with open rearing of *Aphidius matricariae* on *Rhopalosiphum padi* with barley as a host plant, a method developed for introducing aphid predators (Kuo-Sell, 1989). Pesticides were not applied before August (fenarimol against powdery mildew) and insecticides not before October (pirimicarb against aphids).

3. Monitoring

Both anthocorids and thrips were monitored with one-sided sticky traps of 200 cm² (Genap B.V.). Since monitoring of the anthocorid was given the priority in this experiment, yellow traps were chosen (Dissevelt, 1992). Per house 6 traps were used and replaced weekly, which was reduced to 4 traps per 2 weeks from June onward.

The phytoseiid population was established by examining 30 randomly chosen leaves with a stereomicroscope. This sampling was carried out three times in the critical period of the experiment: early May, mid-June and late July. A final sample of 50 leaves was taken shortly before the crop was cleared. For additional information samples of 50 fruits were taken in August and in November.

4. Results and Discussion

In Plot A thrips peaked mid-April with 180 adults per trap in one week. In Plot O two thrips peaks of about 70 occurred, one in April and one in October. Best thrips control was achieved in Plot A+O, where the traps never recorded more than 17 thrips. More details are presented in Ramakers & van den Meiracker (1992).

In spite of the relatively high density of traps only 1% of the release generation of *O. insidiosus* was captured, so the effect of the monitoring itself was considered negligible. Hence the concern of some growers about yellow sticky traps disturbing the establishment of anthocorids is probably not justified. When the thrips population collapsed, 2 anthocorids per trap per week were recorded. Populations of *O. insidiosus* in Plot O and Plot A+O developed very similar (Fig. 1), indicating that the anthocorids neither suffered nor profited by the presence of the phytoseiids. Based on this and an earlier experiment (van den Meiracker & Ramakers, 1991) it is hypothesized that on sweet pepper the anthocorid population is mainly determined by the host plant itself, in particular the abundance of flowering and the amount of available pollen.

On the other hand, a large difference was observed between both phytoseiid populations, particularly in May (Fig. 2, left graph), when the incidence of *A. cucumeris* reached 100% with 9.6 individuals per leaf in Plot A compared to only 67% and 1.5 individuals in Plot A+O. The high population level in Plot A proved to be unstable and declined in the course of the summer. Finally both plots became similar (leaf incidence 63% and 60% respectively). It is concluded that the positive correlation of the predatory mites with the thrips (cf both graphs in Fig. 2) was more obvious than the supposed negative correlation with the anthocorids.

O. insidiosus did not maintain year-round activity. Like in the previous year (van den Meiracker & Ramakers, 1991), the anthocorid ceased reproduction in the second half of October, and was not found any more when the crop was cleared early December. The

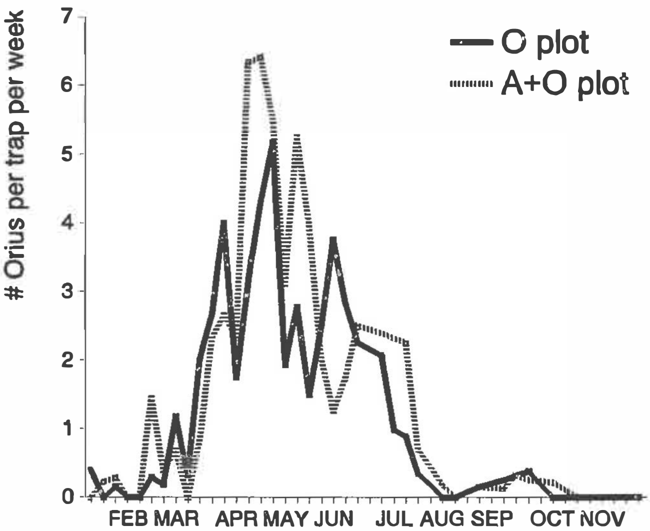

Figure 1. Population trends of *Orius insidiosus* in the presence (A+O plot; dotted line) and absence (O plot; solid line) of *Amblyseius cucumeris*. Number of adult anthocorids recorded by yellow sticky traps.

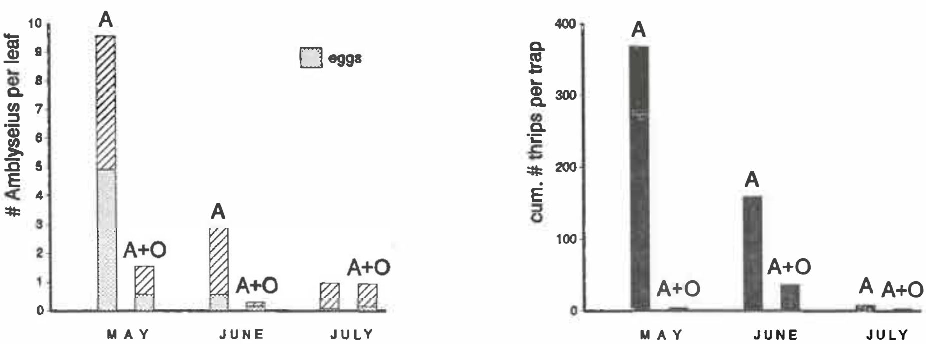

Figure 2. Left graph: Abundances of *Amblyseius cucumeris* in the presence (A+O plot) and absence (A plot) of *Orius insidiosus*; number of phytoseiids including eggs on leaves.
Right graph: Corresponding abundances of Western Flower Thrips; cumulative number of adult thrips on yellow sticky traps in 3 weeks previous to leaf sampling.

incidence of *A. cucumeris* on leaves ranging between 30 and 100% in summer had decreased to only 2% by that time, although maintenance on the fruits was better (22% in August and 30% in November). The decline of the predators populations this late in the season is not of practical significance, but it suggests that early introduction in young December plantings is problematic.

IPM in greenhouses evolves towards multiple biocontrol, with sometimes even simultaneous use of two natural enemies against one pest (Ramakers, 1992). The Central Bureau for Fruit and Vegetable Auctions in the Netherlands have started to market IPM products under a special label. For growers who want to carry this label, the introduction of three or four natural enemies is mandatory. To meet the consequent complexity of decision making in IPM, expert models are being developed with sweet pepper and chrysanthemum as pilot crops. A decision support system for sweet pepper with the triangular relationship between WFT, *Amblyseius* and *Orius* as the main element has been completed (van der Maas, 1992).

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FRANKLINIELLA OCCIDENTALIS PREDATION BY NATIVE NATURAL ENEMIES.

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Abstract
Vegetable and ornamental plants (cucumber, tomato, bean, pepper, strawberry and carnation) were sampled for native predators of *F. occidentalis*. The main predatory species were *Orius majusculus*, *O. laevigatus* (Hem. Anthocoridae), *Dicyphus tamaninii* and *Macrolophus caliginosus* (Hem. Miridae). Nymphal developmental time and predation rate, when fed with *F. occidentalis* at 25°C were studied for each species. Mean developmental time ranged from 12.9 days for *O. majusculus* to 16.0 days for *M. caliginosus*. Mean number of *F. occidentalis* killed per day ranged from 4.9 for *O. majusculus* to 3.1 for *M. caliginosus*.

Introduction.

Frankliniella occidentalis (Perg.) (Thysanoptera, Thripidae) (Western Flower Thrips) has recently become a pest of vegetable and ornamental crops in the Mediterranean area, both in greenhouses and the open field. Populations of general predators, such as mirid bugs, had been observed in non-sprayed vegetable crops in the catalan Mediterranean coast (Albajes 1980). However, the composition of the predatory fauna that establishes on different plant species varies depending on plant characteristics, prey availability and geographic location.

The objectives of this project are: to study the predators present on several vegetable and ornamental crops that host *F. occidentalis*, to determine which species are most abundant and are associated with most crops and to study nymphal developmental time and predation when feeding upon *F. occidentalis* larvae.

Material and Methods.

Field crops. The field sampled was located on the North Mediterranean coast of Spain, and had subplots of cucumber, tomato, bean, pepper, strawberry and carnation. It was surrounded by ornamental crops, both in greenhouses and the open field, with high levels of *F. occidentalis*. These experiments were conducted from June, 1991 until September, 1992. There were two replicates of 3x5 m^2 per crop arranged in a random distribution. Four plants per plot were sampled for natural enemies and pests every 7/15 days. *F. occidentalis* parasitism was evaluated by collecting larvae from carnation, strawberry, cucumber and bean and identifying them in the laboratory. Our sampling procedure for predators and *F. occidentalis* was: whole plant for cucumber; the seven youngest leaves for tomato; 12 leaflets and 2 flowers for bean; 12 leaves and 6 flowers for pepper; 12 leaflets and 2 flowers for strawberry in 1991 and Berlese/Tullgren funnel separation of 20 flowers per plot in 1992; flower observations for carnation in 1991 and Berlese/Tullgren funnel separation of the flowers in 1992. The Berlese/Tullgren funnel improved thrips sampling. Before including a predator species in the sampling, it had to be shown in the laboratory to feed on *F. occidentalis*. Whitefly adult sampling was: three upper leaves for cucumber and tomato, and the same procedure as for predators on bean, pepper and strawberry. The presence of secondary pests was also recorded.

Because of the incidence of Tomato Spotted Wilt Virus (TSWV), the peppers were replanted in August, 1991.

Insect rearing. *F. occidentalis* was reared on cotton cotyledons and pod beans in the laboratory, using a mesh cage (0.75x1.5x1 m) with continuous light. Adults were allowed to lay eggs for four days on newly expanded cotton cotyledons. Afterwards, plants were cut and dried on

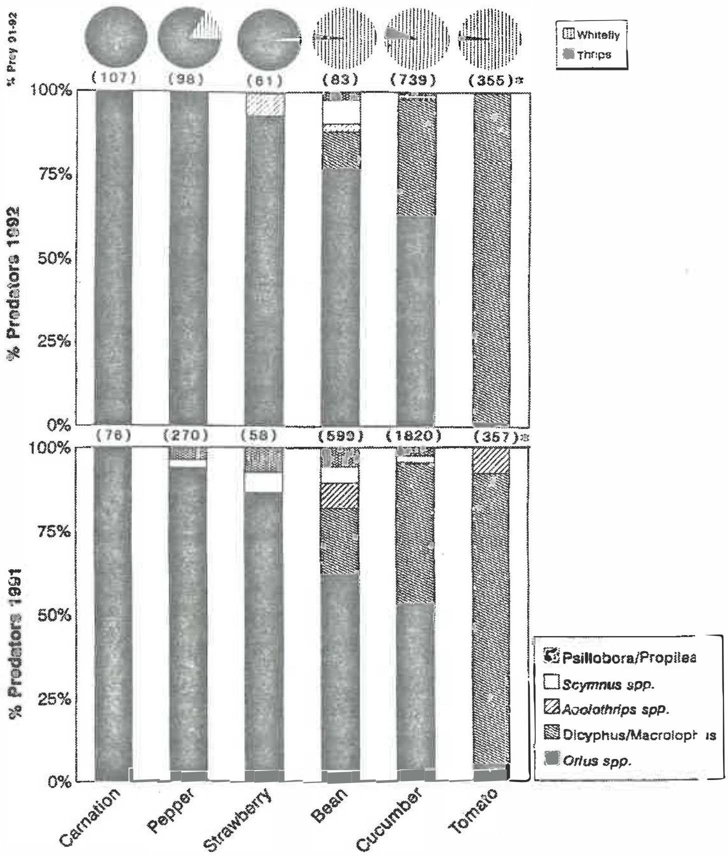

Fig. 1. Relative abundance of prey and preda:ors in experimental carnation, pepper, strawberry, bean, cucumber and tomato plots.
* ( ) total number of predators.

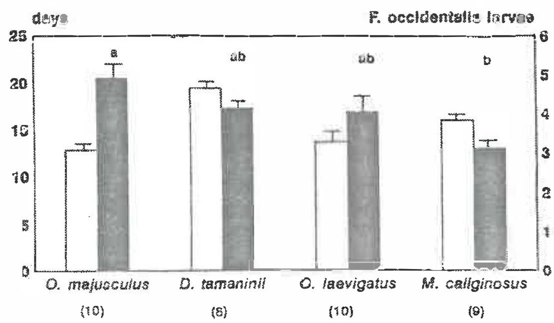

Fig. 2. Nymphal developmental time (days) and number of *F. occidentalis* larvae killed per day. Bars with the same letter are not significantly different (p=0.001; LSD test). ( ): number of replicates.

trays with pod beans and vermiculite. Larvae emerging from the cotton cotyledons move to the bean pods while the cotton is drying, and become concentrated. The second instar larvae move to the vermiculite layer where they pupate and reach the adult stage. New bean pods were added every four days.

Orius spp. were reared at 25°C in glass jars with *Ephestia kuehniella* eggs, pollen and water, and with pod beans as an oviposition substrate. Nymphs were kept separated from adults. The jars were filled with filter paper to increase surface and avoid cannibalism.

Dicyphus tamaninii and *Macrolophus caliginosus* were reared on tomato plants infested with *Trialeurodes vaporariorum.* Plants were kept in a small heated greenhouse and prey was added periodically.

Preimaginal development of predators. The preimaginal developmental time and the number of *F. occidentalis* larvae killed by four predator species (*O. majusculus, O. laevigatus, D. tamaninii* and *M. caliginosus*) were studied under controlled conditions (25±1°C, 70±10% RH, 16:8 L:D).

Newly hatched first instar nymphs of each predator specie were isolated in plastic cages (8.3 cm diameter and 9 cm high) with bean leaves and a known number of *F. occidentalis* larvae. The bean leaves were kept fresh with moistened cotton wrapped around their petiole. Bean leaves were changed three times a week. At that time surviving *F. occidentalis* larvae were recorded, and new prey added.

Results and Discussion

Parasitism of *F. occidentalis* larvae was not detected from 593 larvae collected on carnation, strawberry, cucumber and bean.

The main pests were: greenhouse whitefly, *T. vaporariorum* and western flower thrips *F. occidentalis.* Mites, aphids, leafminers and worms were secondary pests.

The more abundant predators were two *Orius* species (*O. laevigatus* and *O. majusculus*), *D. tamaninii* and *Macrolophus caliginosus.* Less abundant predators were: *O. niger, Deraeocoris spp.* (Hem. Miridae), *Scymnus interruptus, S.levaillanti, Propylea 14-punctata, Psilobora 22-punctata* (Col. Coccinellidae) and *Aeolothrips spp.* All of these fed upon *F. occidentalis.* The composition of predators and prey was different in each crop, but was consistent in the two years period (fig 1). *Orius spp.* were present and able to reproduce on carnation, pepper, strawberry, bean and cucumber, but not on tomato. Therefore, control of *F. occidentalis* on tomato could not be accomplished by *Orius spp.* Mirid bugs were present and able to reproduce on tomato, cucumber and beans where they could reduce thrips populations. On tomato, cucumber and bean, where whiteflies and thrips coexist, preference studies should be done to determine the efficiency of the predators in reducing thrips populations. *D. tamaninii, M. caliginosus* and *Orius spp.* are already reported in the literature as whiteflies predators (Arzone, 1976; Gabarra *et al.* 1988; Malausa *et al.* 1987). Because only strawberry flowers were sampled in 1992, no coccinellids or mirid bugs were recorded. TSWV was only detected in pepper.

Figure 2 provides developmental time, predation during nymphal development and number of *F. occidentalis* larvae killed per day of the four main predator species we found in the field. These data show that all four species are able to complete their nymphal development feeding only on *F. occidentalis. D. tamaninii* consumes more prey and has a longer nymphal development than the other predator species. Daily larval predation was highest for *O. majusculus* (4.91±0.361) and lowest for *M. caliginosus* (3.10±0.183), and these means were statistically different. These prey consumption rates can then be compared with those of other known *F. occidentalis* predators. For example, the consumption rate for *Neoseiulus cucumeris* pairs is 3,24 *F. occidentalis* larvae per day (Castagnoli *et al.*1990).

This study indicates that there are several predators capables of feeding on *F. occidentalis* in different crops. Adult predation, fecundity and prey preference of these predators need further investigation.

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THE FUNCTIONAL RESPONSE OF THE WHITEFLY PARASITOID *ENCARSIA FORMOSA*.

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Summary
A stochastic simulation model has been developed to simulate the foraging behaviour of the parasitoid *Encarsia formosa* on a tomato leaflet infested with immatures of *Trialeurodes vaporariorum*. Inputs for the model were parameters describing physiological and behavioural processes and the environment. Outputs of the model were the number of hosts encountered, parasitized and killed by host feeding of each stage and the residence time of the parasitoid on the leaflet.

Introduction

Simulation models are being developed to find out more about the tritrophic system host plant- pest insect- parasitoid in order to understand failure or success of biological control (van Roermund & van Lenteren, 1990). The (sub)model presented here simulates the foraging behaviour of a parasitoid on a leaf. Input parameters for tomato, *T. vaporariorum* and *E. formosa* were used during the simulations. From the simulation results at different host densities, functional response curves could be generated. The functional response is the relationship between the number of parasitizations of an individual parasitoid per unit of time as a function of host density. Holling (1965) distinguished three types of functional responses. The consequences for the dynamics of the host and parasitoid populations will be discussed.

Description of the model

A stochastic Monte Carlo simulation model was developed for the foraging behaviour of the parasitoid (van Roermund & van Lenteren, in prep.b and c). *E. formosa* is a synovigenic and solitary parasitoid. The egg capacity per female is 8-10 (van Vianen & van Lenteren, 1986). The parasitoid forages on both sides of a leaflet by walking and drumming on the leaf surface. Hosts are only present on the lower leaf side and are encountered randomly (van Lenteren et al., 1976). This means that the walking pattern does not have to be described for the simulations, but that calculation of the encounter rate suffices. After an encounter, 4 behaviours on that host (handling types) can be distinguished: antennal rejection, ovipositorial rejection, oviposition and host feeding (van Lenteren et al., 1980).

After a certain time since the start, or if occurred, since the latest encounter, the parasitoid moves from one leaf side to the other or flies away from the leaflet. Van Roermund et al. (in press) quantified the parasitoids' leaving tendency, i.e. the probability per unit of time to leave the leaflet and the tendency, i.e. the probability per unit of time to change from one leaf side to the other. Intra-patch experiences, such as contact with honeydew, antennal or ovipositorial rejections and ovipositions which had a significant effect on these tendencies were quantified as multiplication factors.

Input parameters of the model were obtained from several experiments (van Roermund & van Lenteren, in prep.a): size (mean diameter) of each host stage; width of the parasitoids' searching path; walking speed; walking activity; variation in walking activity; maximum egg load (number of mature eggs per parasitoid); relative egg maturation rate; the probability for a certain handling type to occur after an encounter (success ratio); handling times; variation in handling time; maximum number of host feedings per parasitoid per day; the basic tendency to change from the lower leaf side to the upper or vice versa; multiplication factors for the significant effects on the tendency to change leaf sides; the basic tendency to leave the leaflet; multiplication factors for the significant effects on the leaving tendency; leaflet size and temperature.

The model is initialized with the number of hosts per leaflet for each stage, the initial parasitoid egg load, the time step of simulation and the time at which the simulation finishes. The parasitoid started on the lower leaf side with a full batch of mature eggs, the time step was 1.2 seconds, the temperature was 25°C, tomato leaflet size was 22 cm^2 and the whitefly stages L1, L2, L3, L4, prepupa and pupa were equally available on the lower leaf side. Two situations were simulated: (a) the parasitoid was foraging on a leaflet on the bottom of a petridish during 2 hours and (b) on a leaflet on the plant during a daylength of 16 hours. Only in the last case the parasitoid was able to move from one leaf side to the other and to leave. Number of replicates was 100 and 1000 parasitoids respectively. Honeydew on the upper leaf side was assumed to be absent.

Results

Validation

Independant observations of searching parasitoids on a leaf infested with immatures of the greenhouse whitefly from the literature were used to validate the model. Experiments were done in petridishes, where the parasitoid could not leave or reach the other leaf side. Excellent fits between simulated and experimental data were found (van Roermund & van Lenteren, in prep.b).

The functional response on a leaflet on the bottom of a petridish

From the simulation results at different host densities, Fig.1a could be generated. Each data point represents the average result. The functional response curve is a Holling type II (Holling, 1965). An exponential increase at low densities was not observed. Under the simulated conditions, mean number of encounters, number of ovipositions and host feedings after 2 hours were 25, 6.5 and 1.5 respectively. Variation (not shown) resulted from the random encounter of hosts and the variable walking activity and handling times.

The functional response on a leaflet on the plant

When number of ovipositions is expressed per unit of residence time, the functional response during a single visit of a leaflet can be generated, which is the simulated number of ovipositions during the total residence time (Fig.1b). It is neither of type I, II or III, but increases rapidly with host density to an optimum of 2.06 per hour, after which it decreases to 1.25. The maximum number of ovipositions during a visit at high host densities was 15.6. Mean residence time, total number of encounters and host feedings were 14.0 hours, 209.3 and 2.9 respectively. Variation (not shown) resulted from the random encounter of hosts, the variable walking activity and handling times and from variation in the time since the start or, if occurred, since the latest encounter that the parasitoid continued searching on a particular leaf side and on the leaflet.

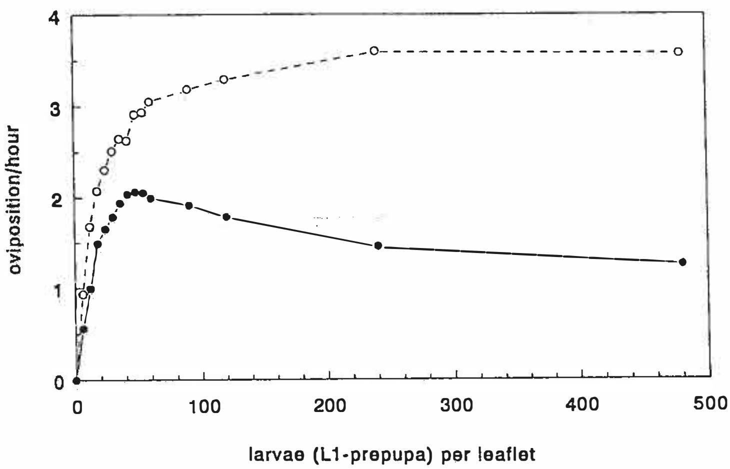

Fig.1. Simulated functional response (a) after 2 hours on a tomato leaflet on the bottom of a petridish (open dots) and (b) on a tomato leaflet on the plant (closed dots).

Discussion

Validation of the simulation results with the experiments is very good. As simulated number of encounters are similar to the observed number, random host encounter seems to be correct, at least at the simulated conditions. *E. formosa* probably does not use chemical cues to locate hosts or infested leaves (Noldus & van Lenteren, 1990).

The shape of the simulated functional response curve after a fixed exposure time is a Holling type II. This agrees with Fransen & van Montfort (1987) and Enkegaard (1992). An exponential increase in number of encounters or ovipositions was never observed. Sabelis (1981) simulated a type II response for predatory mites foraging for spider mites using different simulation approaches, of which Monte Carlo simulation and the stochastic queueing technique yielded similar results close to the observations.

Type II functional responses can be described by the time budget or disc equation (Holling, 1959). The shape of the curves is described by two parameters: the handling time (T_h) and the attack rate (a'). According to the simulations, T_h and a' depend on many experimental conditions. Therefore, a description of observed functional responses is not sufficient and simulation studies are necessary.

The simulated functional response during a single visit of a leaflet is neither of type I, II or III (Holling, 1965), but increases to a maximum of 2.06 ovipositions per hour after which it decreases at higher host densities, due to a decreasing walking activity and success ratio at low egg load. A linear increase of the functional response at low densities was observed, because both number of ovipositions and residence time increased linearly. Mean number of ovipositions of 15.6 per day can be laid by *E. formosa* in immatures of the greenhouse whitefly, if they start with a full batch of mature eggs and if host density is not limiting. Fransen & van Montfort (1987) did petridish experiments at the same conditions and found maximum oviposition levels of 11.0-19.1, depending on the host stage. However, on subsequent days the simulated maximum number of ovipositions is slightly lower, due to a limiting egg maturation.

The most important physiological or behavioural parameters determining the functional response on a leaflet on the plant were the initial egg load, the probability of oviposition (success ratio), walking speed and walking activity. Except success ratio, these parameters can be influenced in a positive way by manipulation of temperature or leaf structure. When comparing different synovigenic and solitary parasitoid strains or species with a random searching behaviour, attention should be focussed on these parameters. The leaving tendency and the tendencies to change leaf sides had a negligible effect, because they changed total number of ovipositions and residence time in the same way.

Functional responses of type III may be caused by an increase in walking speed, walking activity, success ratio, an accelerated increase in giving up time or by a decrease in handling time after encounters or ovipositions. Such changes were never found for *E. formosa* during direct observations (van Roermund & van Lenteren, in prep.a; van Roermund et al., in press). According to theory only in case of a type III response, density-dependance occurs and populations tend to be stabilized. However, functional responses are only one factor in determining the dynamics at the population level. The shape of the response and the effect of several input parameters might be different when several leaflets can be visited by the parasitoids in a vegetation or crop. For instance the effect of the tendency to leave might depend on the probability to find other infested leaves. As *E. formosa* probably does not distinguish between clean and infested leaves before landing (Noldus & van Lenteren, 1990), this will depend on host aggregation.

The simulation model of the foraging behaviour will be used on a plant- and vegetation level, when the parasitoid is able to fly from one leaflet to another. The (sub)model will be incorporated in a simulation model of the population dynamics of the greenhouse whitefly and *E. formosa* in a tomato crop in which hosts have a clustered distribution (van Roermund & van Lenteren, 1990). Life history data for the greenhouse whitefly and *E. formosa* as a function of temperature (van Roermund & van Lenteren, 1992a and b) will be used as input. Goal is to get better insight in the tritrophic relationship at the population level and to understand why and when biological control will be feasible.

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PERFORMANCE OF ENCARSIA FORMOSA SHIPMENTS FROM COMMERCIAL INSECTARIES

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Summary

Two shipments of whitefly parasitoids were received from each of three commercial natural enemy producers. All wasp samples were identified as *Encarsia formosa* Gahan. Shipments that arrived on tobacco leaves from one insectary produced an average of 78 adult whiteflies per 100 parasitized scales. The number of emerged parasitoids was usually much different (from 5 to 284%) from the number promised by the insectaries. The cumulative % parasitoid emergence through time, from receipt of the shipment until all wasps had emerged, was similar for each insectary, but differed between insectaries. There was no significant difference in parasitism of greenhouse whitefly over 24 h among wasps from any insectary or shipment.

1. Introduction

Greenhouse growers in the United States have expressed concern over inconsistent performance of the whitefly parasitoid, *Encarsia formosa* Gahan, issuing from shipments from commercial insectaries. Unreliable release numbers precludes reliable recommendations for release strategies, and can make reliable biological control difficult to achieve. We were interested in determining the extent of differences among shipments from several insectaries in numbers of emerging parasitoids, emergence rates through time, and parasitoid performance.

2. Materials and methods

Two shipments of whitefly parasitoids were purchased about 6 months apart from each of three U.S. distributors of natural enemies. Each distributor received their parasitoids from a different foreign producer. The advertised minimum shipment of wasps was ordered. Upon arrival, the number of parasitized whitefly nymphs (black scales) with and without parasitoid exit holes was recorded under a microscope, and the material was placed into sealed plastic containers and kept in the laboratory at ca. 22°C and 12:12 L:D. The starting number of exit holes was removed from further calculations, because most of the wasps that had emerged during transit were dead. The number of black scales with and without exit holes was then recorded daily until two consecutive days occurred when no wasps emerged. Five newly emerged wasps were removed daily for the first four days of emergence and individually placed onto caged bean plants infested with an abundance of 2nd-4th instar greenhouse whitefly nymphs at ca. 22°C and constant light. These wasps were removed after 24 h, and the number of resulting black scales on each bean plant was recorded after 14 days. Additional wasps from each sample were collected for species determination.

3. Results and Discussion

Wasps from all three insectaries were identified as *E. formosa* (M. Rose, pers. comm.). Shipments that arrived on tobacco leaves from Insectary C produced an average of 78 adult whiteflies per 100 parasitized scales. No whiteflies emerged from the other shipments that were on cards. The release of additional pests is unacceptable for biological control on ornamentals that have an extremely low pest tolerance. The use of shipments arriving on leaves should be avoided unless complete host mortality can be achieved.

The number of emerged parasitoids was usually much different (from 5 to 284%) from the number promised by the insectaries (Figure 1). Shipping damage caused some differences, as some of the black scales were crushed on arrival. This problem can be partially solved by adequate packaging. Handling/preparation of the shipments, adverse conditions during transit, and/or the duration of transit times (unknown) may also have been detrimental. Figure 1 illustrates one difficulty in recommending reliable parasitoid release rates to growers. Unless emerging parasitoid numbers are consistent, parasitoid emergence from each release should be monitored. Parrella et al. (1992) also noted inconsistencies in numbers of emerged *E. formosa* in a biological control study.

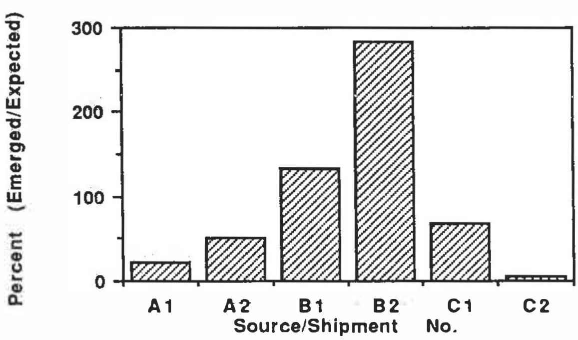

Figure 1. Number of *E. formosa* adults that emerged from two shipments (1 & 2) from three commercial insectaries (A, B, & C), as a percentage of the number promised by the insectary.

The cumulative % parasitoid emergence through time, from receipt of the shipment until all wasps had emerged, was similar for each insectary, but differed between insectaries

(Figure 2). Complete emergence occurred after 5, 7, and 12-14 days from Insectary A, B, and C, respectively. The longer emergence periods for Insectary C occurred because the parasitoids were in various instars upon arrival. Long or short emergence periods may be more useful in some situations than in others, depending on the age distribution of the whitefly population or other factors.

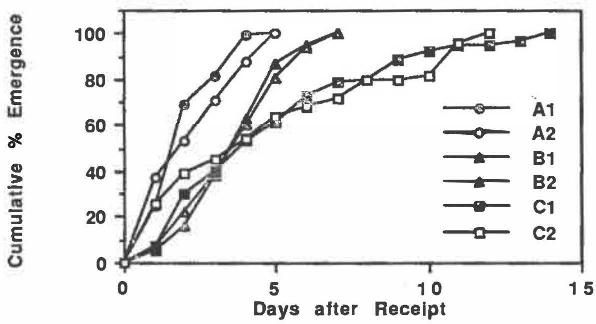

Figure 2. Cumulative percent emergence through time of adult *E. formosa* from two shipments (1 & 2) from three commercial insectaries (A, B, & C).

There was no significant difference in parasitism of greenhouse whitefly over 24 h among wasp samples from any insectary or shipment (Figure 3). Thus, differences in parasitoid performance in greenhouses might not be due to differences in the wasps themselves. These results suggest that parasitoids from any of these three insectaries that emerge from a release will perform in a similar manner, although we did not evaluate all aspects of parasitoid performance.

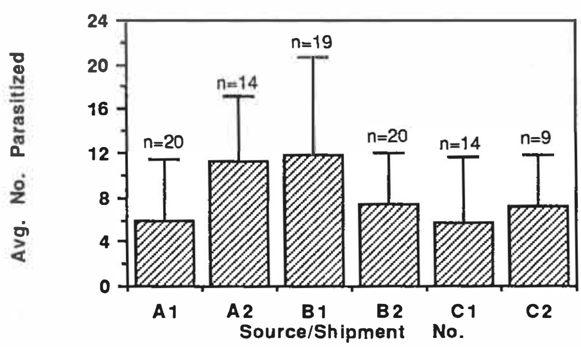

Figure 3. Average number of greenhouse whitefly nymphs parasitized over a 24 h period by individual *E. formosa* from two shipments (1 & 2) from three commercial insectaries (A, B, & C).

Acknowledgements

The technical assistance of Brad McFall and financial support of the American Floral Endowment and the New York State Department of Agriculture and Markets is gratefully acknowledged.

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EXPERT SYSTEM FOR INTEGRATED CROP MANAGEMENT OF GREENHOUSE CUCUMBER

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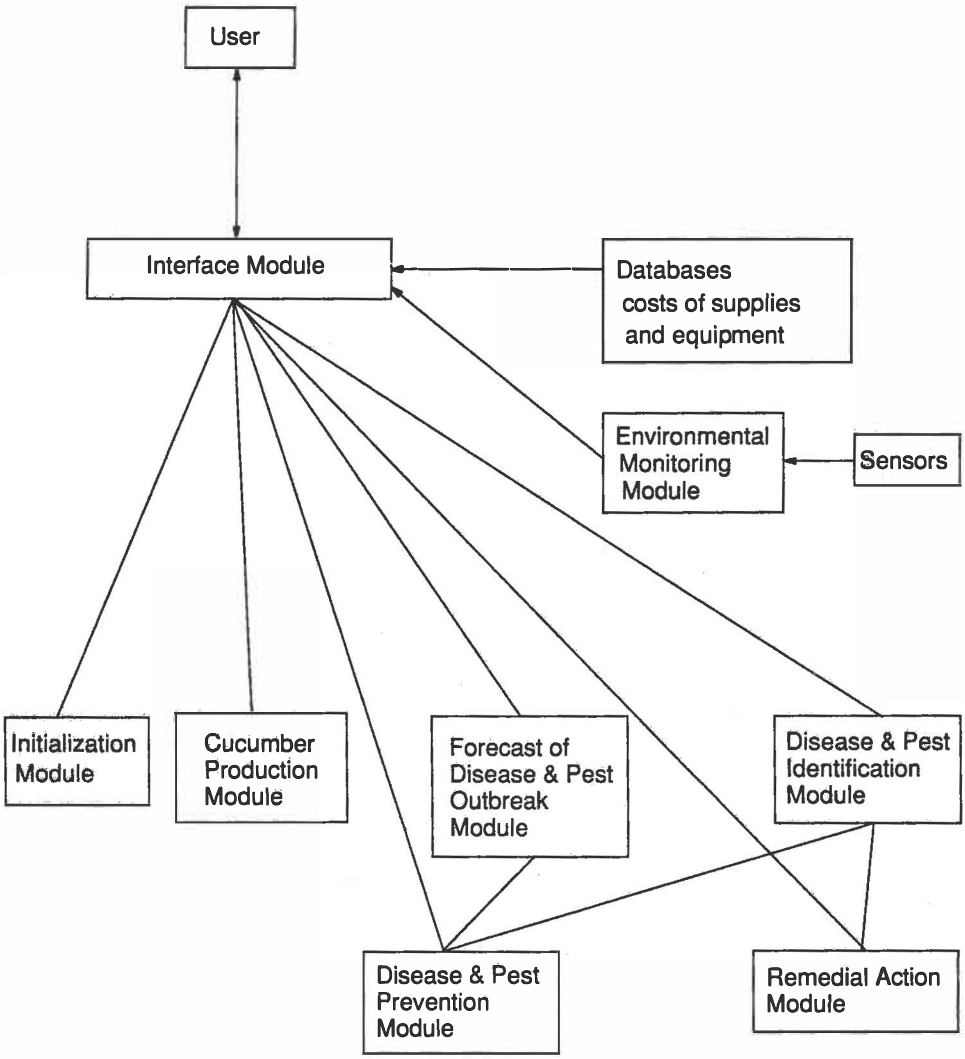
Abstract
The conceptual design for an expert system for integrated crop management of greenhouse cucumber is described. The system will integrate knowledge on pest and disease protection strategies and production practices into one common decision-making process. The objective of the system is to reduce the incidence of pests and diseases within the greenhouse while maintaining acceptable and profitable production levels. Daily advice will be provided for all stages of production including the monitoring of pest populations.

Introduction
Managing a greenhouse crop is a multidisciplinary approach that involves pest and disease protection strategies and production practices (Shipp *et al.*, 1991; Jarvis, 1992). Effective crop management requires the grower to integrate these different strategies and practices into a common decision-making process that is defined as "integrated crop management". Acquisition of knowledge by the grower in these areas and integration of this information into a format that is understandable and useful is often a difficult and complex task. Availability or access of information to the grower is a formidable problem by itself. However, the greatest problem is the conflicting recommendations that can result from control practices on one hand and production practices on the other. An example is the recommendation for spraying a fungicide for disease control that is also harmful to biological control agents. Another case may be the recommendation of environmental conditions favorable for entomopathogens that can also promote disease outbreaks.

These problems can be minimized with the use of an expert system. An expert system is a computer program that mimics the experts in assisting people to diagnose problems, select among alternatives and plan and manage operational systems (Barrett and Jones, 1989). An expert system is composed of an knowledge base, an inference engine that analyzes the knowledge base and an end-user interface that accepts inputs and generates outputs (Waterman, 1986). The development team consists of domain experts, a knowledge engineer and a select group of growers (end-users).

System Design
Our objective is to develop an expert information package for integrated crop management of greenhouse cucumber. Management practices will be recommended to reduce the incidence of diseases and pests within the greenhouse while maintaining acceptable and profitable production levels. The system will integrate pest, disease and production strategies. Advice will be provided for all stages of the production cycle (planning, seeding, transplanting, training, pruning, harvesting and post-harvest handling). The system is designed for the grower as the main user, although extension services, industry and researchers will also find the program useful for their respective needs.

Fig. 1. Schematic diagram of an expert system for integrated crop management of greenhouse cucumber



To accomplish the design objectives, the expert system consists of different knowledge modules (Fig. 1):

a) pest and disease identification
b) remedial action for pest and disease control
c) forecast of pest and disease outbreaks
d) pest and disease prevention
e) production

The system also has an interface, a start-up and an environmental module. The interface module provides an interface between the user and other modules and databases. The interface module controls the execution of the other modules. The start-up module initializes the system for the grower and contains information about the grower's greenhouse operation (i.e., size of greenhouse, growing season, fertigation system, number of workers, etc.). The environmental module monitors the climate of the greenhouse and stores this information in a database file for use by the other modules. Database files also contain information on costs associated with the greenhouse operation such as supplies, energy, pesticides, biological control agents and the economics of marketing the crop. To date, the pest and disease identification, remedial action and pest and disease prevention modules have been essentially completed. Work has also been initiated on the production module.

Pest Modules

Knowledge on insect and mite pests is required for four different modules. The pest identification module is used to identify greenhouse whitefly, western flower and onion thrips, melon aphid, two-spotted spider mite, fungus gnats, striped and spotted cucumber beetle, chrysanthemum and vegetable leafminers, plant bugs and lepidopterans (European corn borer, cabbage looper and corn earworm). Pest identification is an interactive program with the user being prompted for taxonomic characteristics of the insect or mite. Based upon the answers given, the user is led through a series of questions until the program provides one or more possible identifications. The user is then presented with a computer graphic image of the suggested pest identification along with a descriptive narrative of the pest.

The remedial action module recommends control measures for the identified pest. The recommended control actions can include cultural, biological, environmental and chemical measures. The basic algorithm for this module is: consult knowledge base to determine control actions; display all possible controls and their respective costs; recommend the most feasible control action and place the recommended control action on the daily list of tasks.

The objective of the module on forecasting pest outbreaks is to identify cultural and environmental situations that may result in a pest outbreak. To achieve this objective, the greenhouse environment is monitored continuously for solar radiation, temperature and vapor pressure deficit for each greenhouse zone. On a daily basis, the environmental data for each greenhouse zone is reviewed. Any conditions such as extreme temperature or vapor pressure deficit that are conducive to a pest outbreak are flagged. The program will query the grower for the density levels of any pests and use rule-base reasoning to determine the probability of a possible pest outbreak.

The objective of the pest prevention module is to recommend actions to prevent future outbreaks of a pest. Actions may include environmental and fertigation settings, cultural practices, biological control agents and pesticides. The algorithm for this module uses rule-based reasoning to determine the prevention actions. All possible preventation action and their respective costs are displayed. The program recommends the most feasible prevention action from a cost:benefit perspective and places this recommendation on the daily list of tasks.

Conclusions

The expert system is designed to be used by the grower in two different modes. In the first mode, the grower notices a problem with the cucumber crop and consults the expert system to diagnose the problem. Once the problem is identified, the expert system will recommend the appropriate remedial and preventive actions. In the second mode, the grower consults the expert system to check the daily list of management tasks for the crop. The environmental conditions for the previous 24 h are reviewed and conditions conducive to pest and/or disease outbreaks are flagged. Appropriate preventive action is recommended, such as biological and chemical agents, changing environmental settings or modifying fertilizer applications.

The use of expert systems for integrated crop management of greenhouse crops will assist the growers in operating a more efficient and cost-effective production system. There will be reduced chemical usage (fertilizers and pesticides) through more efficient and less-conflicting management practices. The end-result should be improved fruit quality and increased yield production. Development of an expert system for greenhouse cucumber will serve as a model for other greenhouse crops.

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ARTHROPODS IN THE ANTIPODES: PESTS AND BIOLOGICAL CONTROL IN PROTECTED CROPS IN AUSTRALIA

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Abstract
Pest control in plants under protected cropping in Australia is largely reliant on use of pesticides. The range of pests in Australia is similar to those in other parts of the world except that several key pests are absent. High house temperatures and low humidity often result in high pest pressure for most of the year. While there is a long history of successful biological control in Australia, it is only recently that mass rearing of arthropods for continual release has occurred. There is a limited range of biological control agents currently available for use, of which in glasshouses *Phytoseiulus persimilis* has been the most successful.

Introduction
Australia is a relatively isolated island continent of over 7.5 million square kilometres with two-thirds lying in the temperate zone and about a third within the tropics. Despite its size, Australia is highly urbanised with the majority of its population located in coastal centres. Crop production areas are often dispersed and considerable distances apart. Because of its close historic ties with Europe, most horticultural crops, production methods and pests are those borrowed from Europe. Australia is, however, fortunate in not having several key pests which cause severe problems in Europe and North America.

No accurate data exists regarding the extent of protected cropping in Australia. Traditionally, protected cropping has been carried out in Dutch- and British-designed glasshouses, although houses are now being designed for Australian conditions. There is increasing use of plastic tunnels. Climate control is not common, with only a small proportion of structures being heated, and a minority with cooling. As a result, summer temperatures in many production houses exceed 35oC for extended periods, and can even well exceed 40oC with low humidity. Substantial areas of shadehouses are used, primarily in the nursery industry.

Crops most commonly produced under protection are nursery stock, cutflowers, vegetables and, to a lesser extent, strawberries.

Biological Control in Australia
Since the 1880's, Australia has been active in developing biological control programs, particularly through inoculative releases of organisms targeted at exotic arthropod and weed pests. The control of prickly pear, *Opuntia* spp. in the 1920's is a spectacular example of successful biological control. Traditionally biological control has been undertaken by the national scientific organisation, CSIRO (formerly CSIR) with support from State Departments of Agriculture. A review of early biological control programs was undertaken by Wilson (1960). There are currently four commercial producers of mass reared biological control agents in Australia, but the range of organisms is limited.

Recently there has been greater restriction place on the introduction and use of exotic biological control agents. Legal action taken by apiarists and graziers in the 1980's, prevented the release of organisms for control of the weed, *Echium plantagineum* L. This resulted in legislation (the Biological Control Bill) in 1985-6 which provides for detailed assessment of proposed biological control programs prior to importation and release of any agents.

Major Pests in Protected Cropping

Spider Mites. Spider mites are regarded as the most important pest in protected cropping in Australia. The major species is *Tetranychus urticae*, but *Tetranychus ludeni* also occurs in the northern half of Australia. Resistance to most miticides, including the ovicides Clofentezine and Hexythiazox is widespread (Edge, 1988).

Following the discovery of the Chilean predatory mite *Phytoseiulus persimilis* on the east coast in 1978 (Goodwin and Schicha, 1987) probably from an accidental introduction from New Zealand, successful trialling and commercialisation took place in the 1980's. The history and status of *P. persimilis* in Australia has been recently reviewed (Spooner-Hart, 1991).

Whitefly. The greenhouse whitefly *Trialeurodes vaporariorum* is a pest of field as well as glasshouse-grown crops. In 1933 and 1934, *Encarsia formosa* was introduced, with liberations made in Tasmania 1934-5, New South Wales 1935-6, Victoria 1935-7 and South Australia 1936 (Wilson, 1960). The parasite established well, and appears to suppress the pest. While not normally regarded as a problem, isolated infestations of whiteflies may be severe. This is most common in houses practicing integrated mite control. Preliminary investigations using releases of *E. formosa* have commenced (J. Altman, personal communication).

Verticillium lecanii was introduced into Australia in the mid 1980's, but field trials with whiteflies was not encouraging, probably due to the unfavourable microclimate.

Australia does have sweet potato whitefly, *Bemesia tabaci*, but it appears the strain is innocuous.

Caterpillars. Lepidopterous pests found in protected crops include budworms (*Helicoverpa* spp.), loopers (*Chrysodiexis* spp.) and *Spodoptera* spp., as well as the native leafroller *Epiphyas postvittana*. Although *Bacillus thuringiensis* has been used against several of these species, results have been variable, and most growers continue to rely on organophosphorus, carbamate or synthetic pyrethroid insecticides.

Aphids. Several aphid species, in particular *Myzus persicae* pose problems on a range of plants. While several species of parasitic wasps and predators (especially Coccinellids and, to a lesser extent, lacewings and syrphids) suppress field infestations of aphids, there has to date been no investigation on biological control in protected crops.

Thrips. *Thrips tabaci*, the native *Thrips imaginis* and *Heliothrips haemorrhoidalis* all can cause damage in protected crops. The former two species can appear in plague proportions in spring where they primarily damage flowers and developing fruit, but may also transmit virus diseases. Preliminary investigations into use of *Amblyseius* spp. for thrips control have commenced. The western flower thrips *Frankiniella occidentalis* is not present in Australia.

Mealybugs. The species *Planococcus citri* and *Pseudococcus longispinus* infest a range of foliage and ornamental plants. Limited releases of the native predator *Cryptolaemus montrouzieri* and the introduced parasite *Leptomastix dactylopii* have shown promise (D. Papacek, personal communication). Both species are mass reared in Australia for use in citrus.

Leafminers. Leafminers do not pose a major problem. Australia is fortunate not to have *Liriomyza trifoliae*.

Tarsonemid Mites. The broad mite *Polyphagotarsonemus latus* and cyclamen mite *Steneotarsonemus pallidus* are becoming increasing problems in the central and northern parts of Australia. While there is anecdotal evidence of predation in the field, detailed investigations have only recently commenced (R. Parker, personal communication).

Limits to further development of biological control and IPM

These can be summarised as follows:

1. Restriction of pesticide use in integrated control programs for other pests (especially thrips and caterpillars).
2. Limited range of biological control agents available.
3. Lack of grower understanding of principles of biological control and IPM.
4. Continuing inconsistency in results achieved in some crops and situations.

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SUITABILITY OF *APHIS GOSSYPII* GLOV., *MACROSIPHUM EUPHORBIAE* (THOM.), AND *MYZUS PERSICAE* SULZ. (HOM.: APHIDIDAE) AS HOST FOR SEVERAL APHID PARASITOID SPECIES (HYM.: BRACONIDAE).

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Abstract
Host suitability of *Aphis gossypii* Glov., *Macrosiphum euphorbiae* (Thom.), and *Myzus persicae* Sulz. (Hom.: Aphididae) for the aphid parasitoids *Aphidius colemani* Vier. (one strain cultured on *A. gossypii* and one strain cultured on *M. persicae*), *A. matricariae* Hal., and *Lysiphlebus testaceipes* Cress. (Hym.: Braconidae) was tested in the laboratory. Thirty aphids of one species were offered to individual parasitoid females for two hours. Suitability was measured as the number of mummies found. Numbers were corrected for mortality of aphids assuming that parasitized and unparasitized aphids had the same chance of dying.

None of the parasitoids produced mummies on *M. euphorbiae*. *Aphidius colemani* produced on average 21 to 24 mummies on *A. gossypii* and 14 to 17 on *M. persicae*. No significant differences between the two strains were found. *Aphidius matricariae* produced on average 13 mummies on *M. persicae*, but less than 2 on *A. gossypii*. *Lysiphlebus testaceipes* produced on average 8 mummies on *A. gossypii* and less than 2 on *M. persicae*. It is concluded that *A. colemani* seems to be the most suitable species for use in aphid control. *Lysiphlebus testaceipes* might be used for control of *A. gossypii*, but seems to be unsuitable for control of *M. persicae*.

Introduction
Several aphid species can be important pests in glasshouse crops. In the Netherlands most problems occur with the cotton aphid, *Aphis gossypii* Glov. (Hom.: Aphididae), in cucumber crops (Van Schelt et al., 1990). Cotton aphid is highly resistant to selective insecticides (Cross et al., 1983), and use of broad spectrum pesticides inhibits the use of other biological control methods. Because biological control of cotton aphid is not reliable, research is performed on the usefulness of several aphid parasitoids for control of cotton aphid.

It would be convenient if the parasitoids used for biological control of cotton aphid, also could be used in biological control of other important aphid species, like the sweet potato aphid (*Macrosiphum euphorbiae* (Thom.) (Hom.: Aphididae)), and the green peach aphid (*Myzus persicae* Sulz. (Hom.: Aphididae)).

Macrosiphum euphorbiae is the most important aphid pest in tomato and egg plant. Although this aphid species still can be controlled by selective aphicides it is useful to test whether aphid parasitoids can be used for control too, to anticipate on possible development of resistance. *Myzus persicae* is the most important aphid pest in sweet pepper. Biological control is performed successfully on a large area. The natural enemies used are *Aphidius colemani* Vier. (Hym.: Braconidae) and the gall midge *Aphidoletes aphidimyza* Rond. (Dipt.: Cecidomyiidae) (Van Schelt et al., 1990).

The suitability of the aphid species mentioned above as host for the parasitoids *Aphidius colemani* (two strains), *Aphidius matricariae* Hal., and *Lysiphlebus testaceipes* Cress. (Hym.: Braconidae) has been tested under laboratory conditions.

Materials and methods

The parasitoids tested are reared in small glasshouse compartments on different hosts and host plants as shown in table 1. All cultures are maintained on the same host plant and host aphid species as the parasitoids were collected from. Cultures have been maintained at the Glasshouse Crops Research Station under natural light and a minimum temperature of 20 C from december 1990 onwards.

Individual females were released into a petri dish with a sweet pepper leaf with 30 second instar individuals of the aphid species to be tested. After the parasitoid had parasitized the first aphid, she was left in the petri dish for two hours. Afterwards the aphids were transferred to a petri dish with agar and a leaf disk of the preferred host plant (cucumber for *A. gossypii*, egg plant for *M. euphorbiae*, and sweet pepper for *M. persicae*). The aphids were followed in their development until the formation of mummies. Leave disks were replaced with fresh ones every 3 to 4 days. The number of mummies produced was corrected for mortality of aphids assuming that parasitized and unparasitized aphids had the same chance of dying. Each aphid-parasitoid combination consisted of 10 replicates.

Data were analyzed with ANOVA, if significant differences were found, data were analyzed further with a T-test.

Results

The average number of mummies produced in each aphid-parasitoid combination is given in figure 1. Results of the analysis of variance are given in table 2.

Myzus persicae is a good host for *A. colemani* and *A. matricariae*, although parasitization by *A. matricariae* is significantly lower than parasitization by *A. colemani* cultured on *A. gossypii* ($p < 0.01$; T-test after ANOVA). There is no significant difference between the two strains of *A. colemani*.

None of the parasitoids produced mummies when *M. euphorbiae* was offered as host, even though all of the parasitoids were observed to start parasitizing *M. euphorbiae*.

Lysiphlebus testaceipes is very unsuccessful in parasitizing *M. persicae*. The number of mummies produced is significantly lower than for both *Aphidius* species ($p < 0.01$; T-test after ANOVA).

Table 1. Rearing conditions of the aphid parasitoids.

Parasitoid species	Host aphid	Host plant
Aphidius colemani-A	*Aphis gossypii*	Cucumber
Aphidius colemani-M	*Myzus persicae*	Sweet pepper
Aphidius matricariae	*Myzus persicae*	Sweet pepper
Lysiphlebus testaceipes	*Aphis gossypii*	Cucumber

Table 2. Analysis of variance on the number of mummies produced by individual females (corrected for aphid mortality).

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Parasitoid species	3	2384.62	794.87	30.51	<0.001
Aphid species	2	4366.06	2183.03	83.79	<0.001
Parasitoid * Aphid	6	2502.15	417.03	16.01	<0.001
Residual	108	2813.76	26.05		
Total	119	12066.59			

The number of mummies found on *A. gossypii* is clearly different between the parasitoid species. *Aphidius matricariae* does not parasitize *A. gossypii* successfully. The number of mummies found for *A. colemani* is significantly higher than for the other species ($p < 0.01$; T-test after ANOVA). Within *A. colemani* there is no significant difference between the two strains. *Lysiphlebus testaceipes* does parasitize *A. gossypii* successfully although the number of mummies found is much lower than for *A. colemani.*

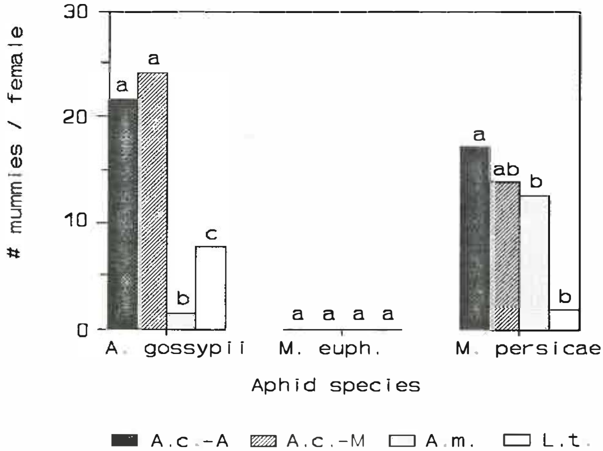

Figure 1. Number of mummies produced on *A. gossypii, M. euphorbiae*, and *M. persicae* by several parasitoid species (n=10). Different letters indicate a significant difference between parasitoid species within an aphid species (p< 0.01; T-test after ANOVA).
A.c.-A = *A. colemani* cultured on *A. gossypii* A.m. = *A. matricariae*
A.c.-M = *A. colemani* cultured on *M. persicae* L.T. = *L. testaceipes*

Discussion

Suitability in these tests is a combination of host acceptance cf. Vinson (1976) (willingness of the female parasitoid to deposit an egg) and host suitability in strict sense (survival of the egg to adulthood (in the present study: survival until formation of the mummy)). Probably the results are a combination of both processes. It took for example a long time from the introduction of the parasitoids until the first attack when *M. euphorbiae* was offered. If a suitable host was offered however (e.g. *M. persicae* for *A. colemani* and *A. matricariae*), the first parasitization occurred generally within a few seconds.

Aphis gossypii and *M. persicae* were shown to be good hosts for *A. colemani* in a previous study by Tardieux & Rabasse (1986). They also did not observe formation of mummies on *M. euphorbiae* even though the parasitoid showed parasitization behaviour. Tardieux & Rabasse (1986) did not find any first instar larvae in attacked *M. euphorbiae.* It is however still not known whether the absence of larvae is due to rejection by the parasitoid during the process of oviposition or due to mortality in the egg stage. Present findings are contradicted by Star & Schmutterer (1975), who did find *A. colemani* emerging from *M. euphorbiae* in the field.

Powell & Wright (1988) have shown that there can be differences in suitability of an aphid species as host for different strains of the same parasitoid species. In the present study no differences were found between two strains of *A. colemani*, even though the parasitoids have been reared on the same aphid species for at least 1.5 years.

Aphidius matricariae has been recorded from *A. gossypii* several times (Star , 1966, 1976, 1979). The low number of mummies produced by *A. matricariae* on *A. gossypii*, as found in this study, is confirmed by records from Schlinger & Mackauer (1963). They rarely found *A. matricariae* on *A. gossypii* in the field. They also quoted that *A. matricariae* has been recorded from *M. euphorbiae* although they questioned whether this observation was correct. In the present study no mummies were found on *M. euphorbiae*.

The suitability of *A. gossypii*, the low suitability of *M. persicae*, and the non-suitability of *M. euphorbiae* as host for *L. testaceipes* has also been shown by Carver (1984) and Schlinger & Hall (1960).

Conclusions

It can be concluded that none of the parasitoids is suitable for use in biological control of *M. euphorbiae*. *Aphidius matricariae* is clearly unsuitable for use in biological control of cotton aphid. Only very few mummified *A. gossypii* could be found in the tests. *Lysiphlebus testaceipes* could be useful for biological control of cotton aphid. A major drawback of this species is that is does not parasitize *M. persicae* very well. This implies that if *L. testaceipes* is used for control of *A. gossypii*, still another parasitoid might be needed for biological control of *M. persicae*. The most promising species for use in biological control of both *A. gossypii* as *M. persicae*, is *A. colemani*.

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HOST PLANT AFFECTS FITNESS AND HOST ACCEPTANCE IN THE APHID PARASITOID *Lysiphlebus testaceipes* (Cresson).

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Abstract
The effect of the host plant on the bionomics and host acceptance behaviour of the aphid parasitoid *Lysiphlebus testaceipes* (Cresson) was studied under controlled conditions. Reciprocal transfers of *Lysiphlebus*, parasitizing the cotton aphid *Aphis gossypii* Glover, from cucumber to cotton and vice versa have significantly affected the development time of the parasitoid as well as its fecundity, emergence rate and host acceptance rate. The results indicate that there is no host plant biotype in *Lysiphlebus*, yet a conditioning effect of the plant on the parasitoid does exist. The latter is an important point to consider when applying the parasitoid in protected crops.

Introduction

Lysiphlebus testaceipes (Cresson) (Hymenoptera: Aphidiidae) is a polyphagous aphid parasitoid. It was introduced to Israel in 1988 for biological control of the cotton aphid *Aphis gossypii* Glover (Homoptera: Aphididae) (Argov & Dreishpoun, 1990). Currently, the parasitoid is mass-reared at the Biological Control Industries, Sede Eliyahu for to be used with another aphidiid, *Aphidius colemani* Viereck, against the cotton aphid and the green peach aphid *Myzus persicae* Sulzer in protected crops.

In a series of laboratory tests, Marullo (1985) has presented data demonstrating the existence of host plant biotypes of *Lysiphlebus*. Thus parasitoids originating from mummies of *Aphis craccivora* reared on *Robinia* plant failed to parasitize the same aphid on *Vicia faba*. Identical results were obtained with parasitoids transferred from mummies of *Aphis fabae* reared on *Pittosporum* to the same herbivore but on *V. faba*. Complete parasitization was obtained only with parasitoids reared from the same host on the same plant or on botanically related plants. Stary et al. (1988a) has reported on field data which stand in contradiction with Marullo's approach. Furthermore, Stary et al. (1988b) indicated that *Lysiphlebus* successfully attack its hosts on different parts of the plant whether it is a weed, shrub or tree and concluded that neither the morphology nor the chemical composition of the plant affect the activity of the parasitoid. Recently, Stadler & Volkl (1991) showed that *Lysiphlebus* prefers to search for hosts on exposed parts of the plant (stem, leaves) rather than on concealed parts.

Mass producing parasitic wasps on a certain herbivore and host plant might condition the natural enemy to a specific herbivore and host plant and therefore negatively affect its performance in the field, once it is introduced against another herbivore on different host plant. This hypothesis, as well as the above mentioned dispute on the existence of plant and herbivore biotype in *Lysiphlebus*, led us to study the conditioning effect of the host plant and herbivore on the parasitoid. Here we present results of a first series of experiments aimed at elucidating the effect of host plant switching on various life history parameters of *Lysiphlebus* and its host acceptance behaviour.

Material and methods

Plants and insects. Potted cucumber plants (vr. "Tamara") and cotton plants (vr. "Eden"), bearing 2-4 true leaves, were infested by an ample amount of the cotton aphid. The infested plants were held individually for experiments in cages comprised of a transparent and ventilated PVC cylinder (30 cm high and 12.5 cm in diameter). Parasitoids were maintained for at least three consecutive generations on the cotton aphid - host plant system, prior to being used for experiments. Mummies were kept singly for parasitoid emergence in small glass vials (3 cm high and 1 cm in diameter) provided with fine streaks of honey. Adult wasps, maximum 24 h old, were sexed, mated and subsequently introduced into the experimental arena.

Test procedure. For testing development time, 2-3 mated females were introduced on infested plant for 6 h. By the end of this period the wasps were removed and the plants were held in temperature of 25$\pm$1°C and light regime of 16L:8D. When mummies has appeared they were isolated individually in small glass vials and adult emergence was recorded every 12 h.

For studying fecundity and emergence rate, mated pairs of *Lysiphlebus* were exposed to infested plants under conditions of 23$\pm$3°C and light regime of 16L:8D. Upon mummification, the leaves from each plant were detached and held for parasitoid emergence in ventilated plastic cups. When emergence ceased, the total count of mummies per plant served as a measure of fecundity for a single female. Rate of emergence was determined by recording the number of mummies out of which the wasps failed to emerge versus mummies out of which the parasitoids has successfully emerged. In addition, a sample of wasps was taken for subsequent introduction as a second and third generation on the test plant.

Host acceptance was studied by direct observation of a female parasitoid on an infested plant, of which only two leaves were left in order to facilitate the observation. The wasp's activity on the plant was recorded for maximum 10 min or less, in case it left the plant before the end of this time period. Each plant was used for a single observation. Ten observations (=wasps) were followed per treatment. The quantitative data registered during each observation were: number of encounters, i.e. physical contact between the parasitoid and the aphid host, and number of oviposition movements, i.e. bending the abdomen underneath the thorax and extending it forwards between the legs in order to insert the ovipositor into the aphid. The latter divided by the former provided a measure of the parasitoid's response rate. The host acceptance observations were carried out in a controlled chamber of 25$\pm$1°C and artificial light.

Results and discussion

The development time of *Lysiphlebus* was significantly longer on cotton than on cucumber (Table 1). Transferring wasps from cucumber to cotton significantly lengthened their development time on the cotton aphid. However, this trend was reversed during the second generation of *Lysiphlebus* on cotton, where development time was shortened back to the control (cotton-cotton) level. In the reciprocal transfers from cotton to cucumber, development time was slightly lengthened in the first generation, whereas during the second generation it was significantly shortened, close to the control (cucumber-cucumber) level (Table 1).

Fecundity of *Lysiphlebus* on the cotton aphid reared on cucumber was by far higher than its fecundity on the same herbivore reared on cotton (Table 2). All the reciprocal transfers, of both directions, as well as the second generation on the test plant, yielded 5-13 fold less mummies than the control cucumber-cucumber. However, extrapolating from the trend in Table 2, fecundity may improve especially through more cucumber-cucumber generations.

The size of the mummies and wasps originating from cucumber is significantly higher compared to those originating from cotton (H. Prag unpublished data). This may partially explain the higher fecundity on cucumber relative to cotton, although no correlation has yet been studied between body size and fecundity of *Lysiphlebus*.

Emergence rate is a good quantitative indicator of host suitability. Hence, aphids reared on cucumber plant were more suitable for *Lysiphlebus* development than the same aphids reared on cotton (Table 3). Transferring wasps from cucumber to cotton brought about a dramatic drop in

Table 1. **The effect of reciprocal transfers between two host plants, on development time (days from egg to adult at 25°C) of *Lysiphlebus testaceipes*, parasitizing the cotton aphid, *Aphis gossypii*.**

Source plant	Test plant	n	Mean development time (days)
Cucumber	Cucumber	198	9.3 a*
Cucumber	Cotton	44	15.5 e
Cotton	Cotton II**	78	11.5 c
Cotton	Cotton	164	11.5 c
Cotton	Cucumber	190	11.8 d
Cucumber	Cucumber II	289	9.8 b

* - Identical letters within the column mean no significant difference (nonpaired T-test, $P<0.05$).
** - A second generation on the test plant after being transferred from the source plant.

Table 2. **The effect of reciprocal transfers between two host plants, on fecundity of *Lysiphlebus testaceipes*, parasitizing the cotton aphid, *Aphis gossypii*.**

Source plant	Test plant	n	Mean number of mummies
Cucumber	Cucumber	10	210.6 a*
Cucumber	Cotton	10	24.6 b
Cotton	Cotton II**	9	16.9 b
Cotton	Cotton	12	33.8 b
Cotton	Cucumber	8	30.4 b
Cucumber	Cucumber II	10	43.6 b

* and ** - See comments on Table 1.

Table 3. **The effect of reciprocal transfers between two host plants, on emergence rate of *Lysiphlebus testaceipes*, parasitizing the cotton aphid, *Aphis gossypii*.**

Source plant	Test plant	Total number of mummies	Emergence rate (%)
Cucumber	Cucumber	2106	94.9 a*
Cucumber	Cotton	184	64.1 c
Cotton	Cotton II**	72	81.9 b
Cotton	Cotton	406	68.5 c
Cotton	Cucumber	243	91.4 b
Cucumber	Cucumber II	436	89.4 b

* - Identical letters within the column mean no significant difference (G-test for goodness-of-fit, $P<0.05$).
** - See comment on Table 1.

Table 4. The effect of reciprocal transfers between two host plants, on host acceptance behaviour of *Lysiphlebus testaceipes*, parasitizing the cotton aphid, *Aphis gossypii*.

Source plant	Test plant	Number of encounters	Number of ovipositions	Response (%)
Cucumber	Cucumber	378	319	84 ab*
Cucumber	Cotton	120	40	33 c
Cotton	Cotton	206	184	89 a
Cotton	Cucumber	118	93	79 b

* - Identical letters within the column mean no significant difference (G-test for goodness-of-fit, $P<0.05$).

emergence rate, yet during the subsequent generation this rate has significantly increased, implying that host suitability may improve even further through more cotton-cotton generations. On the other hand, transferring parasitoids from cotton to cucumber exhibited high emergence rate, close to the control (cucumber-cucumber) level (Table 3).

Analysis of host acceptance behaviour of *Lysiphlebus* revealed the highest acceptance rate in the control treatments (cucumber-cucumber and cotton-cotton) (Table 4). The reciprocal transfers demonstrated a significant decrease in acceptance, especially in the cucumber-cotton treatment. These results partially corroborate the poor fecundity of *Lysiphlebus* once transferred from one host plant to another (see Table 2).

In conclusion, our data support the approach of Stary et al. (1988a), suggesting that there are no host plant biotypes of *Lysiphlebus*. However, a conditioning effect of the plant on the parasitoid was clearly demonstrated here. This is an important point to consider when using *Lysiphlebus* in augmentative or seasonal inoculative releases in protected crops, particularly on plants which are botanically distant from the plant used in mass-production.

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SOME OBSERVATIONS ON THE QUALITY OF BIOLOGICAL CONTROL ORGANISMS USED IN GREENHOUSES

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Abstract
The predatory mites *Phytoseiulus persimilis* and *Amblyseius cucumeris*, and the parasitoid *Encarsia formosa* are used in Alberta greenhouses in biological control programs to control spider mite, thrips, and whiteflies respectively. Following persistent complaints from growers about poor quality and lack of efficacy, several shipments from three commercial suppliers were evaluated. In the case of *P. persimilis* and *A. cucumeris*, there was significant divergence from stated contents both among suppliers and among batches. In laboratory tests for survival and fecundity, predator mites from most batches performed poorly. Emergence of *E. formosa* from parasitized whitefly pupae was generally less than 60 percent. The results are discussed in relation to possible causes such as shipping stress, starvation, improper storage, and disease.

Introduction
Greenhouse vegetable growers in Alberta adopted biological controls for spider mite and whitefly control in 1981. In 1989, there were numerous complaints from the growers about *Phytoseiulus persimilis* Athias-Henriot, particularly those shipped on vermiculite. They appeared to be dead on arrival or to have escaped in transit. Spider mite was not being adequately controlled. There were certainly problems with container design and delivery systems, but when these were eventually straightened out, the problem with poor spider mite control remained. Preliminary trials we conducted in 1990 indicated severely reduced fecundity and longevity of predators from two sources. Complaints continued to come in from growers in following seasons, only now these included *Encarsia formosa* Gahan and *Amblyseius cucumeris* Oudemans. Many growers became frustrated and returned to using chemical pesticides. In 1991 and 1992, we expanded this study. We examined the performance of all three biological control agents, and looked for health problems that might be caused by disease and might be brought out by shipping stress and environmental fluctuations within the greenhouse environment. In the 1991 proceedings of the IOBC working group "Quality Control of Mass Reared Arthropods", a preliminary list of criteria for quality control for product control procedures was presented (van Lenteren & Steinberg 1991). This list was amended and supplemented in 1992 (D. Elliott, personal communication). A similar group, the Association of Natural Bio-control Producers, was formed in the United States in 1990. Members are attempting to develop similar guidelines but have not yet published them. The quality control procedures followed were developed in the absence of the IOBC guidelines but are very similar.

Materials and Methods
Phytoseiulus persimilis. Shipments were obtained from three commercial producers, located in Canada, Europe, and the United States. The shipments are designated as from sources A, B, and C, and are not otherwise identified in order to protect commercial interests. Eight separate shipments were received from each source between April and July, 1991. Companies were requested to treat them as they would all normal customer orders. Each shipment consisted of two separate containers with the same number of stated contents in each of the pair. The containers held *P. persimilis* on a vermiculite carrier. The first container in each shipment was used to assess the total number of *P. persimilis* present. The second container was used to assess the percentage of

live mites present, and the survival and fecundity of female mites. Specimens were also submitted for transmission electron microscopy and for staining to determine if internal pathogens were present.

Number present The total contents of the first container were sieved in small batches through screens. The total number of *P. persimilis* (all motile stages) were counted.

Percentage live The contents of each of the second containers were mixed well and approximately 10ml of vermiculite placed in each of five separators. The separator consisted of a small petri dish glued to the bottom and centre of a larger petri dish containing water plus soil wetting agent to break the surface tension of the water. Two 150 watt incandescent light bulbs were suspended ~30cm above the separators. Live mites became very active and in attempting to leave the vermiculite, fell into the soapy water and drowned. After 24hr, the water was sieved to collect "live" mites. The vermiculite was similarly sieved to remove "dead" mites. The percentage of live mites in each sample and the percentage of those gravid were then calculated.

Longevity and fecundity Twenty live female mites were randomly collected from each second container and confined individually on small leaf disc arenas. Two-spotted spider mites were provided as food. The arenas were maintained at high humidity and kept in a growth chamber at 25°C and a 16l:8d cycle. Each arena was examined daily (except weekends) over a seven day period. Records were kept of the number of eggs laid by each *P. persimilis* and whether the mite was live or dead. Eggs were removed and hatch recorded. At the end of a seven day period, the average longevity and fecundity of female mites was calculated. Fecundity was calculated as mean eggs/day/mite based on the number of females in the batch at start-up.

Amblyseius cucumeris. Shipments could be obtained from suppliers A and C only. Four separate shipments were received from each supplier during February and March 1991. Each shipment consisted of two containers of *A. cucumeris* on bran. One container was used to assess the total number of *A. cucumeris* present. The other was treated similarly to those containing *P. persimilis* in order to assess longevity, fecundity, percentage live, and percentage of females with eggs. Samples of mites were sent for electron microscopy and also stained for pathogens.

Number present With 10,000 mites supposedly present in each container, it was decided to assess total numbers by subsampling rather than a total count. There were five replicates of 10ml bran samples per container. The total volume of bran in the container was measured in order to extrapolate the sample count to an estimate of total number of mites present.

Percentage live The percentage live could not be assessed by placing under lights because the mites were less active than *P. persimilis* and were disinclined to leave the curls of the bran. We attempted to determine this information from the preserved material; however, it was difficult to separate dead mites from cast skins of these and bran mites. Besides, the percentage of dead mites appeared to be very low, so we did not make this assessment. The percentage of adult mites with eggs and percentage of adults in the batch were calculated.

Longevity and fecundity The procedures followed were basically the same as those for *P. persimilis,* except that first instar western flower thrips larvae were used as food.

Encarsia formosa. Shipments were obtained from Sources A and C. A total of four shipments were received in February and March 1992. Two thousand parasites were ordered from each source. Source A were on 20 cards (100/card), Source C on 42 (50/card plus two extra cards). Samples were sent for electron microscopy and stained for pathogens.

Number present and percentage live On arrrival, 20 cards from each source were checked under the microscope for holes in the black scales indicating pre-emergence had taken place. Cards were then placed individually in small, snap-top plastic jars and maintained in a growth chamber at a constant temperature of 25°C and 16h light period. Emerged *Encarsia* were counted after 7 and 14 days. Results are reported as the total percentage of parasitized scales where emergence occurred, the percentage of scales where pre-emergence occurred, and the mean number of wasps emerged per card.

Longevity and fecundity We were not able with present resources to determine these parameters.

Results

Phytoseiulus persimilis. The mean number present in the container varied from the number stated but was within acceptable limits for source B. Two shipments from source C were seriously short. Source A showed the most variation in numbers, from 326 to 8461 in containers stated to contain 1000 mites. The percentage of live mites was high in shipments from source B, but was sometimes low in those from sources A and C. Only rarely were any females gravid on arrival.

Mite survival from those in the established AEC colony ranged from an average 5.50-6.25 days. Comparable figures for sources A, B, and C were 1.35-6.53, 2.37-5.35, and 2.42-5.54 days respectively. The percentage live after 5 days generally fell far short of the 80% suggested by IOBC guidelines (van Lenteren & Steinberg 1991). Egg laying also differed from that of the established colony. AEC mites laid from 2.35-3.92 eggs/female/day, which is within the range of 2.4-4.0 reported in the literature (Ragusa 1965, Laing 1968, Kennett & Caltagirone 1968, Amano & Chant 1977). Sources A, B, and C females laid 0.09-2.71, 0.19-1.97, and 0-1.20 eggs/day respectively. The percentage of these eggs that hatched was generally very high. After the first day, the number of eggs laid by surviving mites did not decline much over the seven days; rather the death of the others lowered the overall production for the batch.

Amblyseius cucumeris. The mean number in the container far exceeded stated contents in shipments from source A, and was very short in those from source C. In neither case was the number present consistent from batch to batch. The percentage of females with eggs on arrival ranged from 38.8-62.0 for source A and 17.8-58.3 for source C. The percentage of adult mites was higher in source C containers.

Mite survival ranged from 2.42-5.42 days for source A mites and 3.55-4.61 days for source C. Source A mites laid averages of 0.40-1.05 eggs/day, and source C mites 0.29-0.58 eggs/day. These figures are lower than the 1.5-1.6 reported in the literature (El-Badry & Zaher 1961, Gillespie & Raney 1988).

Encarsia formosa. Almost all wasps emerged within the first seven days. The percentage of wasps that emerged prior to receipt was low except for two shipments. The total percentage emergence ranged from 49.45-59.05 for source A, and from 43.38-65.78 for source C. This is much lower than the >90% emergence reported in tests carried out just prior to shipment, and the 80% stated as an acceptable level (Ravensberg 1991). The total number of emerged wasps per card ranged from 52.85-107.3 for source A (100 expected) and 34.75-72.3 for source C (50 expected).

Discussion

The results clearly demonstrate that Alberta growers were justified in questioning the quality of the biologicals received. Shipments of all three biologicals were in many cases short on stated contents. In some cases they were in excess of stated contents, but the enormous variation in numbers present makes it impossible to accurately assess the "effective dose", for present or future reference. As timing of releases and early establishment is usually necessary for good control, it is not acceptable to receive far fewer viable organisms than ordered. The quality of those individuals that were present is also of concern. The mites performed poorly in a favourable environment with food provided. Conditions in a commercial greenhouse are not so kind. *Phytoseiulus persimilis* were clearly starved on receipt, as few females were gravid and most were emaciated in appearance. White gut was very common in mites from all sources. *Amblyseius cucumeris* came with food and about half the females were gravid. Pre-emergence of *E. formosa* indicates poor or prolonged storage. These wasps are usually crushed when setting out cards or because they have spent time confined may not have sufficient energy to fly to a new food source after release. The low % emergence raises a question about the viability of the survivors. All shipments were received from source within 48hr of shipping, and processed immediately except for occasional shipments which arrived late in the day. These were refrigerated overnight and processed early the following day. Although 24h is preferable, 48h is the norm for shipments from out of province to Alberta growers and is not an unreasonable period if biologicals are kept cool and fed.

The causes of the quantity and quality problems are open to question. Quantity problems relate directly back to the supplier, who should be running checks on each batch. Quality problems are more difficult to pinpoint. Deterioration from prolonged storage, improper packaging, and inadequate food during storage/shipping are factors also under the direct or indirect control of the producer. These are not the responsibility of the end purchaser. A packaging and expiry date on each package would assist consumers in evaluating whether the product as received is likely to perform. Starved biologicals may not recover no matter how well they are treated on arrival.

Other possibilities for poor performance are genetic inbreeding and disease. The latter has been poorly documented, and generally appears to have been handled by attempting to decrease stress on that culture, or by supplementing or replacing it with one from another supplier with no knowledge of the condition of that culture either. There are only two documented cases of disease in *P. persimilis* (Šuťáková 1988, Šuťáková & Arutunyan 1990, Šuťáková & Rütgen 1978), one in *A. cucumeris* (Beerling 1991), and none in *E. formosa.* The smaller producers are often not aware of the potential of disease, and the larger producers appear reluctant to discuss the problem as they are afraid of undermining consumer confidence and sales in a competitive market. Nevertheless, consumer confidence is presently being more seriously undermined by poor quality and performance. We have found several microorganisms infecting all three biologicals. These include viruses, microsporidia and other protozoa, rickettsia, fungi and bacteria. These will be reported on at a later date.

Acknowledgements

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BIOLOGICAL CONTROL OF THE GREENHOUSE WHITEFLY ON THE ORNAMENTAL *GERBERA JAMESONII*: HOW DOES *ENCARSIA FORMOSA* BEHAVE IN A PATCH? PART II.

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Abstract
Patch time allocation experiments of the parasitoid *Encarsia formosa* on the host plant *Gerbera*, cultivar Tennessee, showed the same residence and giving-up times as on two previously tested *Gerbera* cultivars. A negative correlation between walking activity of the females and egg load was found after 4 eggs have been laid. This explains a decrease in walking activity of parasitoids on leaves where hosts are present compared to a constant walking activity on leaves without hosts or on leaves where less than 5 eggs are laid.

Introduction
Patch time allocation experiments with *E. formosa* showed that wasps stayed at least twice as long on *Gerbera* leaves with hosts available as on uninfested leaves. Residence time on infested leaves with a high hair density was somewhat longer than on a cultivar with a low hair density, but did not differ significantly (Sütterlin et al., in press). Previous work by our group indicated that on leaves with hosts parasitoids showed an overall lower walking activity than on leaves without hosts. This was contrary to our expectation and also does not agree with Van Vianen & van de Veire (1988), who found that searching times were longer on a leaf with hosts than on clean leaves. Direct observations of the parasitoids search and oviposition behaviour pointed to a slow down in walking activity after a number of eggs had been laid. *E formosa* is synovigenic and has c. 8 mature eggs available when starting to search for hosts after sunrise (Van Vianen & van Lenteren 1986). In this paper we report about experiments aimed at answering the question whether there is a relationship between walking activity and egg load.

Material and methods
Host plants and whitefly hosts. The *Gerbera* variety Tennessee (high hair density, 363 trichomes per cm^2) was used for the experiments. Leaves were infested by placing the plants whitefly rearing cages during 4 hours. All adults were removed from the leaves and the plants were reared separately in glasshouses at 20 - 22 °C and 16 hours photophase. This resulted in a mean host density of 34 L_3/L_4 whitefly larvae per leaf after approximately 3 weeks.
Parasitoids. *E. formosa* originated from Koppert Biological Systems. Only newly emerged females of less than 16 h old were used in the experiments, which had had the opportunity to feed on honey.
Experimental procedure. An infested leaf was attached to an intact plant. A parasitoid was released in the center of the lower side of this infested leaf just before the experiment started. The experiment was exactly carried out as described in Sütterlin et al. (in press). We measured residence time, giving-up-time, walking activity and host acceptance. Only the first three parameters will be discussed in this article. The walking activity of parasitoids on leaves with hosts was determined in two situations: in experiments which were terminated when wasps left the leaf voluntarily and in experiments where the total time on a leaf was limited to 1.5 hours.

Table 1. Mean residence times of *Encarsia formosa* on infested *Gerbera* leaves

Gerbera cultivar	Fame[1)]	Parade[1)]	Tennessee
Mean (seconds)	9664.6	14065.6	13279.9
σ(n-1)	5517.2	6739.4	6989.1
Number of wasps	19	19	8

[1)] Data from Sütterlin et al., in press

Table 2. Mean giving-up times of *Encarsia formosa* on infested *Gerbera* leaves

Gerbera cultivar	Fame[1)]	Parade[1)]	Tennessee
Mean (seconds)	1580.3	3005.6	1941.8
σ(n-1)	1264.0	1733.4	1536.4
Number of wasps	11	11	8

[1)] Data from Sütterlin et al., in press

Table 3a. Mean walking activity (%) of *Encarsia formosa* on infested *Gerbera* leaves; duration of experiments 1.5 hours

Gerbera cultivar	Fame	Parade
Mean (%)	59.90	61.82
σ(n-1)	22.92	17.72
Number of wasps	12	12

Table 3b. Mean walking activity (%) of *Encarsia formosa* on infested *Gerbera* leaves; duration of experiments until parasitoid left voluntarily

Gerbera cultivar	Fame[1)]	Parade[1)]	Tennessee
Mean (%)	47.74	45.53	39.25
σ(n-1)	23.84	17.88	20.54
Number of wasps	19	19	24

[1)] Data from Sütterlin et al., in press

Results

Residence time. The residence time is the time wasps stay on a leaf. Only females that left the leaf voluntarily were used for analysis. Residence times were the same on the three tested *Gerbera* cultivars (table 1; Kruskal-Wallis test gave no significant differences). The mean residence time on infested *Gerbera* leaves was 12337 seconds (about 3.5 hours).

Giving-up time. The giving-up time is here defined as the period a parasitoid stays on the leaf after the last encounter with a host. Also here only those females that left the leaf voluntarily were taken into account. No statistically significant differences between the three tested cultivars could be detected (Kruskal-Wallis test). The mean giving-up time on infested *Gerbera* leaves was 2176 seconds (about 36 minutes)(table 2).

Walking activity. The walking activity is defined as the percentage time walking of the total time spent on the leaf. If hosts were encountered by the parasitoid, handling time was not included in the total time spent on the leaf. In the first experiment on walking activity (results in table 3a) the wasps were taken from the leaf after 1.5 hours. Mean walking activity was the same on both cultivars and amounted to 61%.

During the second experiment, where observations were terminated after the parasitoids left the leaf voluntarily, the walking activities were also not significantly different on the three cultivars (table 3b). The mean walking activity in these experiments was 44 %.

In a third experiment, where observations were terminated after the parasitoids left the leaf voluntarily, the walking activities were determined for each interval between ovipositions (figure 1). A significant negative correlation was found between the walking activity of *E. formosa* and the number of eggs laid. A decrease in walking activity is observed after the 4th oviposition.

Discussion and conclusions

1. The residence and giving-up times of *E. formosa* on three *Gerbera* cultivars, Fame, Parade and Tennessee, are the same (table 1 & 2).
2. Van Roermund et al. (in press) found for *E. formosa* searching on tomato, that parasitoids increase their search time to about 40 minutes after ovipositing in an unparasitized host, which is very similar to the average giving-up times of 36 minutes we found on *Gerbera* (table 2).
3. The residence times on hairy cultivars (Tennessee and Parade) is similar (3.8 hours) and tends to be longer than on the less hairy cultivar (Fame, 2.7 hours)(table 1).

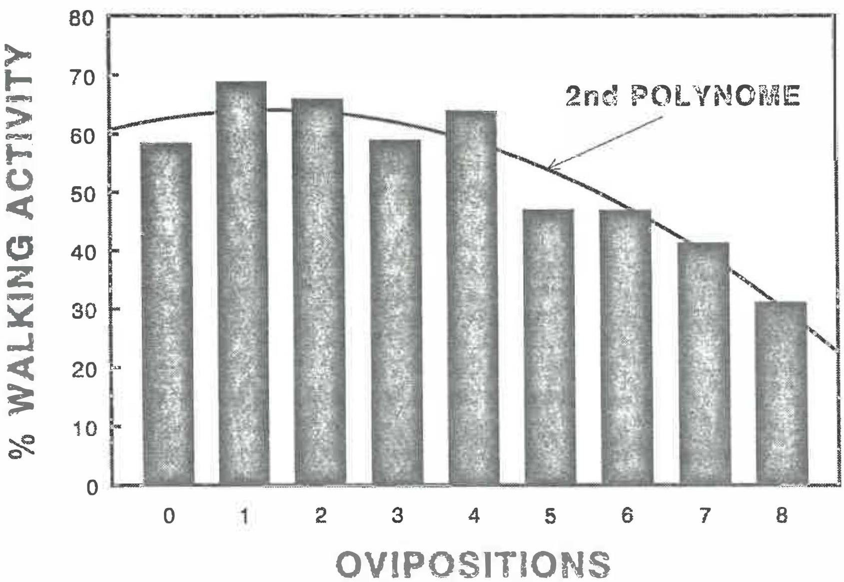

Figure 1. **Percentage walking activity of *Encarsia formosa* on infested *Gerbera* leaves cultivar Tennessee, before the first and after consecutive ovipositions**

4. The walking activity of *E. formosa* in the time-limited experiment with infested leaves is 61 % (table 3a). In experiments with no time limitation the walking activity was 44 % (table 3b). The 'time-limited' parasitoids showed the same high walking activity (61 %) as earlier found by Sütterlin et al. (in press) in an experiment with uninfested leaves where wasps were observed up to the moment they left (walking activity 62 %).
5. The walking activity of *E. formosa* parasitoids decreases with their egg load, but only after the 4th oviposition (figure 1). The parasitoids are synovigenic and on average eight mature eggs are available when hatching. After each oviposition maturation of a new egg starts and takes a certain amount of time which is dependent on temperature (Kajita & van Lenteren, 1982; Van Vianen & van Lenteren, 1986). The negative correlation between walking activity and egg load might be explained by a increasingly lower motivation to search for hosts when fewer eggs are available. This is supposed to have resulted in a decrease of walking activity in experiments where wasps could leave voluntarily (table 2 and figure 1). In the time-limited experiments and in experiments without hosts the walking activity remains high, because the egg load does not reach the level at which search motivation decreases.
6. These results are essential to understand the search and parasitization dynamics of *E. formosa*. The data will be incorporated in a population dynamic model by Van Roermund (in prep.) to evaluate the effects of changes in walking activity, residence and giving-up times on parasitization of whitefly in large, commercial greenhouses.

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DEVELOPMENT TIME, SURVIVAL AND FECUNDITY OF *ENCARSIA FORMOSA ON BEMISIA TABACI* AND *TRIALEURODES VAPORARIORUM.*

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Abstract
The possibilities to control *Bemisia tabaci* with *Encarsia formosa* are discussed based on recently collected data concerning immature mortality, development time, fecundity and lifespan of the parasite when developing on either *Trialeuroodes vaporariorum* or *B. tabaci. E. formosa* develops slower, shows a higher mortality and is less fecund when *B. tabaci* is offered as host. Combined with a lower percentage acceptance of *B. tabaci* by the parasite when offered together with *T. vaporariorum* we remain of the opinion that *E. formosa* is not sufficiently effective to be used in a self perpetuating control system when the crop is infested exclusively with *B. tabaci*, or with both whitefly species. Control might be obtained through regular inundative releases of *E. formosa* during the cropping season.

Introduction
The sweetpotato whitefly, *Bemisia tabaci* Gennadius (B-strain), was accidentally imported in the Netherlands in 1987. Since then it has spread over most of northern Europe, infesting many vegetables and ornamentals. Initially, *B. tabaci* did not create very serious problems. In Germany and Italy, the sweetpotato whitefly seems to be reasonally well controlled on poinsettia (*Euphorbia pulcherrima* Willd.) through weekly releases of *E. formosa* (Albert 1990, Benuzzi et al. 1990) although control is more difficult than that of greenhouse whitefly. Additionally, Benuzzi et al. (1990) mention that biological control resulted in a better reduction of *B. tabaci* than chemical control. Others reported that *E. formosa* cannot develop in *B. tabaci* (Onillon pers. comm.) or does insufficiently control this whitefly on poinsettia (Parrella pers. comm.).

In 1991 the pest status of *B. tabaci* has drastically increased and attempts to develop biological control have been intensified. As a first approach we tested whether *E. formosa* Gahan (Koppert Biosystems strain) could be used for control of *B. tabaci.* Boisclair et al. (1990) reported that *E. formosa* could not be used in a seasonal inoculative release system (van Lenteren & Woets 1988) when the crop is infested exclusively with *B. tabaci* because the juvenile mortality of *E. formosa* is very high and the fitness of *E. formosa* females reared from *B. tabaci* is much lower than parasites reared on *Trialeurodes vaporariorum* (Westwood). Also Benuzzi et al. (1990) reported the mortality of *E. formosa* on *B. tabci* to be much higher than on *T. vaporariorum.*

As a follow up of Boisclair et al.'s 1990 research, we studied the development time of an *E. formosa* population which was exposed for the first time to *B. tabaci.* Development time, juvenile mortality and fecundity were measured for the offspring of this first generation. As a control the same parameters for *E. formasa* were determined when developing on *T. vaporariorum.*

Material and methods
E. formosa was reared on *T. vaporariorum* on tobacco plants under normal Dutch greenhouse conditions (night temperature c. 20°C, day temperature c. 25°C). All experiments were done on poinsettia in a climate room (T=21°C, RH=65 +/-5%, light intensity = 6000 Lux (1st exp.), 8000 Lux (2nd and 3rd exp.), light regime = 16 L/8 D, light on 6.00, light off 22.00.)

Experiment 1: development time of E. formosa on B. tabaci and T. vaporariorum. *E. formosa* females (origing Koppert Biosystems) were individually put in leafcages and allowed to oviposit for 24 hours in either *B. tabaci* or *T. vaporariorum.* Development of immature stages was checked 3 times per day (08.00, 13.00 and 18.00) until all adults had emerged.

Experiment 2: lifespan and fecundity of first generation E. formosa females which developed on B. tabaci. Fifteen parasite females which emerged either from *B. tabaci*, or from *T. vaporariorum,* where exposed daily to *B. tabaci* and *T. vaporariorum* respectively, on poinsettia untill all parasites had died. Whitefly larvae were dissected and checked for signs of host feeding.

Experiment 3: mortality of E. formosa. Parasites (origin Koppert Biosystems) were allowed to lay eggs during 24 hours in an ample number of either *B. tabaci* or *T. vaporariorum.* About 50% of the exposed whitefly larvae were dissected. The development of the remaining larvae was followed by daily checks between 09.00 and 10.00 until emergence had occurred.

Table 1. Developmental time of *E. formosa* on *T. vaporariorum* and *B. tabaci*

Host species	Day when first larvae coloured black/brown (in days after parasit.)	Average development time (in days)	Number emerged
T. vaporariorum	12	24.5 (s.d. 1.5)	219
B. tabaci	16	29.8 (s.d. 2.2)	285

Table 2. Fecundity, host feeding and lifespan of *E. formosa* on *T. vaporariorum* and *B. tabaci* (based on 15 parasite females per host species)

Host species	Ovipositions/ female/day	Host feedings/ female/day	Fecundity	Lifespan in days
T. vaporariorum	5.0	2.8	59.2	11.9
B. tabaci	5.9	2.3	51.3	8.7

Table 3. Juvenile mortality of *E. formosa* when developing on *T. vaporariorum* and *B. tabaci*

Host species	Total no. larvae	% parasitism based on dissection	% parasitism based on change of colour	% pupae with dead parasites
T. vaporariorum	391	45.7	57.9	41.6
B. tabaci	563	34.7	46.6	55.9

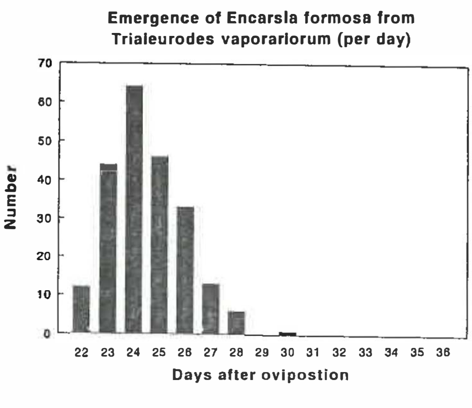
Results

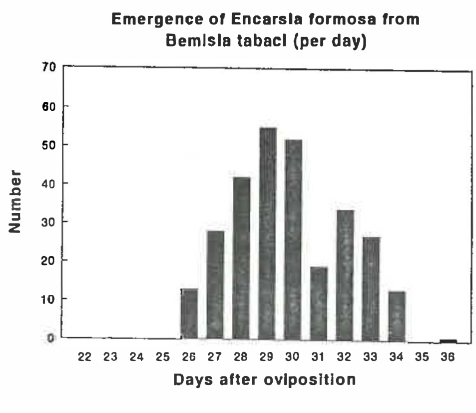
Experiment 1. The first parasitized *T. vaporariorum* larvae turned black on the 12th day after parasitism, the first parasitized *B. tabaci* larvae turned brown on the 16th day (table 1). Emergence of *E. formosa* which developed in *T. vaporariorum* started 22 days after parasitism, and 26 days after parasitism in *B. tabaci* (figure 1). Emergence peaked on day 24 with *T. vaporariorum* as host and on day 29 with *B. tabaci* as host. Emergence took place over a period of 7 and 9 days for the two hosts respectively. It is clear that the development time of *E. formosa* is considerably longer - 5.3 days at 21°C - on *B. tabaci* than on *T. vaporariorum.*

Experiment 2. It was not possible to determine the fecundity and lifespan of *E. formosa* properly, because quite a number of parasites escaped from the leafcages. The data must, therefore, only be used as an indication for the effect of the different hosts on the fecundity and lifespan of the parasite. The average lifespan of *E. formosa* developed on *T. vaporariorum* is longer on *T. vaporariorum* than that of *E. formosa* developed on *B. tabaci* on *B. tabaci* (table 2). The number of ovipositions and host feedings are similar for parasites developed on both types on hosts. "Fecundity" of *E. formosa* which developed on *T. vaporariorum* is somewhat higher than for parasites which developed on *B. tabaci.*

Experiment 3. Percentage parasitism was determined in two ways. First more than 200 of the larvae of each host species were dissected for egg presence. This gave 45.7% parasitism of *T. vaporariorum* larvae and 34.7% parasitism of *B. tabaci* (table 3). The remaining larvae were allowed to develop till emergence and based on colour changes (black for *T. vaporariorum* and brown for *B. tabaci*) we could also determine the percentage parasitism which was 57.9 and 46.6 respectively. Based on the fact that the latter percentages were about 10 percent higher than the percentages based on dissection, we have to conclude that we apparently missed some eggs during dissection. Earlier articles reported a total juvenile mortality of less about 20% when *E. formosa* develops on greenhouse whitefly on tomato and cucumber (van Roermund & van Lenteren 1982). We found much higher percentages, 41.6% dead immature parasites in *T. vaporariorum* and 55.9% in *B. tabaci.* Although mortality in *B. tabaci* was considerably higher than in *T. vaporariorum* it is clear that there is apparently a strong effect of the host plant - poinsettia - on parasite mortality.

Figure 1. Daily emergence of *E. formosa* on *T. vaporariorum* (left) and *B. tabaci* (right)





Discussion and conclusions

Under northern European glasshouse conditions population growth of *E. formosa* is much slower on *B. tabaci* than on *T. vaporariorum*. This is mainly caused by a considerably slower development of the parasite in sweetpotato whitefly than on greenhouse whitefly (about 30 and 25 days respectively). Immature mortality of the parasite was high (40-56%) on both hosts, and is supposed to have been influenced by the host plant poinsettia as normally we do find about 20% mortality when *E. formosa* develops on greenhouse whitefly. The daily host kill rate (the number of hosts killed through host feeding + the number of parasitized hosts) is about the same for the two host species. Fecundity and lifespan were not measured reliably enough, but are somewhat higher on greenhouse whitefly than on sweetpotato whitelfy. Combined with a lower percentage acceptance of *B. tabaci* by the parasite when offered together with *T. vaporariorum* (Boisclair et al. 1990) we remain of the opinion that *E. formosa* is not sufficiently effective to be used in a self perpetuating control system when the crop is infested exclusively with *B. tabaci*, or with both whitefly species. Control might be obtained through regular inundative releases of *E. formosa* during the cropping season.

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BEHAVIOURAL RESPONSES OF WESTERN FLOWER THRIPS TO ANISALDEHYDE, AND IMPLICATIONS FOR TRAPPING IN GREENHOUSES

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Abstract
Preliminary observations in a flight chamber olfactometer and simple field bio-assays involving chemical and visual cues indicate that the behavioural responses of western flower thrips, *Frankliniella occidentalis* (Pergande), to *p*-anisaldehyde involve chemokinesis as opposed to anemotaxis, an odour-induced visual response, or chemotaxis. Previous experiments have probably underestimated the effect of volatile chemicals on thrips trapping because of an influence of volatiles from baited traps on unbaited traps. We provide evidence that yellow water traps baited with *p*-anisaldehyde increase capture of western flower thrips females in greenhouses by a factor of over 10.

Introduction

In greenhouses, thrips traps are used for a number of reasons including early detection of insects in a crop (Brødsgaard 1989, Gillespie & Vernon 1990), prediction of thrips outbreaks (Higgins & Myers 1992), and potentially for the establishment of economic thresholds and control of thrips by mass trapping (Kawai & Kitamura 1987). Where it is important to detect the presence of thrips at low densities or where traps are used for control, traps must be designed to maximise catch of target thrips species. Several factors are known to influence the efficiency of thrips traps including trap color (Brødsgaard 1989), size (Kirk 1987), orientation (Coli et al. 1992), height above the crop (Gillespie & Vernon 1990), colour bordering the trap (Czenz 1987), and volatile chemicals (Kirk 1985, Brødsgaard 1990, Teulon & Ramakers 1990, Teulon et al. in prep.).

Results from previous experiments examining the use of volatile chemicals for thrips traps in greenhouses may be misleading because volatiles from baited traps may have influenced trap capture of nearby unbaited traps (Brødsgaard 1990, Teulon et al. in prep.). Depending on the behavioural response of thrips to volatile chemicals, simple comparative bioassays may underestimate (e.g., due to a chemokinetic resonse), or overestimate (e.g., due to a chemotactic response) the effect of these chemicals on thrips capture.

We report on experiments concerning the behavioural response of female western flower thrips (WFT), *Frankliniella occidentalis* (Pergande), to *p*-anisaldehyde and discuss implications for trapping thrips in greenhouses.

Response of WFT to *p*-anisaldehyde and colour in a flight chamber olfactometer

The behavioural responses of female WFT exposed to four treatments were recorded: 1) no anisaldehyde and no yellow cue; 2) no anisaldehyde and yellow cue (ca., 12cm height x 15cm dia.); 3) anisaldehyde (ca., 0.5ml of *p*-anisaldehyde applied to a cotton dental roll) and no yellow cue; and 4) anisaldehyde and yellow cue. Tests were conducted in a glass flight chamber (1.2 x 0.5 x 0.5m) through which room filtered air was passed at 0.11 m/sec. The lowest number of thrips taking flight occured in the presence of *p*-anisaldehyde with (μ=2.4) or without (μ=1.8) a yellow cue compared to treatments without *p*-anisaldehyde with (μ=3.3) or without (μ=3.6) a visual cue. Most upwind flights occured in the presence of the yellow cue with (μ=1.5) or without *p*-anisaldehyde (μ=2.1) compared to the absence of a yellow cue with (μ=0.5) or without *p*-anisaldehyde (μ=0.6) (Hollister 1993).

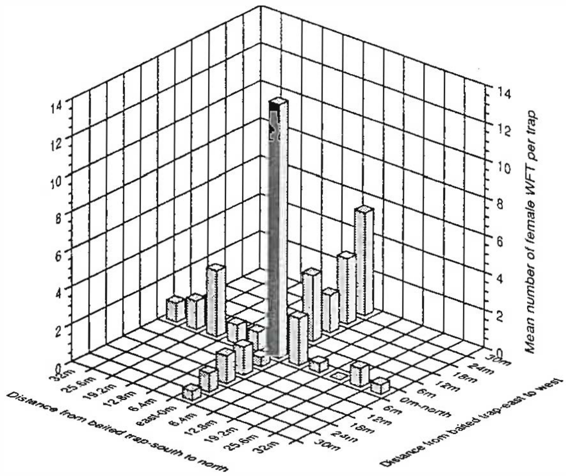

Fig. 1. **Mean (n=2) number of WFT females caught in yellow water traps in a sweet pepper glasshouse with only the centre trap baited with *p*-anisaldehyde.**

Response of thrips to water traps with and without *p*-anisaldehyde and colour

Black and yellow water traps (ca., 12cm height x 15cm dia.) with and without *p*-anisaldehyde were set in a 2.5ha sweet pepper (var., Spartacus, Gold Flame) glasshouse in Northumberland County, PA. Traps were placed just above the top of the crop canopy (approx. 1.5m) on plywood shelves attached to glasshouse support posts. *P*-anisaldehyde (2ml) was placed in a vial (3ml), stoppered with a cotton wool wick and suspended over water traps with wire. After 43 hours yellow water traps with *p*-anisaldehyde captured the greatest number of WFT females (μ=222.1), with significantly decreasing numbers captured in yellow traps with no *p*-anisaldehyde (μ=91.7), black traps with *p*-anisaldehyde (μ=25.9), and black traps with no *p*-anisaldehyde (μ=1.9), respectively (Hollister 1993).

Effect of *p*-anisaldehyde on thrips capture in yellow water traps over distance

Yellow water traps (see above) were placed in 2.5 ha tomato (var., Trend) glasshouse in Northumberland County, PA. A single trap with *p*-anisaldehyde (see above) was placed in the middle of an array of traps without *p*-anisaldehyde extending in the four cardinal directions. Five traps were spaced at 6m intervals for a distance of 30m east and west of the centre baited trap and at 6.4m intervals for a distance of 32m north and south of the centre baited trap. Traps were placed just above the crop canopy (approx. 3m) on plywood shelves attached to glasshouse support posts.

After 48 hr (2 samples x 24 hr) relatively few female WFT were caught in the east (μ=3.4), south (μ=5.9), and west (μ=4.2) traps (without *p*-anisaldehyde) compared to the central trap (μ=56) (with *p*-anisaldehyde) and traps to the north (μ=82.9) (without *p*-anisaldehyde). Thrips capture in the centre baited trap was 12.4 times greater than the average capture of traps to the east, south, and west but 2 of 5 non-baited northern traps exceeded the centre trap capture.

This experiment was repeated in a sweet pepper (var., Flair F1) glasshouse in Northumberland County, PA with a similar design to that described above. After 2 weeks (2 samples x 1 wk.) more WFT females were caught in the centre trap (μ=13.5) (with *p*-anisaldehyde) compared to the unbaited traps in all four cardinal directions (Fig. 1). Fewer thrips were captured in nonbaited traps to the north (μ=0.9), east (μ=1.0) and south (μ=1.6) compared to nonbaited traps extending to the west (μ=3.0). Capture in the centre baited trap was 11.5 times greater than the average capture in nonbaited traps to the north, east, and south and 4.5 times greater than the average capture to the west.

Thrips host finding behaviour

A knowledge of thrips host finding behaviour is critical for assessing the effectiveness of thrips traps with volatile chemicals (Teulon et al. in prep.). For example, if an odour-induced visual response or a kinetic response is involved, traps without volatile chemicals but in the active space of a chemical from elsewhere may catch more thrips than if no chemical was present. Alternatively, a chemotatic response may draw thrips away from traps without chemicals so that these traps catch fewer thrips than they would in isolation. The behavioural response of thrips may also influence the use of volatile chemicals in thrips pest management (Teulon et al. in prep.). For example, chemotactic responses may draw thrips into glasshouses and thus lead to greater infestations.

For insects, olfactory enhancement or induction of visual orientation and odour-modulated optomotor anemotaxis are considered the only behavioural mechanisms involved in distant orientation, while chemotaxis and/or chemokinetic responses have been described for close range orientation (St_dler 1992).

Host finding behaviour for thrips is unlikely to involve anemotaxis because thrips are weak flyers and host finding would be limited to times of very slight air movement. In the flight chamber an air flow of 0.22 m/sec impeded the upwind flight of thrips and deflected them laterally (Hollister 1993). There was no evidence for odour-modulated anemotaxis for WFT females in flight chamber olfactometer experiments: the presence of *p*-anisaldehyde reduced the number thrips taking flight and in the absence of a visual cue the number of net upwind flights was similar with and without *p*-anisaldehyde.

A possible odour-induced visual response has been suggested for thrips (Kirk 1985, 1987, Brødsgaard 1990, Teulon & Ramakers 1990) but increased catches of WFT females in black water traps with *p*-anisaldehyde compared to those without (see above) suggest that olfaction is important in the absence of colour. Clear water traps with *p*-anisaldehyde also catch more WFT females than clear traps without (Teulon unpubl. data). Furthermore, in the flight chamber olfactometer with a yellow visual cue, the number of thrips taking flight and the number of net upwind flights decreased in the presence of *p*-anisaldehyde compared to no *p*-anisaldehyde.

Flight chamber olfactometer experiments provide no evidence for chemotaxis in WFT females: the presence of *p*-anisaldehyde reduced the number of thrips taking flight and in the absence of a visual cue the net upwind movement was lowest in the presence of *p*-anisaldehyde compared to other treatments.

Chemokinetic responses such as orthokinesis (change in speed or frequency of locomotion) and klinokinesis (change in frequency or rate of random turning) may be involved in host finding for insects (St_dler 1992). Flight chamber olfactometer experiments suggest an orthokinetic response of WFT females to *p*-anisaldehyde: in the presence of *p*-anisaldehyde (with and without a visual cue) the number of thrips taking flight was reduced. No measurements of change in frequency or rate of turning were made so it was not possible to determine if there was any klinokinetic response. Assuming that flying thrips respond to *p*-anisaldehyde in a similar fashion to those taking flight, orthokinesis may be involved in the behavioural response of WFT to traps with *p*-anisaldehyde.

Trapping thrips in glasshouses with anisaldehyde

Preliminary observations in a flight chamber olfactometer, and simple field bio-assays involving chemical and visual cues (see above), indicate that the behavioural response of WFT females to *p*-anisaldehyde probably involves chemokinesis as opposed to anemotaxis, an odour-induced visual response, or chemotaxis. This should be verified with more intensive studies along with the influence of thrips age and sex, and aspects related to chemical specificity, mixtures of chemicals, alternative chemicals, formulations and interactions with colour. If chemokinesis is the main behavioural response of thrips to volatile chemicals, previous experiments investigating the use of volatile chemicals for thrips trapping in greenhouses (Brødsgaard 1990, Teulon & Ramakers 1990, Teulon et al. in prep.) have probably underestimated the effect of the chemical on thrips trapping because volatiles from baited traps may have influenced trap capture of nearby unbaited traps.

With a central baited trap surrounded by non-baited traps placed in the four cardinal directions the influence of *p*-anisaldehyde is more apparent. In both tomato and sweet pepper glasshouses, catches of WFT females in baited traps were over 10 times those of unbaited traps in three directions, this is a significant improvement in capture of WFT females over proportions previously recorded in greenhouses (Teulon & Ramakers 1990, Teulon et al. in prep.). In the fourth direction, the high number of thrips caught may have been due to air currents carrying *p*-anisaldehyde to unbaited traps and/or large localised thrips populations. This requires further investigation.

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ADULT ACTIVITY OF FOUR *ORIUS* SPECIES REARED ON TWO PREYS

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Abstract
Several Anthocorids of the genus *Orius* are among the most promising candidates for biological control of the western flower thrips, *Frankliniella occidentalis* (Perg.), a pest harmful to ornamental and vegetable crops. Adults of the species *O. majusculus* (Reuter), *O. laevigatus* (Fieber), *O. niger* Wolff and *O. insidiosus* (Say) were tested in the laboratory (t = 26+/-1 C; RH = 80+/-5%; photoperiod L:D = 16:8) by being fed *ad libitum* two preys: UV-sterilized *Ephestia kuehniella* (Zell.) eggs and *F. occidentalis* adults. In all the species, the females fed on *E. kuehniella* showed greater longevity and higher oviposition than those fed on *F. occidentalis*. Although its imaginal longevity was higher or not significantly different, *O. niger* showed a lower oviposition on both preys in comparison to the other species, thus appearing to be the least suitable species for mass-rearing at the tested conditions.

Introduction
Since its introduction to Italy (Arzone et al., 1989), the western flower thrips (WFT), *Frankliniella occidentalis* (Perg.), has become a major pest of ornamentals and, mainly in southern Italy, of strawberry, eggplant, pepper and tomato, as well as a vector of tomato spotted wilt virus (Tommasini & Maini, in press).

Among the predator species being tested for biological control, several polyphagous Anthocorids of the genus *Orius* seem to be very promising candidates. In Italy, wild populations of some indigenous species have been found to limit WFT outbreaks, especially during summer, while the American species *O. insidiosus* (Say) is already being distributed by some northern European biofactories. Although several studies have been conducted to improve mass-rearing techniques of some *Orius* species (Stoltz & Stern, 1978; Takara & Nishida, 1981; Kiman & Yeargan, 1985; Zaki, 1989; Alauzet et al., 1990; Ruberson et al., 1991; Fischer et al., 1992), comparative performance experiments will be necessary to determine which of these species perform best as to both mass-rearing and release in various field conditions.

The aim of the present study was to provide an initial, comparative evaluation of the three palearctic species *O. majusculus* (Reuter), *O. laevigatus* (Fieber) and *O. niger* Wolff and the neartic *O. insidiosus* (Péricart, 1972).

Materials and methods
The three palearctic species were collected in Italy during 1991, in WFT-infested greenhouses and the initial *O. insidiosus* stock was supplied by Koppert Biological Systems (The Netherlands). All the species were reared and the tests run in a climate chamber at 26+/-1 C, 80+/-5% RH and 16:8 (L:D) photoperiod, and fed on frozen *Ephestia kuehniella* (Zell.) eggs.

Freshly-emerged pairs of the four *Orius* species were isolated in transparent plexiglass cylinders, 9 cm in lenght and diameter, capped with a wad of fine cotton. The predators were fed every two days: in the first experiment on UV-sterilized *E. kuehniella* eggs stuck to cardboard with arabic gum, and in the second experiment on *F. occidentalis* adults. The number of prey supplied in both experiments was *ad libitum* (>500 *E. kuehniella* eggs and >200 *F. occidentalis* adults). Every two days, too, a bean pod was placed in each cylinder, as substrate for predator oviposition and WFT feeding; at the same time, the number of surviving predators (dead males replaced) and of eggs layed was counted. The number of prey consumed in 24 h was monitored every 8 days

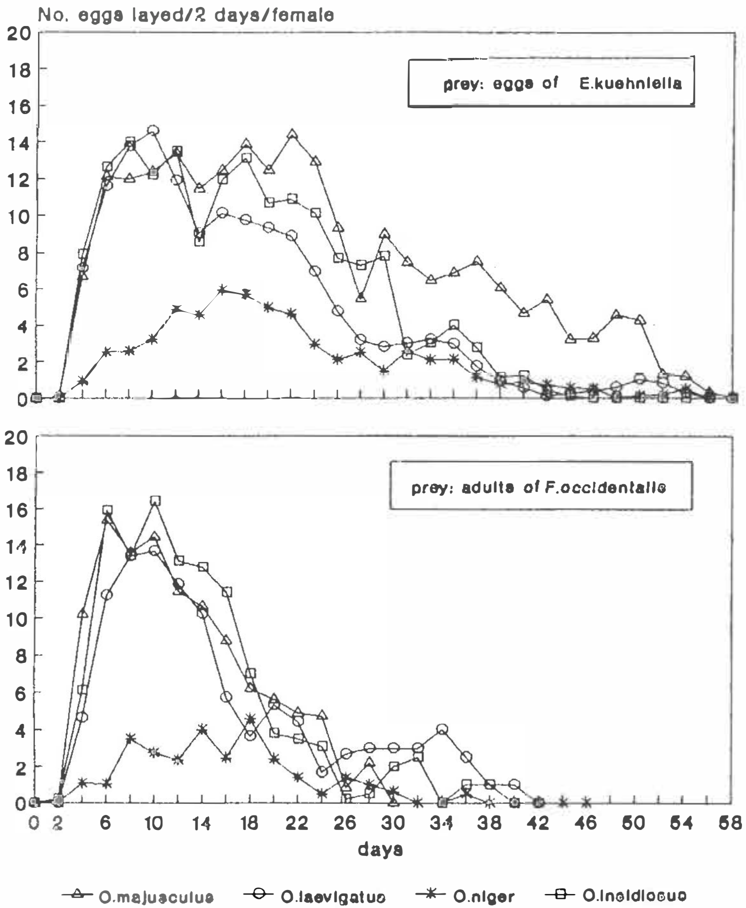

Fig.1: Oviposition of four *Orius* species fed on *Ephestia kuehniella* eggs or *Frankliniella occidentalis* adults.

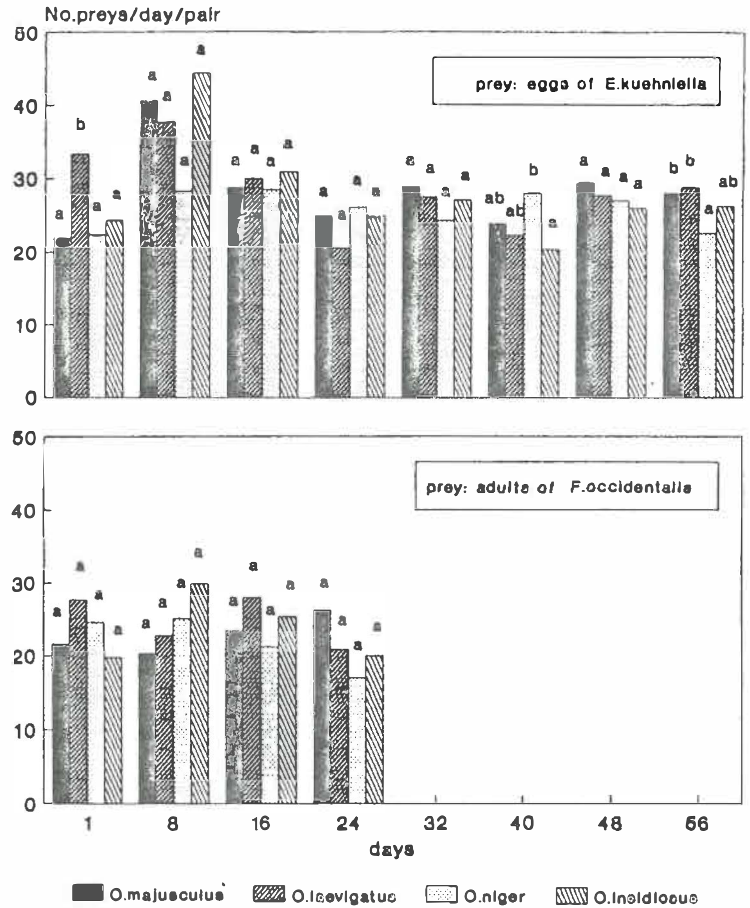

Fig.2: Predation of four *Orius* species (pairs) fed on *Ephestia kuehniella* eggs or *Frankliniella occidentalis* adults. Different letters show significant differences, within the data of the same day ($P<0.05$); Kruskal-Wallis test, followed by distribution-free multiple comparison; Dunn's procedure valid for unequal sample size.

Table 1. **Imaginal development of four *Orius* species fed on *Ephestia kuehniella* eggs or *Frankliniella occidentalis* adults (Average +/- SE).**

Species	Pair No.	*Ephestia kuehniella* Longevity (days)		Total eggs laid/♀		Pair No.	*Frankliniella occidentalis* Longevity (days)		Total eggs laid/♀	
O. majusculus	63	47.0	2.8b	174.0	13.4c	36	19.7	1.3a	87.1	8.8b
O. laevigatus	64	38.6	2.3a	118.6	9.4b	42	18.0	1.5a	55.6	7.8b
O. niger	29	50.0	3.4b	54.1	11.1a	36	18.4	1.9a	16.8	4.3a
O. insidiosus	65	42.3	1.8ab	144.3	9.5 bc	46	17.1	1.3a	65.7	8.4b

Different letters in the same column indicate significant differences (P<0.05), by Kruskal-Wallis test, followed by distribution-free multiple comparison; Dunn's procedure valid for unequal sample size.

beginning from the day of emergence, by supplying ca. 500 *E. kuehniella* eggs or 80 *F. occidentalis* adults per predator pair. The number of spontaneously collapsed *E. kuehniella* eggs and the natural mortality of *F. occidentalis* were monitored by keeping an equal amount of prey in cylinders for 24 h without predators (12 replications per prey).

Results and discussion

Table 1 reports the average longevity and the total oviposition per female of the four *Orius* species fed on *E. kuehniella* eggs or on *F. occidentalis* adults. In all the species, the females fed on *E. kuehniella* showed significantly higher rates of longevity and total oviposition than those fed on *F. occidentalis*. Of the species fed on the same prey, significant differences in longevity were found with *E. kuehniella*, but not with *F. occidentalis*. *O. niger* layed fewer eggs than the other species, both with *E. kuehniella* and *F. occidentalis*.

The oviposition patterns are reported in figure 1. Females usually began oviposition between the third and the fourth day after emergence, although sporadic cases of earlier oviposition were found. *O. majusculus*, *O. laevigatus* and *O. insidiosus* showed an high oviposition rate with both prey, beginning from day 5-6 after emergence, although oviposition in the females fed on *F. occidentalis* started to decline 8-10 days before that in females fed on *E. kuehniella* - a difference that was less marked in *O. niger*, because of its lower oviposition.

The daily predation activity per pair of the four species is shown in figure 2. Neither the number of spontaneously collapsed *E. kuehniella* eggs (1.3+/-1.0; Average+/-SD), nor the natural mortality of *F. occidentalis* adults (7.8+/-2.9) were subtracted from the daily predation data. Significant differences among the four species were registered only at the beginning and the end of life of the predators fed on *E. kuehniella*; no differences were found with *F. occidentalis*.

Conclusions

The adults of the tested species showed a similar predation capability, confirming their effectiveness with *F. occidentalis* adults.

The predators fed with UV-sterilized *E. kuehniella* eggs performed better than those fed on *F. occidentalis* adults, both with regard to female longevity and the number of eggs layed per female. Nevertheless, under the laboratory conditions, *O. niger* proved less suitable for mass-rearing than the other three species, mainly because of the low number of eggs layed.

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CONTROL OF WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* WITH THE PREDATOR *ORIUS INSIDIOSUS* ON SWEET PEPPERS.

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Abstract
The western flower thrips, *Frankliniella occidentalis* could be controlled efficiently in a commercial sweet pepper crop with multiple releases of *Orius insidiosus* starting a few days after transplant. This introduction method gave satisfactory control during the entire growing season, lasting from med January until mid December. For detection of adult thrips and *Orius*, blue sticky plates were very useful, but quantitative monitoring, using 18 plates, was only successful when population densities were high. Flower sampling was satisfactory to reflect population density changes for both nymphs and adults of thrips and *Orius*.

Introduction
Nowadays the two main pest insects of sweet peppers are the western flower thrips (WFT), *Frankliniella occidentalis* Pergande and aphids. Of these two, WFT is the more dangerous, as it cannot be controlled with pesticides, either due to resistance or incompatibility of the chemicals with current IPM programmes.

When WFT occurs in high densities, there is a considerable risk of it functioning as a vector of TSWV (Tomato Spotted Wilt Virus) (Trottin-Caudal et al., 1990). The biological control of WFT with the predatory mite *Amblyseius cucumeris* Oudemans sometimes poses problems (Gilkeson et al., 1990) so that an alternative predator would be very much appreciated. Among the ones currently being tested is the predatory bug *Orius*. Several species are recorded in Belgium (*O. niger*, O. *laevigatus, O. minutus*). (Péricart, J., 1972).

The present study describes the efficiency of *O.insidiosus* for the control of WFT, applied in a multiple release scheme, starting early in the season, on a commercial sweet pepper crop. Different sampling methods (blue sticky plates, flower samples) for monitoring WFT and Orius were also studied.

Materials and methods
The experiment was conducted on a commercial sweet pepper farm in a glasshouse of 6,600 m2 consisting of 20 sections. On 16 January 1992 sweet pepper plants (cv. Mazurka, n=36,000), height 0.3 m, were planted on rockwool mats. At the same time, 18 blue sticky plates (7x14 cm)(Biopax-Catch it; Silva Miljöab-Knäred, Denmark) were hung 10 cm above the top of the plants, in 18 different sections, and raised weekly to keep them 10 cm above the plants until they reached a maximum height of 2.4 m. WFT and *O. insidiosus* were monitored until November on these plates which were replaced weekly by fresh ones.

On 17 January the first *O. insidiosus* adult bugs (n=1000) were preventively released; from our own laboratory experiments we know that *O. insidiosus* can produce progeny when fed exclusively on pollen. The first WFT nymphs were found on some plants spread all over theglasshouse, on 30 January; they probably originated from an adjacent cold lettuce glasshouse

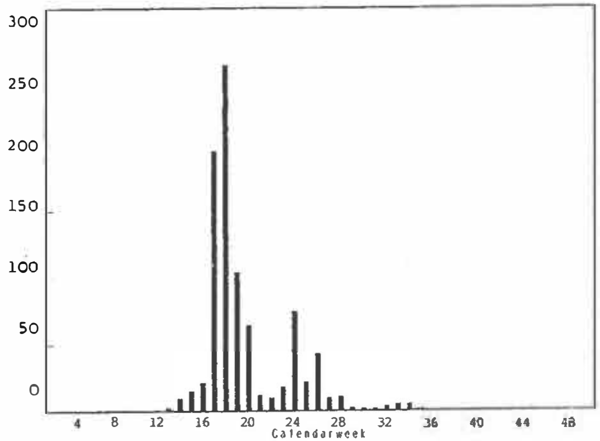

Fig.1: Mean number of caught WFT per trap

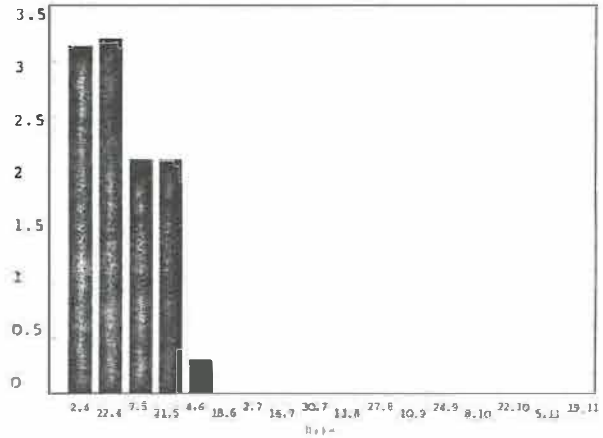

Fig.3: Mean number of WFT per sweet pepper flower

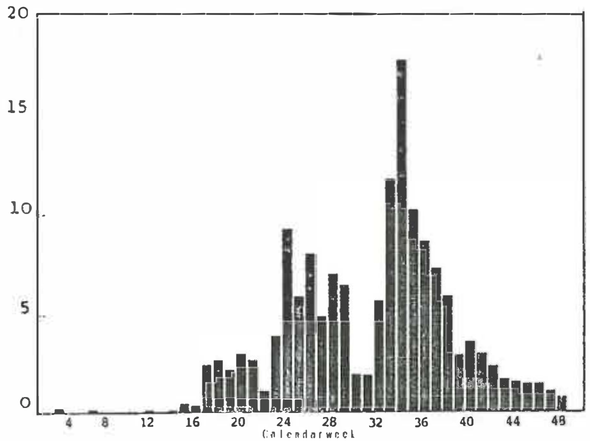

Fig.2: Mean number of caught *O. insidiosus* per trap

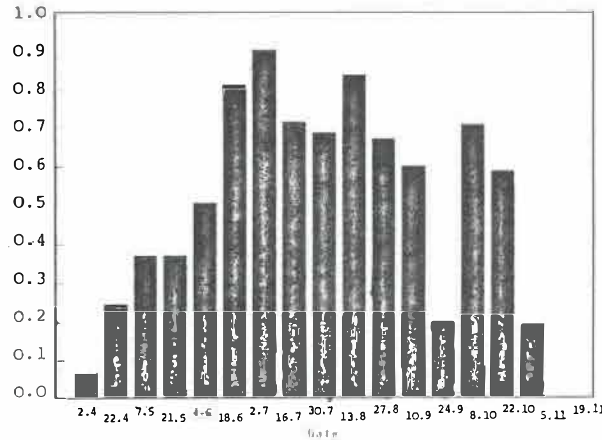

Fig.4: Mean number of *O. insidiosus* per sweet pepper flower

where thrips were present. It was only on 20 February that we detected a few WFT on the sticky plates. Further releases were done on 31 January (n=1000); 7 February (n=1,200); 21 February (n=1,150); 5 March (n=800); 23 March (n=1,400; 3 April (n=1,200); 9 April (n=1,300); 17 April (n=2,400), 30 April (n=1,500)and 8 May (n=1,300).

Flower samples were taken as WFT and *O. insidiosus* prefer the flowers to hide in. Ten flowers were randomly collected in each of the 20 glasshouse sections, based on a stratified random sampling method; starting on 2 April, a total of 200 flowers were detached every fortnight, and put in small glass vials for identification and counting the number of WFT and *Orius* nymphs and adults. The means and the variances of the numbers of adult WFT and *Orius* found on the sticky traps and in the flowers (included nymphs of both species) were calculated. The optimum sample size (plates, flowers) with a predetermined precision was also calculated.

Results and discussion

Fig. 1 shows the number of WFT adults caught on the blue sticky plates during the growing season. The first 13 weeks, low numbers of thrips are trapped, due to the low population density. A steady increase of WFT population starts during week 14. The highest number was trapped during week 18; from then onwards the population decreased to extremely low values from week 29 to 48 (the end of the growing season). Variance equals the mean during the first 11 and the last 13 weeks, while it is larger than the mean during the increasing trap catches indicating the aggregated distribution of WFT between week 11 and 35, and the random distribution at the beginning and at the end of the growing season. The number of sticky plates to be sampled for a precision degree (SE=20 % of the mean) is much too high in the first 13 weeks and the last 14 weeks, but satisfactory between week 14 and 34 (n varies between 3 and 35 with a mean of 16). According to the aforementioned statistical data, quantitative WFT monitoring with 18 blue sticky plates is unreliable in the periods of low WFT trap catches.

Fig. 2 shows the number of *O. insidiosus* adults caught on the plates. From week 17 a sharp increase in *Orius* catches occurs, with a maximum during week 34; from then onwards a slow decrease was found, but even at the end of the growing season *Orius* were still trapped on the plates. The increase in *Orius* catches is probably due to the fact that because of the decrease in thrips population the flight activity of *Orius* intensifies, so they are trapped more often. The comparison between the variance and the mean coincides with those for the thrips catches which means that initially population densities are randomly (Poisson) distributed, becoming more clustered in the middle of the season, and tending again to a randomised distribution pattern near the end of the growing season. The number of sticky plates to be sampled for a precision degree (SE=20 % of the mean) is much too high (>300) in the first 15 weeks; from the 16th to the 39th week, less than 18 plates are needed (with a mean of 11); during the last 9 weeks a maximum of 37 plates are needed to get the predetermined precision.

Fig. 3 shows the densities of WFT in the sweet pepper flowers. Thrips numbers per flower ranged between 2 and 3 during a 2 month period, from the beginning of April; from early June onwards, they were completely eliminated and this remained so for the rest of the season. The distribution of the WFT in the flowers was clustered (variance larger than the mean). The number of sweet pepper flowers to be sampled for an acceptable precision degree was between 34 and 54 for the 5 dates, with a mean of 48. This number is rather low for an aggregated WFT distribution in a large glasshouse area (6,600m2).

The mean number of *O. insidiosus* adults per flower over a period of 7 months is given in fig. 4. The number of *Orius* increased steadily from early April to early July, and then remained fairly constant for about 3 months, decreasing at the beginning of November and disappearing near the end of November. The distribution of the bug in the flowers was random as the variance equalled or was lower than the mean (tendency to normal distribution) during the entire flower sampling period. The number of sweet pepper flowers to be sampled for a given precision degree varied between 15 and 121 with a mean of 40).

The sampling method for WFT and *Orius* in the sweet pepper flowers was thus satisfactory from a statistical viewpoint. As the number of WFT in the flowers was reduced to zero at the time when 4 *Orius* adults were found on the sticky plates (early June, when counting 18 plates was sufficient), we can assume that , under the experimental conditions, efficient biocontrol of the WFT may be expected when a mean of 4 *Orius* adults are found on the blue sticky plates.

Linear regression analysis for the *Orius* on the plates against the WFT on the flowers, gave an R2 value of 0.65 (negative correlation), while for the *Orius* in the flowers against the WFT in the flowers an R2 of 0.75 was found (negative correlation). No correlations between WFT on the plates and WFT in the flowers were found (R2=0.19), neither for *Orius* on the plates against *Orius* in the flowers (R2= 0.4). The efficiency of *O. insidiosus* on its own, starting early in the season (January) is clearly demonstrated. From 4 June onwards, until the end of the season in November, no WFT adults/nymphs were found in the sweet pepper flowers, whereas *O. insidiosus* adults and nymphs were found in the flowers throughout the season. *O. insidiosus* persisted until mid November, despite the low population densities of the WFT. The aforementioned data coincide nicely with those found by Van den Meiracker and Ramakers (1991). The population build-up and persistence of *O. insidiosus* was due to other food sources such as *Myzus persicae* (which occurred during the entire growing season, but populations were kept low by 6 treatments with Pirimicarb smoke generators), noctuid eggs or pollen. Pollem is the most probable explanation for the survival and reproduction of *O. insidiosus*. In laboratory experiments we found that *Orius* can survive and reproduce on small sweet pepper plants when fed only pollen. Newly hatched *O.insidiosus* nymphs were found on March 12, near colonies of *M. persicae*. Concerning the slow start of *Orius*, which is often given as a reason for insufficient control early in the season, it remains to be investigated whether *O. insidiosus* is not hampered by the fact that the environment does not contain high amounts of prey or pollen, due to removal of flowers or by the fact that pruning techniques remove lots of eggs and nymphs of *Orius*. Reproductive diapause did not occur before 15 October since a few nymphs (1 on 100 flowers) were still found on November 6. However, *O. insidiosus* bugs sampled on October 22, when kept further in the laboratory at L/D: 18/6, did no longer lay eggs for the first 8 days; then they started egg laying again, indicating the fast termination of the diapause which was induced in the glasshouse.

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PROSPECTS FOR BIOLOGICAL CONTROL IN PROTECTED CROPS IN JAPAN

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Abstract

Studies on the use of natural enemies in protected crops were started in the late 1960's in Japan with work on *Phytoseiulus persimilis* and were followed by work on *Encarsia formosa* in the early 1980's. Although much information was obtained, commercial use of natural enemies in protected crops lays far behind that in western countries, where biological control has become a major control measure in several crops. The reasons for this large gap between research and commercial use of natural enemies in Japan are discussed. Lack of IPM programmes for each crop and difficulties in mass production and supply of natural enemies are two major technical limitations. At present, the limitations are being taken away and increase of commercial use is expected.

Introduction

Modern commercial use of natural enemies in protected crops was initiated in the U.K. and in the Netherlands in the late 1960's. Commercial use has remarkably progressed in western Europe in these 20 years. Natural enemies are used on a large scale in greenhouse cucumbers, tomatoes and sweet peppers in this area (van Lenteren and Woets, 1988; Ravensberg, 1992). Basic studies on biological control agents for commercial use have also been done in universities or institutes in cooperation with extension services and producers of natural enemies. The situation was quite different in Japan. Fundamental studies on biological control agents for greenhouse pests have a history as long as that in western Europe. Japanese researchers have made a great contribution in basic and applied studies on *Phytoseiulus persimilis* and *Encarsia formosa* in the 1970's and 1980's. However, only limited progress has been made in commercial application of these two natural enemies. The purpose of this article is to discuss the reasons for this large gap between research and commercial use of natural enemies in protected crops in Japan. In addition, the history of the research on biological control agents for greenhouse pests is reviewed and some recommendations are made for future development of biological control in Japan.

History of research in biological control in protected crops in Japan

Phytoseiulus persimilis

In 1968, researchers formed a voluntary group to promote basic and applied studies on the Chilean strain of *Phytoseiulus persimilis* imported from the U.S.A. . The group comprised one university and seven research institutes or experiment stations and its activity lasted until 1976 (Mori and Shinkaji, 1977). Life history, characteristics of predator, ability of dispersal and competition with domestic predatory mites were studied. More practically, mass production and storage procedures were developed and effect of chemicals was evaluated in the laboratory. In greenhouse trials on strawberry, cucumber, egg plant and some ornamental crops, *Phytoseiulus persimilis* showed an excellent ability to control spider mites. The government started a public enterprise in 1976, where mass production facilities were constructed in several prefectures to promote commercial use of *Phytoseiulus persimilis*. The enterprise continued for four years but resulted in little progress in commercial use.

Encarsia formosa

Encarsia formosa was imported from the U.K. in 1975, the year after the first recognition of occurrence of greenhouse whitefly in Japan. The government organized a big research project on biological control of pests and diseases in 1980, in which studies on *Encarsia formosa* was included. Effects of temperature and initial density of the host and the parasite on the control ability of *Encarsia formosa* were evaluated in greenhouse experiments (Yano, 1988). Monitoring methods to determine the time of introduction of the parasite using yellow sticky traps or binomial sampling of whitefly adult were also developed (Yano, 1990). In the laboratory, a mass production system for the parasite was developed and effect of chemicals on the parasite were evaluated. Considering the integration with control measures for other pests, a control system using *Encarsia formosa* was developed only for whiteflies on tomato plants. The government started a public enterprise for the promotion of use of *Encarsia formosa* in 1986 like they did for *Phytoseiulus persimilis*. Some commercial trials were not successful because of a too late introduction of the parasite or due to effect of chemicals.

Recent development

Several important pests were imported to Japan after 1980. Around 1980, a very serious pest of fruit vegetables, *Thrips palmi,* established in Japan. It is resistant to many insecticides and causes serious damage in both greenhouses and open fields. In 1989 and 1990, some new pests joined the fauna of greenhouse ecosystem in Japan. They were *Bemisia tabaci, Lyriomyza trifolii* and *Frankliniella occidentalis*, which were already key greenhouse pests in other countries. Control of these new pests is difficult with conventional chemical control. Researchers have tried to control these new pests with ecological and biological methods. Some natural enemies showed promising results. *Orius sauteri* effectively suppressed the population of *Thrips palmi* in fields of egg plants (Nagai, 1990). Now the use of this predator is evaluated for control of thrips in greenhouses. *Encarsia formosa* was used to control *Bemisia tabaci* on greenhouse tomatoes. When the parasite was introduced more than three times, it could control the population of *Bemisia tabaci* (Matui, 1992). Two strains of *Verticillium lecanii* were isolated from *Aphis gossypii* and *Trialeurodes vaporariorum* in the field. They showed high pathogenicity to the original hosts in laboratory experiments (Masuda and Kikuchi, 1992).

Factors limiting biological control in Japan

Limiting factors reviewed in the Netherlands

Limiting factors in biological control in greenhouses were reviewed by van Lenteren et al. (1980) and van Lenteren and Woets (1988). They divided limiting factors into two categories, factors making biological control unnecessary or impossible and factors making existing biological control schemes difficult to apply. The factors of the first category are: 1) short damaging period by pests, 2) short cropping period, 3) low tolerance for pest damage, 4) rapid population growth of pests, 5) unfavorable climatic conditions for biological control agents, 6) incompatibility of control measures of a pest with biological control, 7) poor quantity and quality of natural enemies, 8) poor service from natural enemy producers and/or advisory personnel. The factors of the second category are: 1) complicated total integrated control system, 2) use of new pesticide compounds, 3) importation of new pests from abroad, 4) insufficient support by governmental and intergovernmental bodies with respect to registration on pesticides, 5) limited amount of research and poor education of advisory personnel, 6) expensive registration procedure for natural enemies, 7) limited interest in biological control of large chemical companies.

Limiting factors in biological control in Japan
Most of the factors reviewed in the Netherlands hold for the situation in Japan. Higher temperatures in greenhouses in Japan than in the Netherlands cause rapid population growth of greenhouse pests and make cropping periods shorter. The high temperatures are thought to be one of the reasons why use of *Phytoseiulus persimilis* is difficult in many commercial trials. The Japanese market allows very low tolerance for pest damage, which causes dependence on pesticides of growers. In addition to the factors reviewed in the Netherlands, there are some more fundamental reasons applicable in Japan. As technical reasons, lack of IPM programmes for each crop and difficulties in mass production and supply of natural enemies are important. Studies about the use of natural enemies were mainly aimed at the control capability of a natural enemy in a one pest - one natural enemy system. Japanese researchers didn't pay much attention to the integration of use of a natural enemy with other control measures for the non-target pests of the natural enemy. The importance of mass production and supply of natural enemies in seasonal inoculative or inundative releases of natural enemies were not understood very well. Most of the successful examples of biological control in Japan belonged to classical biological control, where permanent mass production and seasonal or periodical supply of natural enemies are usually not needed. Several facilities for mass production of *Phytoseiulus persimilis* and *Encarsia formosa* were built by the support of the Japanese government. Mass production of natural enemies depends on efforts of researchers of prefectural experiment stations, who cannot spend enough time on mass production. Dependence on pesticides by growers is an important social limiting factor. It is related to low tolerance of damage by pests not only in ornamental crops but also in vegetables. Growers are always expecting effective new pesticides when a new, difficult to control pest appears. Actually, some new pesticides have become available for controlling new greenhouse pests such as *Thrips palmi, Bemisia tabaci* etc.. Of course, it is accompanied by the risk of development of resistance to the new pesticides. Legal limitation is the need of registration of natural enemies to be sold as biological control agents. Accumulation of data of control experiments for more than two years is required for registration.

Present status and prospects for commercial application in Japan

Present status
The limiting factors mentioned in the previous section are now being taken away. Many researchers are performing experiments using natural enemies in order to develop IPM schemes for each crop. Extensive studies about the use of natural enemies of thrips, aphids and whiteflies are being done. With the growing public interest in organic farming or sustainable agriculture, the use of natural enemies is seen as an alternative method for chemical pest control. Supply of some natural enemies becomes more convenient. A trading company is now importing natural enemies from the Netherlands and some chemical companies are interested in mass production of natural enemies. These companies are now trying to register natural enemies as control agents. Imported natural enemies are used in control trials in many experiment stations, which attracts attention of growers.

Prospects for commercial use
The present situation is very good and promising for commercial use of natural enemies in Japan, but realization depends on efforts of researchers and companies. Researchers should

concentrate their efforts on good crops for developing integrated control schemes using natural enemies. Less number of important pests, relatively high tolerance for pest damage and the use of pollinators are positive factors. Tomatoes and strawberries are suitable for developing integrated control. Development of methods of use for natural enemies of thrips, aphids and leafminers and use of selective pesticides, which are less toxic to natural enemies, is necessary to develop components for control measures in integrated control schemes. Fortunately, some IGR and JH analogues, which became available recently, seem less toxic to natural enemies in comparison with pyrethroids or organophosphates. It is expected that chemical companies or trading companies become suppliers of natural enemies in Japan. They can provide uniform products of natural enemies of good quality to growers with proper guidance for their practical use.

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